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PREFACE

It has become apparent from the total number of participants of the 4th International River Restoration Conference of the European Centre for River Restoration (ECRR), how River Restoration is becoming an increasing common practice. More then 300 participants from 5 continents and 36 countries attended the conference. Focussing on Europe, more participants from eastern and southern European countries were present at this conference than at previous ones. This might be a sign that the efforts of the ECRR to support these countries in promoting river restoration produced good results, and a demonstration of the importance of the ECRR as a network organisation for the dissemination of knowledge, information and results on river restoration.

Most of the participants came from universities or research centres, few public administrations and consulting companies were represented as well. The objective of organising a less "academic" conference then the previous ones was therefore only partly achieved. Nevertheless, the managers attending the conference were very active and enthusiastic; we can consider this a good start for a better communication between the academic world and practitioners. Many managers wrote contributions for the proceedings; as a result the papers included in the proceedings ranged from high scientific level ones to simple descriptions of a plan or a strategy.

The most common subjects of the presentations were:

- Biodiversity and restoration of hydro-morphological processes
- Basin scale restoration for fisheries rehabilitation
- Restoration and management of physical processes and sedimentation
- Evaluation and monitoring successes in river restoration plans and projects
- Decision making processes to implement river restoration

Most of the presentations were linked to base research, applied research, monitoring, public participation and stakeholder involvement, planning and modelling.

The conclusions and recommendations of the conference give the state of the art of river restoration worldwide, and describe to what extend the present river restoration approaches are suitable for the future. The main conclusion is that there is an increased awareness and understanding of opportunities and benefits related with river restoration through the ecosystem services they deliver. These new policy drivers are, for example, risk management, flood safety, renewable energy, fisheries, urban development, recreation and tourism. The implementation of a number of EU Directives, and chiefly the Water Framework Directive, gives good opportunities for implementation of river restoration measures.

Given these conclusions and recommendations, the ECRR can, and should increasingly be, the selected platform to provide scientists, project managers and decision- makers with the opportunity to re-focus on actual practices and predict future human developments and their impact on river restoration. For this reason, the networking functions of the ECRR should be sustained by the political support of national and EU governments and by the cooperation with national and transnational organisations. To disseminate different types of information about river restoration and to support communication between scientists, policy-makers, and practitioners are challenging assumptions, also with respect to the future developments of the ECRR at both the national and European level.

We would like to thank the Italian River Restoration Centre (Centro Italiano per la Riqualificazione Fluviale - CIRF) for organising and hosting the 4th International River Restoration Conference in such an excellent way. We are also very grateful to the members of the Scientific and Technical Committee for their professional support which resulted in a high-quality conference, and the members of the Management Board of the ECRR for supervising the organization of the conference and the preparation of the proceedings.

Bart Fokkens

President of the ECRR

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Chairperson of the Scientific and Technical Committee

CONTRIBUTIONS

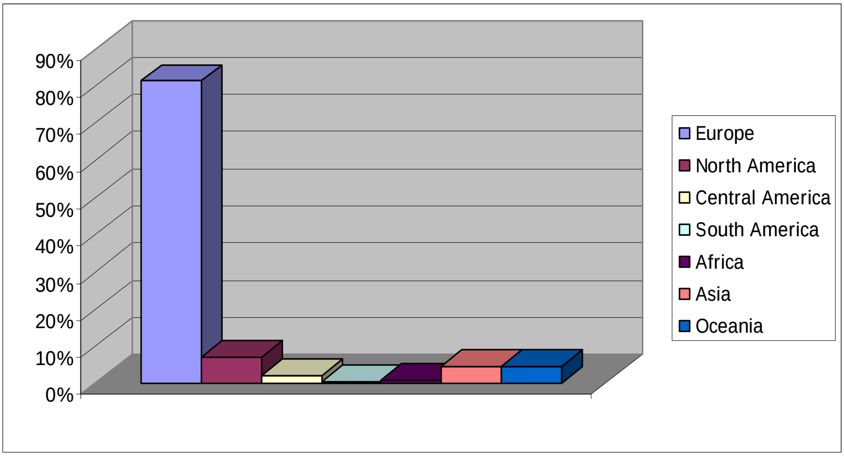
The ECRR (European Centre for River Restoration) is a non profit organization and operates as a network of both national centres and individual members; its mission is to promote ecological river restoration and sustainable river management throughout Europe, fostering their integration in national and European policies.

The 4th International Conference on River Restoration was held from June 16 to 19, 2008, in Venice, San Servolo Island. This event was organized on behalf of the ECRR by CIRF (Centro Italiano per la Riqualificazione Fluviale) and it is part of a series of conferences organized every four years. The previous conferences were held in Denmark (1996), The Netherlands (2000) and Croatia (2004). The aim of the event was to disseminate the most promising applied research solutions to be adopted in integrated River Restoration projects/strategies and to share experiences, concepts, approaches, methods and strategies on River Restoration.

CIRF has been holding the ECRR Secretariat for three years (from June 2006 to June 2009). CIRF is a non profit, self-funded technical-scientific association established in 1999 by a group of researchers with different background to promote the culture of river restoration and related know-how. The main goals of CIRF are: increase the awareness about the benefits of river restoration, through educational activities, publications and dialogue with public authorities, professionals and researchers; coordinate, promote and support pilot studies and innovative projects; foster the involvement of all subjects interested in sustainable management of rivers and territory; provide interaction and coordination with similar international centres.

River Restoration has become an issue at the top of the agenda for Water Authorities and river managers in Europe, especially but not only due to the Water Framework Directive (2000/60/EEC) which aims at improving the status of fluvial ecosystems in a broad, integrated, ecological perspective. At the same time river restoration is an important tool to implement other directives, such as 91/676/EEC (Nitrates), 92/43/EEC (Habitat), 2006/7/EC (Bathing Water), 2007/60/EC (Floods Directive) and 2006/118/EC (Groundwater). Ecological river restoration is a challenging topic and involves a wide range of themes concerning planning strategies, implementation and project assessment for different types of river systems including upland, lowland and urban rivers. Topic areas addressed include ecology, hydrology, geomorphology and social as, to be successful, restoration of freshwater ecosystems must incorporate all of these subjects within a holistic framework. Introducing the term and concept of river restoration at the policy level would bring into the discussion the worldwide experience on the subject, with its ideas, knowledge from applied research, methodologies and techniques.

The Conference participants were 314, coming from five continents (36 countries in total). Italy was the most represented country (51 participants), followed by Spain (35), Austria (21), France (20), England (15), Germany (13), etc. We had a good participation from the Eastern European Countries (Hungary, Romania, Czech Rep., Moldova, Russia, Estonia, Poland) and from Southern Europe (Spain, Portugal, Albania), as a sign that the efforts of the ECRR to involve also these countries (an example is the seminars organized together with the MB meetings) is giving the first outcomes.



The conference programme included 12 keynote speakers from all over the world, 12 scientific technical sessions and 11 workshops leaded by different organizations.

We invited 12 of the major experts on the chosen different topics. We strongly recommended them to give a very update of the state of the art of the specific topic, but also to give useful explanations of the research results for practitioners. The invited speakers gave to the conference an high scientific level, which was greatly appreciated by the audience. One of the goal of the Conference was to create active collaborations among as many participants as possible by giving them room and facilities. This aspect was emphasised with the 11 workshops. More opportunities for exchanging experience were created by the 12 oral and poster sessions.

We received 257 abstracts, 104 of which were oral presentations and 100 were presented as posters.

The proceedings book includes 10 plenary papers, 82 papers both from oral and poster presentations and 11 workshops summary reports.

All the documentation is downloadable from the ECRR website (http://www.ecrr.org/conf08/home.htm). Two excursions were organized with the conference: one field trip along the Zero River during the first day and a post conference trip (joined by 59 people) to Tagliamento and Drava rivers on 20-21 June 2008. The two brochures with the detailed information are available on the ECRR website as well (http://www.ecrr.org/conf08/fieldtr.htm).

A panel session closed the Fourth European Centre for River Restoration International Conference on river restoration: the conclusions and recommendations are reported at the end of this proceeding book.

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INBO, FAO, UNESCO, WWF Italia

Comments of some of the partners are reported on the following pages.

The organizers of the Fourth conference on River Restoration express their thanks to all who have contributed to the scientific and professional success of the Conference. Thanks are also expressed to those offering financial assistance for the organization of the conference. We also like to thank various national organisations, institutions and governments, especially those who contributed directly to the ECRR, to enable the organisation the conference. The editors are grateful to all participants for their contributions.

ECOHYDROLOGY FOR THE SUSTAINABLE MANAGEMENT OF WATER RESOURCES AND ASSOCIATED ECOSYSTEM SERVICES

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Global water quality has declined, and there has been significant loss of biodiversity worldwide, which severely impacts global ecosystems. Such trends provide ample evidence that conventional approaches to water resources management (based on the application of engineering techniques, sectoral interventions, and the elimination of such direct threats as point source pollution) are no longer sufficient to stem the tide of the water crisis. Ecohydrology aims to find solutions that, rather than focusing exclusively on technical issues, better respond to sustainable water resource policies and promote social development. Ecohydrology is a new integrative science promoted by UNESCO that involves finding solutions to issues surrounding water, people, and the environment. One of the fundamental concepts involved in Ecohydrology is that the timing and availability of freshwater is intimately linked to ecosystem processes, and the goods and services provided by fresh waters to societies. This means that emphasis is placed on the hydrological cycle and its effects on ecological processes and human well-being.

Ecohydrology considers the functional interrelations between hydrology and aquatic ecosystems and their biota at the catchment (watershed) scale. It considers the use of ecosystem processes as tools to meet freshwater resource management goals, such as enhancing natural processes of nutrient retention to avoid harmful algal blooms. In effect, it proposes a 'dual regulation' of the system by simultaneously using ecological and hydrological processes to enhance the overall integrity of aquatic ecosystems in the face of human-mediated alterations.

Ecohydrology does not specify the method of incorporating ecosystem processes into management programs, as that is site-specific. As part of the strategy, it focuses on understanding useful ecosystem processes and communicating that understanding to water managers in a way that enables incorporation into planned and existing programmes. Ecohydrology provides a way for policy-makers, governments (at all levels, from the local to the national), and civil society to work towards sustainable water resources management by enhancing the capacity of ecosystems to absorb adverse impacts.

Concretely, it is expected that, by applying new understandings emerging from Ecohydrology research as tools for Integrated Water Resources Management, managers can enhance the resilience of freshwater ecosystems to human impacts, thereby capitalizing on ecosystem services and achieving water management goals with minimal engineering inputs and financial investment (Naiman et al., 2007). In this view, fluvial processes (including energy flows and nutrient cycles) have to be maintained or, as required in many situations, even restored. This is where Ecohydrology and River Restoration find their more natural and logical matching point, and that is why UNESCO-BRESCE enthusiastically decided to support the 4th ECRR Conference on River Restoration held in Venice in June 2008.

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THE IMPORTANCE OF RIVER REHABILITATION FOR FISHERIES

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Key words: FAO Code of Conduct for Responsible Fisheries; river rehabilitation; river restoration; fisheries management; biodiversity;

FAO, through its Fisheries Management and Conservation Service, was one of the partners that contributed to the 4th ECRR Conference on River Restoration. This had been decided because river restoration is an important, though often challenging, topic that needs to be taken into consideration when caring for sustainable fish populations for fisheries or for biodiversity. As part of the Regular Programme activities, the Fisheries Management and Conservation Service provides advice on environmental issues that are important for managing the aquatic resources responsibly and sustainably. It was felt that this Conference was an excellent opportunity for exchange of new ideas in the vast field of river restoration work that has quite divers facets of which fisheries is just one, and to make FAO's work better known to a wider community. Potentially, this could also help influence the thinking of river managers.

The FAO Code of Conduct for Responsible Fisheries and the related Technical Guidelines on Inland fisheries[1], that are the basis for our work, rightly draw the attention to the fact that fisheries management cannot be done in isolation but needs consultations and interactions with all the stakeholders that compete for the use of water for whatever purpose. In many countries, rivers have been – and are still being – intensively modified to provide services such as hydropower production, navigation, irrigation, water abstraction for industry and households, and very often the interests of

[1] FAO Fisheries Department. Inland Fisheries. FAO Technical Guidelines for Responsible Fisheries. No. 6. Rome, FAO. 1997. 36p. and
FAO Fisheries Department. Inland Fisheries. 1. Rehabilitation of inland waters for fisheries. FAO Technical Guidelines for Responsible Fisheries. No. 6., Suppl. 1, Rome, FAO. 2008. 122p

fish and fisheries have been badly neglected as this sector is all too often seen as less important in the economy.

Channelizing the rivers as well as constructing dams and weirs gained, and is still gaining, speed with intensified development in many countries around the globe. Unfortunately, in most cases no, or not enough, attention was paid to the consequences of such development for the aquatic environment and its fauna, including fish, and the construction of physical barriers across the rivers and “river training” – as channelizing is sometimes called – have had serious negative effects on natural fish populations. The obstacles interrupt the longitudinal connectivity, and straightened water courses mean a loss of habitat diversity for riverine species. All this has contributed to diminished abundance of fish species, to their disappearance from modified river stretches and even to their complete extinction – there exist, unfortunately, many examples from around the world.

This trend has to be reversed. In fact, since about three decades, environmental thinking has influenced many international conferences and agreements. Many international organizations and commission now look more deeply into these aspects. Two examples are the Convention of Biological Diversity (CBD) and the EU Water Framework and Habitat Directives, the latter giving more importance to the good ecological status of the water bodies in Europe. In particular in western Europe and in North America, it has been increasingly recognized that a healthy aquatic environment is essential for the wellbeing of the aquatic organisms, and attempts are being made to restore or rehabilitate water courses for the benefit of the aquatic fauna. Thereby, it is extremely important that not only some characteristic structural features of the river are restored but ecosystem functions are brought back into existence. In any case, river restoration should never be done only for “esthetical” aspects but always be linked to the re-creation of habitat for the indigenous species.

River rehabilitation or restoration is technically feasible today. The knowledge of fish pass design and construction, and of re-meandering of river stretches is available and put into practice, at least in some wealthier countries. Increasingly, attempts are being made to restore the aquatic habitat and especially to re-establish the longitudinal and lateral connectivity of rivers as an ecologically vital measure. More and more dams or weirs are now decommissioned (i.e. removed) or at least retrofitted with fish passes. In some countries where, in accordance with the user-pays-principle, the provision of mitigation is required by law, the user of the resource, for example the power production sector, is held liable to bear the costs of the measures that bring the environment back to an acceptable state.

But this is not enough. River rehabilitation or restoration for fish and fisheries has to be done on a much wider scale. Thereby, ideally, the natural processes should be restored in such a way that the benefits can be measures on a basin scale. By means of the Code of Conduct for Responsible Fisheries, the FAO Technical Paper on Habitat rehabilitation for inland fisheries and the new Technical Guidelines on Rehabilitation of inland waters for fisheries, FAO promotes new approaches to fisheries management embracing conservation and environmental, as well as social and economic, considerations. Conservation and restoration measures are promoted as two important management measures that can help to improve fisheries.

Fisheries scientists and managers are encouraged to identify and prioritize problems impacting upon fisheries and the aquatic fauna, as well as to identify and request appropriate technical solutions to these problems. However, the greatest challenges to development and maintenance of aquatic ecosystems for fisheries are the socio-economic aspects. In most cases, when new water development schemes are planned, or when alterations to existing schemes might allow rehabilitation work for fisheries, other stakeholders (for example the water resource planning and management institutions) do not actively solicit the inputs of fisheries specialists at early stages. It is, however, crucial that fisheries specialists be put in a position to interact with other disciplines at the earliest possible stage of water development projects. As most of the factors causing problems for fish communities are outside the immediate control of the fisheries sector, fisheries specialists need to broaden and strengthen their cause by interacting and making alliances with other interested parties in seeking to limit damage to aquatic ecosystems, and to promote rehabilitation.

We are all well aware that the many services the rivers are providing are important and bring convenience for our daily life and that today electric energy is a prerequisite for wealthy economic development. Thus it is not surprising that countries which concentrate on improving their economic welfare promote the most obvious river services such as hydropower production, irrigation and navigation. However, caution is warranted in doing so as the interests of many different stakeholders and user groups, including the fishery sector, might be impacted by such decisions.

There is – without any doubt – an enormous need for river restoration today on a global scale and a lot of work remains to be done. This includes also to work towards convincing others that river rehabilitation work brings about mutual benefits.

INTERNATIONAL NETWORK OF BASIN ORGANIZATIONS (INBO)
RESEAU INTERNATIONAL DES ORGANISMES DE BASSIN (RIOB)

International Network of Basin Organisations (INBO) was established in 1994, by organisations whose common goal was to implement integrated basin water resource management.

INBO has the following objectives :

- to develop permanent relations with the organizations interested in a global river basin management, and facilitate exchanges of experiences and expertises among them,
- to promote the principles and means of sound water management in cooperation programmes to reach a sustainable development,
- to facilitate the implementation of tools for institutional and financial management, for programming, for the organization of data banks, of models adapted to the needs,
- to promote information and training programmes for local elected officials, for users' representatives and for the different actors involved in water management as well as for the executives and staff of the member basin organizations,
- to encourage education of the population, the young in particular,
- to evaluate ongoing actions and disseminate their results.

Today INBO gathers more than 150 members from 50 countries.

The **5th World Water Forum** will take place in Istanbul from 16 to 22 March 2009 at the invitation of the Turkish Government and the World Water Council.
It is a major meeting not to be missed!

The International Steering Committee of the Forum confirmed the nomination of INBO and UNESCO as coordinators of topic 3.1, dealing with **basin management and transboundary cooperation**, in partnership with all other interested Organizations.

Then INBO calls its Members and Friends (among which, ECRR) to get mobilized and come to Istanbul to present their experiences, to exchange and discuss in order to develop and improve basin management and transboundary cooperation in the world.

Management at the level of basins of rivers, lakes or aquifers experienced a quick development in many countries, which made it the basis of their national legislation or tried it in pilot river basins.

The Forum of Istanbul will give us the opportunity of reporting on these progresses, but also on the difficulties which remain and the way still to go, particularly thanks to the full-scale implementation of the European Water Framework Directive, which sets an objective of Good Ecological Status (or Good Ecological Potential when talking of Heavily Modified Waters) of national or international River Basin Districts in EU Member States.

Without doubts, Ecological River Restoration practices are among the most promising measures to reach these goals, and we would like to promote their (expected) benefits.

The recommendations issued during the conference in Venice – June 2008, and the lessons learned from the different case studies, are of utmost importance, and will now feed the preparation process of WWF5 and in particular session 3.1, to which ECRR will contribute.

Moreover INBO and ECRR will collaborate in the near future to propose training events (including internet-based courses) to the attention of staff from Basin Organisations, in order to give them clues to implement River Restoration.

Jean François DONZIER
INBO Permanent Technical Secretary

CHAPTER 1

Keanote Papers

4th ECRR Conference on River Restoration
Italy, Venice S. Servolo Island
16-21 June 2008

LINKING SCIENCE, MONITORING AND MANAGEMENT TO IMPROVE THE HEALTH OF WATERWAYS IN SOUTH EAST QUEENSLAND, AUSTRALIA

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ABSTRACT
The rivers and coastal waterways of South East Queensland, Australia, are unique and complex ecosystems that have a high conservation value and support major recreational and commercial fisheries and tourism activities. The rapidly growing urban population is heavily reliant on good quality water supplies from the region's catchments – as are the agricultural districts, which contribute significantly to the local economy. However, urban and rural development has led to declining water quality and predicted population increases in the region are likely to further impact on the ecological and economic health of its waterways and catchments. At the same time there are growing community expectations to reverse the existing decline in water quality and ecosystem health. In response to these concerns, government, industry and community stakeholders have worked in close cooperation to develop a whole-of-government, whole-of-community approach to understanding and managing the region's waterways. The key elements of this Healthy Waterways Partnership include: the implementation of management actions ranging from upgrades of wastewater treatment plants to improved planning regimes and rehabilitation of riparian vegetation; a multi-disciplinary science program that informs these management decisions and monitors their effectiveness; and a promotional and educational program that ensures that there is broad community awareness and support for action. This paper provides an overview of the experience gained through development of the Partnership and highlights some of the key factors that have contributed to its current success.

Keywords: Adaptive management, ecosystem health, estuaries, monitoring, rivers, water quality

1. INTRODUCTION

The South East Queensland (SEQ) region of Australia provides an excellent case study of the challenges for ecological sustainable management of rivers and coastal ecosystems in the face of global change (Dennison and Abal, 1999; Abal et al., 2005a; Bunn et al., 2007). The SEQ region extends 240 km from the city of Noosa to the New South Wales border at the Gold Coast, and 140 km west to the Great Dividing Range, with 15 major catchments and a combined catchment area of nearly 23,000 km^2. Nearly 3 million people live within South East Queensland and enjoy a high standard of living in what is the fastest growing region in Australia (Abal et al., 2005b). Moreton Bay is a marine park and is listed as a wetland of international significance under the Ramsar Convention for the protection of wetland habitats and migratory birds. The Bay and estuaries support significant fisheries and are extensively used for recreation and tourism. The catchments are the region’s primary water supply, largely for urban use but also for agriculture.

However, human activity since European settlement has left a significant ecological footprint. Only about one quarter of the original vegetation in the region remains intact, though much less occurs along stream and river corridors in some catchments. The catchment hydrology has been substantially altered, not just through the construction of dams and weirs but also because of changes in land-use and vegetation that have resulted in altered run-off responses to rainfall events, generating ‘flashier’ stream flows. Nutrients (particularly nitrogen), fine sediments and, to a lesser extent, other toxicants have been identified as causes of significant environmental problems. The high catchment to bay ratio for Moreton Bay (14:1) is a complicating factor and results in residence times that range from days in the eastern Bay to several months in the western embayments (Abal et al., 2005b).

Concerns about the future security of water supply (both in terms of quantity and quality) and the viability of industries that are dependent on healthy waterways (e.g. tourism, fishing), in the face of a rapidly growing population and changing climate, have been major drivers for change in the way that waterways and catchments are managed in the region. This has been accompanied by increasing community expectations for improved water quality and ecosystem health and a growing recognition that it is cheaper to protect environmental assets of high value than to try and restore degraded systems. Initial work has identified a range of social and economic impacts resulting from factors such as increased human health risks, loss of income, reduced recreation and tourism opportunities, and increased water treatment costs (Rolfe et al. 2005).

2. SEQ HEALTHY WATERWAYS PARTNERSHIP

Although public concern about declining water quality in Moreton Bay and the Brisbane River was noted in the mid-1970s, it was only in the 1990s that a coordinated approach began to address this. The *Brisbane River Management Group* started in 1993, and was extended to include all waterways in 2001 with the development of the SEQ Regional Water Quality Management Strategy (SEQRWQMS, 2001). This resulted in the formation of the *Moreton Bay Waterways and Catchments Partnership* in 2002 – now known as the SEQ *Healthy Waterways Partnership* (www.healthywaterways.org). The Strategy was a joint Federal, State and local government initiative and was developed directly by a broad range of stakeholders. This allowed an effective, "whole of community" approach to the development and agreement of the management actions contained in the Strategy. The development of the Strategy was overseen by a Management Committee of elected officials from the sponsoring local governments, senior officers from the sponsoring State Government departments and elected industry and community representatives. It was also supported by a Scientific Expert Panel, a Technical Advisory Group of officers from State Government departments and local governments, and an Industry and Community Advisory Group of non-government representatives from industry, fishing, conservation, catchment management, Landcare and indigenous groups. Consultation with the wider community was also undertaken.

An important aspect of the Strategy was the development and agreement by all stakeholders, at an early stage in the process, of a single, clear vision for the future health of the region's waterways. The current vision statement is that:

> *"By 2026, our waterways and catchments will be healthy ecosystems supporting the livelihoods and lifestyles of people in South-east Queensland, and will be managed through collaboration between community, government and industr*y."

The initial approach taken was to identify the values for the region's waterways that reflected the above vision. This involved numerous workshops with stakeholders from across the region. Once an agreed set of values (environmental assets) was identified, measurable water quality or ecosystem health objectives were then set to protect these values. This was underpinned by a robust science program. Finally, management actions were identified to achieve these objectives, working directly with policy makers.

3. STAGED APPROACH TO RESEARCH AND MONITORING

The SEQ Healthy Waterways Partnership has adopted a staged approach in the development of the Strategy and its associated research and monitoring program. Stage 1 (1993 to 1995) reviewed available information and delivered a framework for the development of the Strategy. The Stage 2 workplan (1996 to 1998) focused on urban areas in the lower catchment, marine and estuarine areas of the Moreton Region and was developed by six local councils, the Queensland Environmental Protection Agency and other State government agencies, industry and community.

A key outcome of the early work in Stage 2 was the identification of major point source impacts from waste water treatment plants in the lower Brisbane River and western Moreton Bay, and the recognition that nitrogen was the nutrient of particular concern (Dennison and Abal, 1999; Udy and Dennison, 2005). A large plume of organic-rich sediments was also identified at the mouth of the Brisbane River and re-suspension of these sediments from tidal and wave action and the associated increased turbidity is thought to be responsible for observed declines in seagrass in the western embayments. In turn, this had led to declines in populations of dugongs, turtles and other biota dependent on shallow seagrass habitats.

Stage 3 (1999 to 2001) of the Strategy focused on the freshwater catchment areas of the Moreton region and incorporated the north (Noosa, Maroochy and Mooloolah) and south (Logan, Albert and Gold Coast) regions. A major focus of research, modelling and monitoring in Stage 3 was on the catchment sources of sediments in Moreton Bay and estuaries, seeking to understand where the sediment came from and what were the processes that generated it. Initial catchment modelling suggested that about 70% of the sediment in Moreton Bay originated from < 30% of the region (specifically, the south-western catchments) and sediment tracer studies of cores taken from the Bay and rivers confirmed this (Caitcheon and Howes, 2005). Furthermore, catchment modelling predicted that channel erosion dominates throughout much of the region and this finding was also supported by tracer studies (Caitcheon and Howes, 2005). This result was not surprising given that about 50% of the 48,000 km of streams in South East Queensland have degraded riparian zones. Poor riparian condition is also a major cause of poor water quality and aquatic ecosystem health in streams in the region (Bunn et al., 1999; Smith et al., 2005; Rutherford *et al*., 2004).

4. COMMITMENT TO AN ADAPTATIVE MANAGEMENT PROCESS

Consistent with the philosophy of adaptive management (Walters, 1986), the Healthy Waterways Partnership is committed to (i) ongoing knowledge acquisition, (ii) the critical importance of monitoring; (iii) continuous improvement in the identification and implementation of management actions; and (iv) effective communication of knowledge for policy/planning. The approach recognises that management intervention can seldom be postponed until all of the information required to fully understand the situation is available (Abal et al., 2006).

The Partnership has continued to invest in the refinement and testing of conceptual models (Thomas et al., 2006). These visual tools are not only used to improve our scientific understanding and to identify key knowledge gaps but also to communicate important processes to stakeholders. An Environmental Management Support System (EMSS) was developed in Stage 3 to explore how point and diffuse source loads of sediment and nutrients influenced ambient water quality, and to assess whether water quality objectives can be met downstream (Vertessey and McAlister, 2005). The output of this catchment modelling tool provides input for a receiving water quality model for the tidal waterways and Moreton Bay, developed in Stage 2. Decision support tools such as these have proven useful not only in evaluating the potential efficacy of various management actions aimed at the improvement of water quality, but also to assist stakeholders in determining sustainable loads and setting resource condition targets for waterways. An important contributing factor to the success of the Healthy Waterways Partnership has been the strong link between science and policy makers. The Partnership model has facilitated an open dialogue between the Scientific Expert Panel and key local and State Government policy makers and managers. This has led to targeted management actions, including waste water treatment plant upgrades and riparian restoration (SEQRWMS, 2001; SEQHWP, 2007).

Equally important, has been the commitment to monitoring the effectiveness of management interventions. A comprehensive estuarine and marine Ecosystem Health Monitoring Programme (EHMP) was developed in Stage 2 of the Strategy and implemented in 1999 as part of Stage 3 (Smith and Grice, 2005). This program involves routine (monthly) sampling of water quality parameters at over 250 sites across the region. Other measures of ecosystem health (e.g. seagrass mapping, riparian condition) are also undertaken. A Freshwater EHMP was developed in Stage 3 of the Strategy and implemented in 2002. This involves the measurement of 16 parameters, including measures of fish and invertebrate biodiversity, ecosystem processes and water quality, at over 120 stream sites across the region, twice per year (Kennard *et al.*, 2005; Smith and Grice, 2005; Fellows *et al.*, 2006;

Udy *et al*., 2006). Water quality or ecosystem health objectives have been set to underpin values identified by stakeholders (consistent with the Healthy Waterways vision). The indicators in the EHMP have been carefully selected and tested as either specific measures of these assets or parameters that are known to have a direct influence on them.

A key element of the monitoring program is the development and public presentation of annual 'Report Cards' on the health of waterways in the region. These are based on the robust EHMP data and presented to politicians and senior policy makers each year in a public (televised) ceremony (see www.ehmp.org).

5. IMPLEMENTATION OF THE HEALTHY WATERWAYS STRATEGY

Since 2001, the Partnership has placed a greater emphasis on science and monitoring to underpin the implementation of the Healthy Waterways Strategy. Over twenty of the management actions agreed to in the 2001-2006 Strategy (SEQRWMS, 2001) have been completed and another 38 are in progress. This includes the completion of upgrades to 12 wastewater treatment plants, with another 13 underway at a cost of over $400m. This has led to a 40% reduction in nitrogen loads to Moreton Bay and other estuaries, despite a considerable increase in population at the same time. In addition, ~$60M has been invested in stormwater quality improvement and another $18M in waterway management and restoration, including over 1.5 million trees planted.

However, despite these investments, it is clear that a "business as usual" approach will not be sufficient to maintain and improve the health of the region's waterways, especially in the face of a changing climate and rapidly increasing urban population. While there has been considerable success in addressing point source pollution (Costanzo et al., 2005; EHMP, 2008a), there is an urgent need to tackle diffuse source loads of pollutants entering waterways, especially sediment, from non-urban and developing urban areas. The recently released 2007-2012 SEQ Healthy Waterways Strategy (SEQHWP, 2007) involves 50 stakeholder groups and lists over 500 actions, including the use of water sensitive urban design (WSUD) in 'green-field' urban areas, the progressive retrofit of WSUD in existing urban areas and a significant investment in riparian restoration, channel stabilisation and best-practice land management in rural areas. The latter is estimated to require an investment in riparian 'infrastructure' in the order of $350-500 m over the next decade.

6. SCIENCE CHALLENGES

Previous research undertaken by the Partnership has clearly identified the priority regions contributing to diffuse source loads and the major causal processes that are responsible (Abal *et al*. 2005a; see also additional reports on www.healthywaterways.org). The freshwater ecosystem health monitoring program continues to highlight which catchment streams are in poor condition (EHMP, 2008b). However, additional research and modelling is required to provide advice on the optimum size and spatial arrangement of restoration to achieve the greatest range of benefits for the least cost. This would attempt to optimise restoration to achieve an overall 50 % reduction in diffuse sediment loads entering the receiving waters from catchment sources and improve stream ecosystem health. A large 'proof of concept' study, the "Healthy Country Program" has been initiated, which involves the selection of several 'no regrets' trial areas to showcase a range of restoration activities, including riparian fencing and replanting, and gully stabilisation (http://www.healthywaterways.org/healthy-country.html). The program will be underpinned by the development of a spatial optimisation framework, additional process studies and a targeted monitoring program.

7. CONCLUSION

There are several key lessons from the SEQ Healthy Waterways Program that are likely to be transferable to other regional catchment management programs aimed at improving water quality and aquatic ecosystem health. These include, the importance of a shared common vision, the involvement of committed individuals (scientists, politicians, managers and community), a cooperative approach, the need for defensible science, and effective communication. These factors have been important in the development and success of the Healthy Waterways Partnership in South East Queensland. Furthermore, without this approach, it would not have been possible to stimulate the growing recognition in the region of the important connections between healthy waterways and their catchments.

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RIVER RESTORATION AS A COLLABORATION WITH NATURE

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In January of this year an article was published in *Science* magazine that challenged the wide-spread use of a sinuous, meandering channel form as the 'ideal', historic (pre-settlement) form for guiding restoration designs in the eastern United States (Walter and Merritts 2008). Instead, they claim that swampy and shallow anabranching streams represent the 'real' natural channel. Whether or not you agree with Walter and Merritts, there is no question that visions of single-braded sinuous channels are an intrinsic part of the dominant model used to restore rivers – the so-called 'natural channel design' approach (Fig. 1; Rosgen, 1996; Montgomery, 2008). This has led to many expensive and extensive, earth-moving channel engineering projects (Bernhardt et al., 2005). The emphasis on channel form as a template for restoration has been extended to include a heavy emphasis on sculpting in-stream structural attributes such as the frequency of riffle-pool complexes and the arrangement of rocks and wood.

This pre-occupation with structure has led to frequent declarations of restoration success because an "ideal geomorphic channel" that maximizes in-stream "habitat" has been created. This is despite the fact that evidence of ecological effectiveness is rarely provided. Indeed, many such projects have done more ecological harm than good (Palmer et al., 2005). In this talk, I advocate a fundamental shift in the approach to restoration in which ecological outcome, not channel form, drives project design. Under such a restoration model, hydrogeomorphic processes are important tools used to promote the desired outcome but no assumptions are made concerning the historic channel form. Instead, as I explain below, channel form would be determined based on what maximizes the ecological processes that promote the desired outcome.

Figure 1 - Examples of stream restoration projects in Maryland, USA that emphasize increasing structural complexity and sinuosity.

	%	#
Reported their project was completely successful	75%	35
Had clearly defined measurable objectives	38%	18
Measurable objectives met	2%	9

Figure 2 – Interview with managers of Stream Restoration Project (Data from Hassett et al., 2007).

First let us explore the evidence that a focus on structure is driving restoration despite little evidence of ecological improvements. In completing an extensive analysis of the published literature to evaluate restoration effectiveness, Roni et al. (2005) noted that enhancement of in-stream structures not only has a long history but is one of the most common and widespread restoration activities. He concludes that many of these appear to be linked to higher abundances of fish; however, it is not clear if this is an aggregation effect or if reproduction and survival really increased. Using a modeling approach to investigate the potential effectiveness of physical habitat restoration in increasing long term viability of 32 populations of Pacific salmon, Budy and Schaller (2007) found that 84% of the populations fall below the survival increase needed for viability. The National River

Restoration Science Synthesis project team (www.restoringrivers.org) analyzed over 28,000 projects in the U.S. and found that structural approaches were common in all regions of the U.S. and in the mid-western states in-stream habitat improvement projects made up almost 50% of the projects over a ten year period. Evaluating success was difficult since project records rarely report this, so interviews were conducted with managers for a subset of the projects (Palmer et al., 2007). In general, across the U.S. the findings showed that project managers report success quite commonly even when they do not have measurements or even clearly identified objectives (Fig. 2).

Nagel (2007) reported that natural channel design (NCD) projects are extremely common and while their success structurally has been mixed the structures themselves commonly fail after the first storm. There are also a number of papers criticizing specific NCD projects (e.g., Kondolf et al. 2001, Smith and Prestegaard 2005, Simon et al. 2007) but none of these evaluated the ecological outcome. Base on more than 300 confidential interviews with project managers, Bernhardt et al. (2007) found that while managers reported that ecological degradation typically motivated projects, they typically used post-project appearance or positive public opinion to evaluate success. Written records or independent assessments of project outcomes are so rare that we simply can not say what the true ecological outcome is (Bernhardt et al., 2005). A notable exception is work by Penrose (2007) on the effectiveness of projects at restoring insect biodiversity in 12 streams and he reports little to no increase in diversity in most of the streams with an actual decrease in diversity in 4 of the streams. Further, work by Harrison et al. (2004) and Pretty et al. (2003) examining the effectiveness of in-stream rehabilitation structures found that with respect to invertebrate and fish diversity, restored reaches did not differ from reference reaches indicating little effect of restoration.

Clearly, there is now a large and growing body of evidence that the dominant form-based structural approach to stream restoration either rarely targets ecological goals (and thus does not report ecological outcomes) or the approach is ineffective at improving streams ecologically. Thus, use of a form-based approach to realize our ‘dreams’ of an ideal [healthier] channel has not been taking us down a path that is particularly promising from an ecological standpoint. At best, if the projects hold up they may be protecting valuable infrastructure if they minimize bank erosion.

It is time to let go of the notion of an ideal channel. Indeed, the use of forested reference streams is no longer tenable in many regions of the world because so much alteration of the landscape has occurred. If a significant portion of a watershed has been urbanized or converted to agriculture, even if its riparian corridors are intact, the flow and sediment regimes of its streams will now be fundamentally altered compared to those in a forested watershed. It would be difficult to even maintain a channel form that was designed based on a morphologic template from undisturbed sites. Further, the chances of restoring those biota native to forested reference sites are extremely low since numerous studies have found significant reductions in biodiversity when watershed development is as low as 15% (Wang et al., 2000; Walsh, 2004; Moore and Palmer, 2005). Another approach relies on the “least-impacted” reference site taking into account watershed-scale impacts but this assumes there will not be further land use changes in the watershed.

What I propose is that we consider turning the focus entirely on its head – instead of asking what ‘should’ the stream be, we can ask: what do we *want* the stream to ‘do’. If the focus is shifted to achieving specific ecosystem services then the restoration approach can be focused on what processes need to be influenced in order to achieve that goal. For example, in the mid-Atlantic U.S., many of our watersheds have inadequate stormwater infrastructure and so stream channels are deeply incised and are believed to transport large amounts of sediment and nutrients to coastal waters. The desired “ecosystem services” of the streams are to move water efficiently but retain sediments and nutrients. Thus, instead of designing a stream restoration project based on an ideal template of what streams were like historically in this region or what they are like in fully forested watersheds (of which there are now quite few), channels must be re-designed to slow water down and enhance the interaction of surface water and suspended sediments with vegetation.

Figure 3 - Photo of a Coastal Plain stream in Annapolis, Maryland USA after it has been re-designed to accommodate higher flows and remove pollutants.

Such a project was undertaken in Annapolis, Maryland in which a landscape architectural firm designed a novel ecosystem that is essentially a hybrid of a stream and a wetland (Fig. 3). By using step-pools to reduce stream power and shallow berms and small riffles, water now moves very slowly and nutrients are being retained (in storage in the sediments and in wetland plants) and removed (via denitrification). Sediment settles in the pools and the whole region will very slowly be transformed into a rather large wetland marsh. While a full water year of assessment to monitor water, nutrient, and sediment fluxes has not yet been completed, initial trends suggest this project is quite successful (Filoso and Palmer, unpub. data). I suggest that the reason for this is that the *most* desired services were clearly prioritized and the project design was based on how to obtain the *processes* that support those specific services. In this case, processes included nutrient removal (plant & microbial uptake + denitrification), water filtration to remove sediments (sediment deposition and trapping), and moderating peak flows (absorbing excess energy). The design enhanced the amount of organic matter and stream habitats with low oxygen which are both required for denitrification, provided extensive vegetative plantings which act to trap sediments and slow flows, and added step pools which dramatically reduce stream power. Perhaps we should not technically refer to such a designed ecosystem as a restoration project (Palmer et al., 2005); however, I view restoration as a continuum process that varies from little intervention (removing the insults and letting the site passively restore) to greater and greater levels of channel and riparian manipulation until eventually we have a designed channel that may no longer resembles historic sites.

It is important to note that this example focuses on a project that attempted to recover lost ecosystem services that may be easier than recovering services such as fish productivity or support of biodiversity. The latter are supported by a large number of processes including primary production, organic matter flux, discharge regime, bed mobility, and nutrient cycling, to name a few. While we can potentially rank the relative importance of these for some biota, all must be restored to some extent depending on what flora and fauna are desired. This we are now in a multi-factorial 'world' in which many interacting and complex factors must be considered. The science of restoration ecology is in its infancy in terms of learning how to deal with this complexity and with respect to how to manipulate a system to restore some of these services given the highly degraded nature of many watersheds.

In conclusion, society may have to make some difficult decisions as we move further into the 21st century. Dreams of restoring ecosystems to some former state or some 'pristine' state are no longer tenable in many or most parts of the world and attempts to do so may cause more harm than good.

The example I provided of the re-designed stream is the path we may need to take: prioritize needs and when possible identify specific ecosystem services that can be targeted. By *collaborating with nature*, designs such as this example make use of natural ecological processes to accomplish tasks that can also be accomplished using engineered technology (e.g., pipes and water purification structures). But these are not particularly pleasing aesthetically, may be expensive to maintain, and may cause other forms of environmental degradation (e.g., through polluted emissions or reliance on fossil fuels). I believe the economic and ecological costs are too high for us to continue along the path we have been following – it is time to move beyond attempts to estimate process based purely on form and time to do the scientific work necessary to measure processes directly then restore or enhance them as desired.

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RIVER RESTORATION: RESTORING DYNAMIC RIVERINE PROCESSES IN A CHANGING WORLD . . . OR . . . ERECTING MONUMENTS TO OUR GOOD INTENTIONS

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ABSTRACT

River restoration has become a focus of ecologists, engineers, fisheries scientists, and landscape architects throughout the world. Three fundamental characteristics of ecologically sound river restoration frequently are missing from many projects. River restoration should be designed to 1) restore rivers, 2) restore river dynamism, and 3) anticipate future human and natural change. First, most restoration projects focus on parcels of land rather than viewing a river with two banks and floodplains. Such restoration largely involves transferring perspectives for restoring a plot of land into a riverine environment. In contrast, the river should be viewed as a dynamic network, with spatial frameworks that extend from the network to regional segments to local reaches to project sites. Critical design elements are required at all four scales. But most of all, the project must be viewed as a river, dynamic and changing, reflecting the structure and processes across and along the local reach and nested within the larger river network. Second, many projects construct the structure of the channel, floodplain, and riparian plant communities. Often, the project is designed to be fixed and permanent, unchanging laterally and vertically. Plant communities are planted and maintained, more like gardening that succession of riparian forests and wetlands. The one fundamental property of rivers is dynamism, a concept reflected in both philosophy and river science. But human communities resist dynamism and view rivers as extensions of property. Change is undesirable and uncertainty is abhorred. River engineers often seek to serve social needs and attempt to create relatively static and unchanging stream ecosystems. In contrast, river dynamics can be used as the central process of restoration and create trajectories of recovery that are self-maintained and not addicted to continued human intervention. The third criterion of effective river restoration requires anticipation of future change. The distribution and influence of human communities is often viewed simply in the present and does not account for future growth and changing land use. Climate and biophysical processes similarly viewed as unchanging for the foreseeable future. Both assumptions are ludicrous in an ever changing world. Warming global climate trends are increasing thermal stresses on aquatic ecosystems and risks of extirpation of extinction for many species. Human growth challenges the available landscape and its productivity. Examples from the Willamette River in Oregon illustrate how trajectories of future change can be quantified and incorporated in the restoration of river networks and provide resistance and resilience for river ecosystems in the face of changing climate.

Key words: Restoration, rivers, floodplains, geomorphology, aquatic ecosystems, future scenarios, dynamism

1. INTRODUCTION

Governments and communities throughout the world face growing demands on water resources and increasing land conversion along streams, rivers, and wetlands. Recent assessments of river restoration have observed large numbers of projects, but many lack explicit goals, images of functioning system, and monitoring (Bernhardt et al. 2005). Palmer et al. (2005) identified five standards for river restoration: 1) design based on a guiding image of a more dynamic, healthy river, 2) ecological condition must be measurably improved, 3) river system must be more self-sustaining and resilient to external perturbations so that only minimal follow-up maintenance is needed, 4) no lasting harm should be inflicted on the ecosystem, and 5) both pre- and post-assessment must be completed and data made publicly available. These standards would measurably improve river restoration efforts throughout the world.

This paper describes the six principles that would refine the standards developed by Palmer et al. (2005) and emphasize the dynamic nature of river ecosystems in developing ecologically sound frameworks for river conservation and restoration:

- Ecological restoration is the design of an ecologically sound and more livable future.
- The first priority in river management is conservation of healthy, functioning components of the ecosystem.
- Ecological restoration of river ecosystems is based on restoring river dynamism and avoiding practices that harden and limit natural physical and biological change.
- River restoration must incorporate practices that fundamentally riverine and network based rather than terrestrially oriented and patchwork based.

- River restoration should be designed, monitored, and adaptively managed within a framework of multiple spatial scales of a river that interact to create a river ecosystem.
- River management must anticipate future trajectories of change and identify alternative future trajectories as a basis for adaptive management.

2. ECOLOGICAL RESTORATION

Ecological restoration inherently is the design of an ecologically sound and more livable future. Opponents of restoration often criticize restoration as an attempt to return an ecosystem to a past condition—essentially "turning back the clock". River scientists and managers sometimes slip into this mistaken perception as well. But it is impossible achieve and inappropriate to attempt because river ecosystems are constantly shaping and renewing themselves along trajectories of change. In the practice of restoration, we attempt to encourage future changes that create diverse, productive native communities and dynamic river channels and floodplains that can support these communities (Nagasaka and Nakamura 1999). We design practices that are consistent with the natural processes through which river maintain and restore themselves. We encourage characteristics of rivers that provide the ecosystem services that make a region and human community more livable—clean and abundant surface water and groundwater, aesthetically pleasing surroundings, habitat for native aquatic and terrestrial communities valued by the human communities. The process of restoration is inherently based on future trajectories and intricately links human communities with the ecosystems and resources that support them.

3. FIRST PROTECT THE HEALTHY

The first and most important step in river management is conservation or protection of healthy, functional components of the river ecosystem. This overarching priority cannot be overstated. Restoration practices can inadvertently divert the attention of the public and even the attention of river managers to their attempts to heal degraded portions of the river network and cause them to overlook the continued degradation of intact portions of the river. Hectare by hectare, stream bank by stream bank, tree by tree the ecologically healthy portions of the river are degraded as simply another option to be weighed against other needs of land owners or communities. Each loss is viewed as small and simply one of the choices that has to be made to meet other needs. But year by year, decade by decade, the losses coalesce. Soon the river and its floodplain are dominated by extensive distances of converted and degraded habitats, and healthy intact river channels and floodplains become small patches in a river of degradation. Our efforts to manage healthy rivers must first focus on maintaining the portions of the river that retain the most diverse, native communities and critical ecological processes.

Pitcher (2001) observed several characteristics of resource management systems that create a ratchet effect, which commonly lead to gradual or incremental depletion of fisheries resources. First, he noted that past ecological conditions become harder to restore as species (or genotypes) become extinct. Ecological functions are more likely to be irreversibly changed as biological components are lost. Second, we all have a tendency to evaluate changes in ecosystems based on the condition of those systems when we began our careers. "Accounts of former great abundance are discounted as anecdotal, methodologically naive, or are simply forgotten" (Pauly 1995, as quoted by Pitcher 2001). Third, he observed that management systems tend to invest in technological advances to harvest resources more effectively, which in turn decreases resource availability, which in turn requires further investment in technological capacity to harvest more resources. These three tendencies in management systems create a ratcheting effect that leads to continued depletion of natural resources.

Likewise, restoration practices can inadvertently lead to gradual depletion of aquatic resources and degradation of river ecosystems. The "Restoration Ratchet" is created by our tendency to consider the outcomes of all actions—both conservation and restoration—as immediately and fully effective (Gregory et al. 2007). We have a tendency to balance decisions that cause degradation of river or depletion of aquatic resources with well-intended actions to restore degraded resources. In most restoration practices, ecological outcomes are not realized for decades (e.g., replanting riparian forests for shade or bank stabilization). If we assume that efforts to restore depleted resources immediately counterbalance actions that deplete resources, river ecosystems will inherently decline in fundamental ecological processes community diversity, and abundances of aquatic organisms.

4. RESTORE RIVER DYNAMISM

Floodplains, channels, and biological communities of rivers are dynamic, reflecting the dynamic environmental events and disturbances that inherently shape rivers. Ecological restoration of river ecosystems is based on restoring river dynamism and avoiding practices that harden and limit natural physical and biological change. Though professionals and public will acknowledge the tendency of rivers to move and change, most attempt to limit to ability of rivers to shift within their channels and for plant communities to change in response to disturbances. Human communities resist dynamism and view rivers as extensions of property. Change is undesirable and uncertainty is abhorred. One of the greatest obstacles to river management is the view of rivers and their banks as property to be owned and remain unchanged. Societies often manage rivers to be flowing but unchanging. As a result, river restoration projects are designed to be fixed and permanent, unchanging laterally and vertically.

Dynamism is a fundamental property of rivers. Not just the network of channels that dissect the landscape but also the aquatic communities within them that exhibit change longitudinally, seasonally, and in response to disturbances, both flood and drought. The dynamic environment of rivers and its influence on the biota of streams and rivers has led to emergence several major concepts in stream ecology. The River Continuum Concept (Vannote et al. 1980) was based on predictable longitudinal changes in the structure and function of stream ecosystems from headwater streams to large rivers. Disturbance is a major determinant of the biological structure of streams and rivers. The Flood Pulse Concept (1989) demonstrated that aquatic ecosystems have adapted to patterns and timing of floods and depend on these patterns for resource supply, reproductive cycles, and redistribution and colonization. The Flow Pulse Concept (Tockner et al. 2000) added the regular expansion and contraction of river networks to our understanding of the importance of dynamic change in river to maintain healthy river ecosystems. The role of these hydrologic changes is the basis of the concept of the Natural Flow Regime (Poff 1997). Townsend et al. (1997) examined the structure of aquatic invertebrate communities in New Zealand streams and found that diversity was greatest at intermediate levels of disturbance, consistent with the Intermediate Disturbance Hypothesis.

All emerging conceptual frameworks of the structure and function of river ecosystems are based on the central role of dynamic change in the hydrology, geomorphology, water chemistry, thermal environment, population dynamics, community structure, and primary ecological processes. Yet world rivers steadily are altered to be less dynamic, fixed in place, hydrological less variable, and structurally simple. River engineers often seek to serve social needs and frequently create relatively static and unchanging stream ecosystems. In contrast, river dynamism should be the central process and goal of river restoration. The challenge for river managers and scientists is to educate the public about the importance of this dynamism in their rivers and develop approaches that allow people to live near streams and rivers and yet allow river to be as dynamic as possible.

5. THINK LIKE A RIVER

River restoration must incorporate practices that fundamentally riverine and network based rather than terrestrially oriented and patchwork based. It is surprising how many river restoration approaches are based primarily on terrestrial approaches for restoration, focusing on plots of land adjacent to a river or structures placed in a river to remain fixed at a point. Even floodplain and riparian restoration projects often focus on parcels of land. Plant communities are planted and maintained, more like gardening than the natural succession of riparian forests. Restoration often occurs only on one bank of a river and the response is viewed solely in terms of that plot of land or the organisms found immediately adjacent to the restored plot of land.

But rivers have two banks with a complex channel flowing through them. Restoration of ***the river*** must focus on the river and both of its banks—the reach in which river expresses its physical processes and shapes its biological communities. Any restoration project, whether located in the channel, riparian area, or floodplain, is designed to restore a flowing river and must at some point consider the dynamic river as a whole.

This holistic, dynamic view of the river applies equally to the social elements of river restoration design and the social goals and objectives. Communities along streams and rivers also experience change as certainly as the rivers that shape their development. Planning and restoration of towns and cities must account for human change, but also the environmental changes these communities are likely to experience. Community and urban planning will be more resilient and effective if the dynamics of both the communities and their rivers are viewed as related patterns of future change (Hulse and Gregory 2001).

6. ADDRESS AND INTEGRATE MULTIPLE SCALES OF A RIVER IN DESIGNING RIVER RESTORATION

River restoration should be designed, monitored, and adaptively managed within a framework of multiple spatial scales of a river that interact to create a river ecosystem. The entire river network provides the context for the performance for the different river reaches within the drainage network (Fig. 1). Specific reaches exhibit different hydraulic forces, geomorphology, and riparian communities, shaping local habitats and assemblages of aquatic organisms. Within these reaches, channel morphology and the associated habitats with inorganic substrates, large wood, riparian plant communities differ, creating mosaics of habitats for aquatic communities.

River restoration most commonly is designed at the scale of a plot of land along the river, a series of pools and riffles, accumulations of large wood, or a floodplain to be inundated. The context for a local project is always the next larger scale of physical and biological organization within the river network. And responses within a project reflect the interactions of local habitats within the project and influences both upstream and downstream within the reach. Catchments ultimately integrate the terrestrial and aquatic processes that shape river systems. Therefore, river restoration ultimately must be designed and evaluated within all of the relevant spatial scales, extending from the local habitat up to the entire catchment (Roni et al. 2001). Detailed measurements of responses to restoration are not possible at all scales, but such measurements must focus on the primary river processes and components for which the restoration is designed and to which the aquatic communities respond.

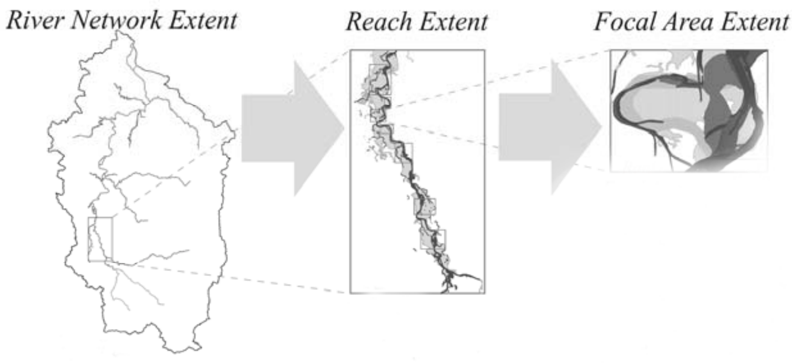

Figure 1 – Scales of rivers required for designing, implementing, monitoring, and evaluating river restoration.

7. ANTICIPATE FUTURE TRAJECTORIES OF ECOSYSTEM AND SOCIAL CHANGE

River restoration often focuses on repairing past damages to a river and is based solely on assessment of the current conditions of the river, the lands along the river, or the catchment. While past degradation and current changes are central to the design of conservation and restoration, efforts to improve ecological conditions can be overwhelmed by future change. It is rare to find regional assessments of future trends that are anticipated for the human communities, changes in land use, water demand, and the ecological condition of streams and rivers. Most restoration actions are designed to repair the consequences of past land use and management practices. Communities are more willing to invest in small projects with immediate or short-term responses. Larger scale issues are more complex and contentious, and communities are hesitant to accept the risks of addressing long-term changes. As a result, most river restoration focuses on short-term choices affecting small, local areas.

In river management, we have a responsibility to anticipate future trajectories of change and identify alternative future trajectories as a basis for adaptive management and design of networks of restoration. One tool that has been developed in landscape management is the development and assessment of alternative future scenarios, which provide spatial projections of alternative choices about human actions and potential ecological and social consequences. Alternative futures have been developed to explore future trends in several large river basins, such as the San Pedro River, Arizona (Steinitz et al. 2003) and the Willamette River Basin (Baker et al. 2004). The study of the San Pedro River clearly illustrated the overwhelming impact of water use on future ecological conditions in the river and arid terrestrial ecosystem (Steinitz et al. 2003). Obviously water withdrawal would be expoected to alter ecological conditions, but policies related to development in a growing huiman population also were found to have major ecological impacts. Social analyses are not simply limited to the more obvious effects of consumption of natural resources. Nassauer et al. (2004) explored residential development in an agricultural region of the upper Midwest of the United States. Most of the public preferred landscapes with natural vegetation and higher ecological conditions. This study demonstrates that social behaviors and preferences can have major roles in the design of future landscapes and the types and locations of restoration that would be more consistent with social desires for a more livable environment.

An example of the application of alternative scenarios of future change is the study of trajectories of land use and environmental change from 1850 to 2050 in the Willamette River Basin in Oregon (Baker et al. 2004). Land use in the 30,000-km^2 basin is comprised of forest land (65%), agricultural land (25%), urban land (6%), rural residential land (4%). Human population in the basin is projected to increase from 2.2 million to more than 4 million by 2050. We developed three spatially explicit future scenarios that included 1) a plan trend 2050 scenario based on current land use practices and policies, (2) a development 2050 scenario in which market forces influenced land use change and current land use policies were relaxed, and (3) a conservation 2050 scenario in which additional, plausible conservation and restoration practices were implemented. Rather than having the team of scientist dictate the assumptions related to these changes, we had a team of regional stakeholders define the types of changes and practices that were most plausible and likely based on their experience and perceptions of the regional communities. We developed models of ecological conditions for fish, macroinvertebrate, and wildlife communities based on empirical field studies and assessments of land cover change and water availability.

One of the most important findings of the alternative-futures analysis was that the restoration and conservation practices that the stakeholder group thought were plausible in the future (as reflected in the conservation 2050 scenario) substantially improved ecological conditions for fish communities, aquatic macroinvertebrates, riparian vegetation, and wildlife, reversing declining resource trends and recovering 20 to 70 percent of the losses sustained since settlement in the mid-1800s (Figure 2). In sharp contrast, both the plan trend 2050 and development 2050 scenarios show either little change or continued decline in natural resources. These spatially explicit projections for the next 50 years in the Willamette River basin clearly indicate that conservation and restoration practices are likely to produce significant ecosystem benefits while accommodating projected increases in the human population. These findings and spatial analyses have been used as a context for basin planning and restoration of the mainstem Willamette River in Oregon.

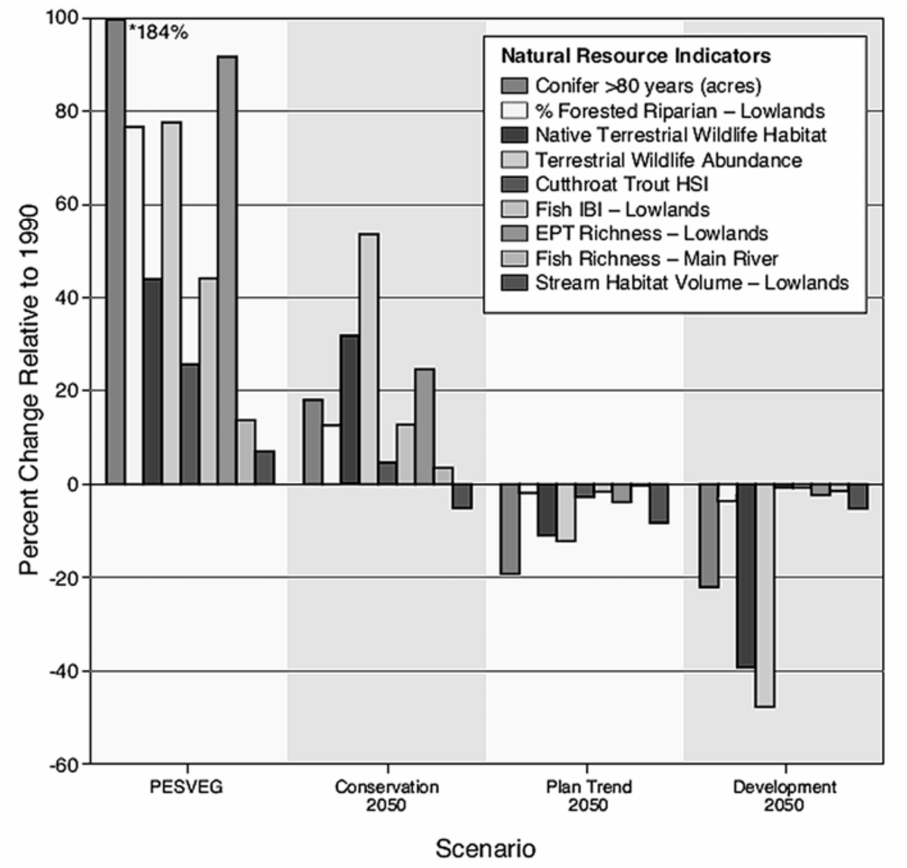

Figure 2 – Percent change in natural resource conditions in the three future scenarios the scenario of change from 1850 to 1990. Changes are expressed as percent change relative to 1990 land use and cover (Baker et al. 2004).

8. CONCLUSIONS

River restoration has become a focus of ecologists, engineers, fisheries scientists, and landscape architects throughout the world. The need for river restoration is evident but complex social issues make river management difficult. Three fundamental characteristics of ecologically sound river restoration frequently are missing from many projects. River restoration should be designed to 1) restore rivers (in contrast to plots of land), 2) restore river dynamism, and 3) anticipate future human and natural change. Surprisingly, these design criteria frequently are overlooked or dismissed when debating alternatives for restoration.

It is not difficult to convince a river manager or an aquatic scientist that rivers are inherently dynamic and change is a positive and restorative process in river ecosystems. Most recent ecological, hydrological, and geomorphical concepts in river science are based on the fundamental importance of on-going, dynamic change in rivers. The difficult challenge is to communicate this fundamental understanding of the dynamic nature of healthy streams and rivers to the public and regional decision makers that shape the future of the world's rivers. River managers have a responsibility to incorporate the principles in their day-to-day practices and planning for our future environment, managing for resilient and dynamic rivers rather than allowing social pressures to cause them to engineer hardened, fixed, and simplified rivers. Solutions in a complex world are never simple, social processes are an inherent part of the landscapes, and compromises in fundamental riverine processes always have ecological consequences.

Stewart Brand asked, "How do we make long-term thinking automatic and common instead of difficult and rare, and how do we make the taking of long-term responsibility inevitable?" in his book "The Clock of the Long Now". The "long now" is essentially the inherent reality of future consequences in day-to-day decisions and actions. Most decision making processes do not address future consequences except in vague and very general terms. Brand concluded that we have to change our approaches, technological tools, and social processes to make the "long now" inherent in management questions we ask and the solutions we explore.

River restoration will play an ever growing role in river management as more and more of the world's rivers are degraded. We will implement restoration projects in both the spirit of hope and the demonstration of our good intentions. But these practices may divert our attention from the continuous, incremental degradation of intact and healthy portions of our river networks. Social expectations that restoration is immediately and fully effective will create a ratcheting effect that permits us to accept on-going degradation simply because we are simultaneously investing in restoration. But river restoration is never immediate and the loss of a diverse and functional river reach is never balanced by our attempts to restore degraded river reaches.

ACKNOWLEDGEMENTS

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'ROOM FOR THE RIVERS': THE STORY OF A MULTIPLE GOAL AND MULTIPLE ACTOR PLANNING PROCESS

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ABSTRACT

In December 2006 the Dutch parliament approved a 2.2 billion Euro program called 'Room for the River'. The program will counter increasing design discharges of the river Rhine mainly by providing more room to the river, especially increasing the discharge capacity of the river as an alternative for 'traditional' strengthening dikes along the river.

'Room for the River' restores some of the resilience in the Rhine river system that has been lost since the 19th century.

This paper focuses on the main characteristics of the 'Room for the River' program and on the complex decision making process with special attention to the decision support system that was successfully used.

1. INTRODUCTION

Room for the rivers as the cornerstone of sustainable flood prevention policy for Dutch rivers only has a very short history of only 10 years. The history of the reduction of room for the rivers is much longer. Especially since the second half of the nineteenth century, when the so called 'normalisation' of the Dutch rivers was started, the rivers have been straitjacketed between strong and high dikes to protect the people, their homes and their belongings from devastating floods. Figure 1 shows the areas that were part of the floodplain around 1850 but are now excluded from it.

This paper sketches the Dutch 'Room for the Rivers'-policy by focussing on the large scale program of the same name currently being implemented: its origin, goals, decision-making process and actual status.

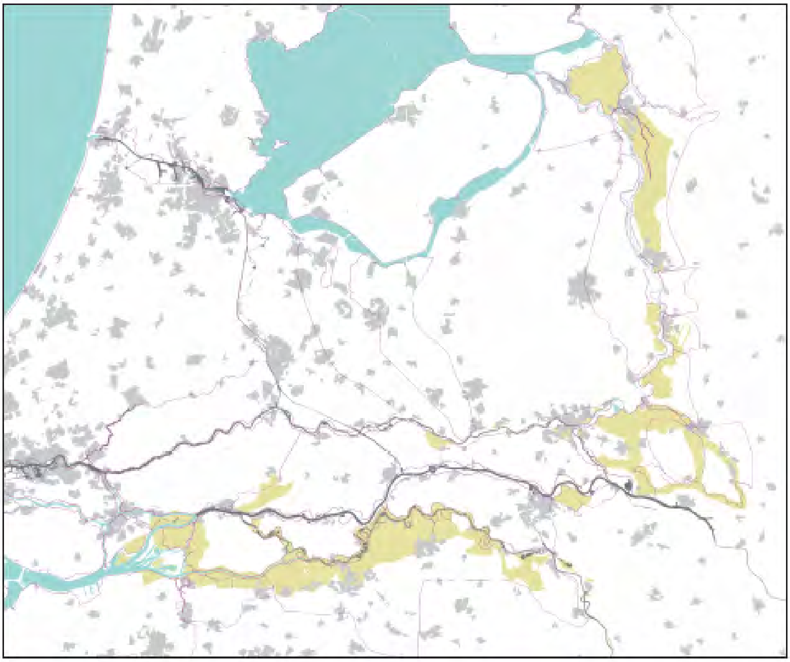

Figure 1 - Lost room for the rivers since 1850.

2. 1990 – 2000: PROLOGUE

'Room for the rivers' did not come out of the blue. Three major developments are the prelude to the paradigm shift from single focus on flood protection measures towards more resilience in river systems:

a. Living rivers: nature development in the floodplains

In the early 90-ties it became clear that nature conservation in the Netherlands was in need of a more offensive approach. Nature development in addition to nature conservation was promoted. Especially along the rivers the potentials were high and soon the first nature development projects started under the overarching theme 'Living Rivers'.

b. Near flood disasters in 1993/1995

In the winters of 1993 and 1995 extreme discharges of the Rhine and Meuse almost caused large scale floods in the central river district of the Netherlands. Hundreds of thousands inhabitants were evacuated from of the endangered areas. These alarming events raised the sense of urgency for better flood prevention programs. At same time further dike enforcement seemed to be a dead end street and the concept of giving more room to the rivers was accepted as a serious alternative.

c. Adaption to climate change: Water management in the 21st century

In November 1998 excessive rainfall caused problems in water management all over the country. They were considered as a sign of climate change and lack of resilience in the Dutch water systems. Under the title of 'Water management in the 21st century' a study was carried out resulting in a large program to increase resilience by creating more room for peak discharges and retention in regional water systems and the main rivers.

Figure 2 - Example of 'Room for the River': creating new side channels in the floodplain.

3. THE ROOM FOR THE RIVER-PROJECT: MAIN CHARACTERISTICS

The operational goal for the 'Room for the River-program is stabilizing water levels in the Rhine branches under design conditions despite increase of design discharge of 1000 m3/sec (from 15.000 m3/sec to 16.000 m3/sec). In this way further strengthening of dikes can be avoided. But flood protection is not the only goal: the program also aims for spatial quality in terms of ecological, recreational, socio-economic and cultural values. Many of these values are hard to quantify of objectify and thus hard to balance: they are negotiable between parties at stake.

The decision making and the implementation process of the 'Room for the River' program is a partnership between national and regional authorities, with the Ministry of transport, Public works and Water management as the final responsible authority.

The whole program has to be completed around 2015 and by that time a strictly limited budget of 2.2 billion Euros will be spent.

One specific characteristic of the program has to highlighted. The final set of individual projects in the program is selected on technical, financial and many other criteria. But they are also considered as first steps on a longer road towards accommodation of an increase in the design discharge of the Rhine to 18.000 m3/sec in the second half of the 21st century. So in any case the short term projects should be no regret or adaptable projects.

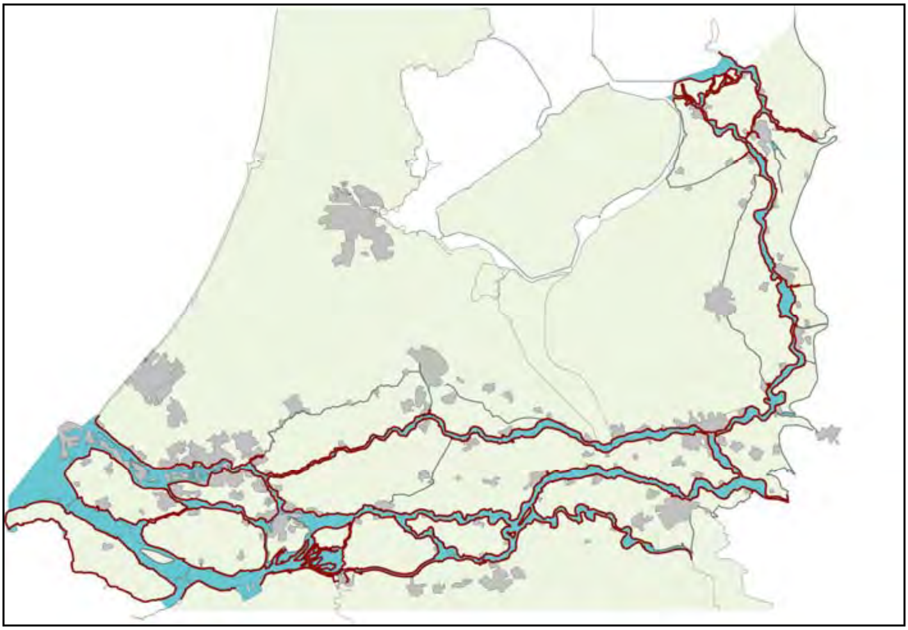

Figure 3 - the project area of the ‘Room for the Rivers’ program.

4. TOOLBOX OF MEASURES

More room for the river can be achieved with different types of measures. In the program the following toolbox of measures was available. From an ecological restoration point of view the bold printed types of measures are the most interesting.

In the existing the floodplain (between the dikes):

- Riverbed deepening
- Groin improvement
- Creating side-channels
- Removing obstacles
- Strengthening of dikes (last option to be selected when other feasible alternatives are lacking)

Outside the existing floodplain:

- Detention areas
- Bypasses/ ‘green rivers’
- Widening of floodplain by displacement of dikes

4. THE DECISION MAKING PROCESS: A CRUCIAL ROLE FOR DECISION MAKING SUPPORT (DSS)

The selection of a final set of projects (measures) that was acceptable to all major stakeholders, that met all technical and environmental criteria and stayed within the budget really was a complex decision making process.

The scheme below shows the major steps that were taken between identifying potential measures and bring down the number of 600 individual measures to a preferred and approved set of measures.

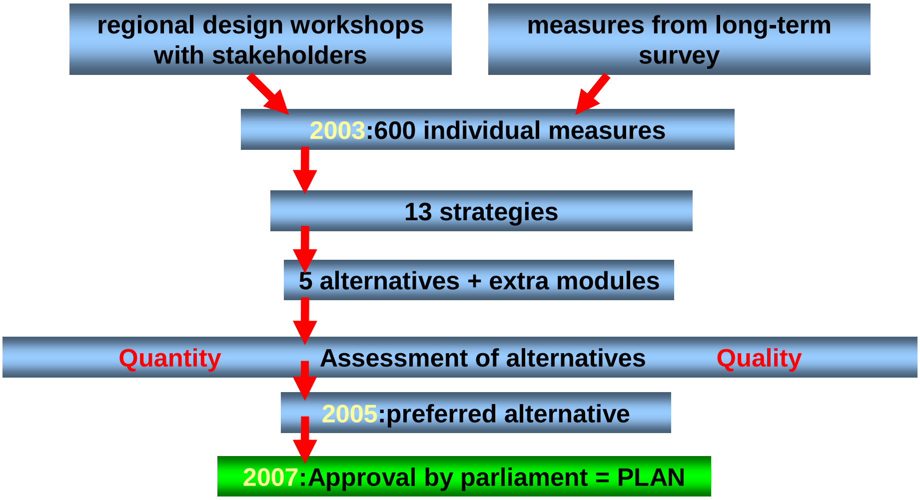

Figure 4 - steps taken in the decision making process of the 'Room for the River'program.

This complex decision making process certainly would have crashed halfway without the use of a practical decision support system: the so called 'Box of building blocks' (in Dutch: 'Blokkendoos'). With this DSS it was possible to compose alternative sets of measures and immediately evaluate the effectiveness and other characteristics. In due course the DSS was accepted by all stakeholders as the single reliable platform for discussion even being aware of its shortcomings due to necessary simplifications. Another advantage of the DSS is that it is available to everybody involved in the process whilst the software runs on every desktop or laptop.

5. THE PLAN

The final plan as the outcome of the decision making process consists of 40 projects (measures) to be detailed and implemented until 2015. In the implementation phase a programmatic approach is chosen. This implies that alternatives for individual projects of the approved plan can be developed with three strict conditions: the alternative must fit into the budget, has to be implemented before end 2015 and strong support from involved administrations.

Figure 5 - The approved plan with 40 projects along the different Rhine branches.

Two of the 40 projects are illustrated below.

Figure 6 - Birdseye view of a bypass around the city of Kampen in the downstream part of the Rhine branch called the Ijssel.

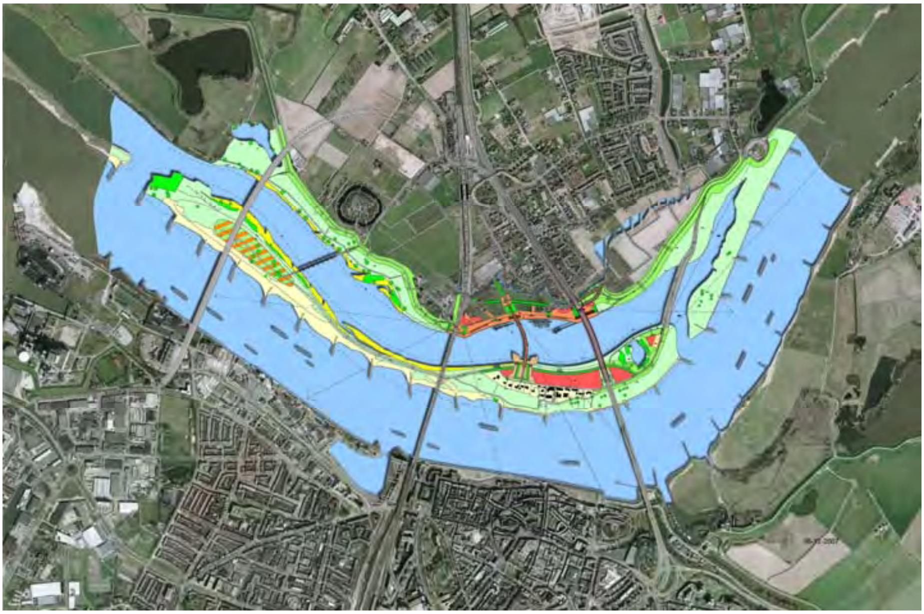

Figure 7 - Widening of the floodplain near Nijmegen in combination with city development along the river.

DECISION MAKING FOR RIVER AND FLOODPLAIN RESTORATION: COPING WITH COMPLEXITY

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ABSTRACT
In this paper I explore the nature of decision-making processes relating to river and floodplain restoration with a view to identifying the principal challenges and drawing lessons from recent experiences. On the basis of in-depth empirical research conducted in England, France and Germany I compare and contrast two generations of restoration schemes: the simpler and smaller-scaled schemes of the early to mid-1990s and the more complex, large-scale projects of today. From these cases I draw observations on the challenges posed by demands and desires for greater cross-sectoral integration and multi-level governance in restoration schemes today. Without challenging the need for a more integrated approach to restoration, I draw attention to the growing complexity of project management and the negative impact it is having on implementation. In the conclusion I argue that coping with complexity is central to implementing successful restoration schemes today and that the key to this lies in improving communication and coordination between policy development and project management.

Key words: floodplain restoration, institutions, policy analysis, Europe

1. INTRODUCTION

The task of restoring rivers and floodplains poses multi-dimensional challenges to policy-makers and project managers alike. Reconfiguring a river and its adjacent floodplain can generate numerous benefits to nature and society, ranging from richer biodiversity, more appealing landscapes and additional recreational opportunities to improved flood prevention. Equally, however, river restoration impinges on a wide variety of interests and institutional arrangements relating to agricultural production, water protection, nature conservation, flood defence, navigation, recreation, urban and rural development and the protection of historical landscapes. A successful restoration scheme needs to enrol stakeholders and institutions not only from such diverse sectors, but also from different scales of action and jurisdiction. The active support of local residents and authorities is generally essential, the political backing and (co-)funding by regional, national and even supranational agencies invariably critical to success. Decision making for river restoration is therefore not just about reaching agreement on a particular plan or design. It is better understood as a continuous process of guiding a scheme in its metamorphosis from the earliest ideas via planning and funding to implementation and ex-post evaluation. This process is generally not linear, but rather highly unpredictable, typically marked by set-backs and delays, sudden breakthroughs, renegotiations over measures etc. This is inevitable, given the diversity of interests involved and the conflicts invariably emerging around the reconfiguration of a river and its adjacent land.

In this paper I explore the nature of decision-making processes relating to river and floodplain restoration with a view to identifying the principal challenges and drawing lessons from recent experiences. On the basis of in-depth empirical research conducted in England, France and Germany I compare and contrast two generations of restoration schemes: the simpler and smaller-scaled schemes of the early to mid-1990s and the more complex, large-scale projects of today. From these cases I draw observations on the challenges posed by demands and desires for greater cross-sectoral integration and multi-level governance in restoration schemes today. Without challenging the need for a more integrated approach to restoration, I draw attention to the growing complexity of project management and the negative impact it is having on implementation. In the conclusion I argue that coping with complexity is central to implementing successful restoration schemes today and that the key to this lies in improving communication and coordination between policy development and project management.

2. THE CASE FOR RESTORING FLOODPLAINS

The importance of restoring functional floodplains is rapidly gaining credence. Since the mid-1980s international scientific communities of ecologists, biologists, hydrologists and geomorphologists have made huge advances in our understanding of how rivers work and how they interact with their natural floodplains (e.g. Ward et al., 1999; Hughes and Rood, 2001; Hughes, 2003; Rohde et al., 2006; Tockner and Stanford ,2002). These studies highlight that natural floodplains are considered the most biologically productive and species-rich ecosystems on earth (Tockner and Stanford, 2002). More recently, policy makers have been showing interest in the value of functional floodplains in helping to address a range of problems, from major flooding events and the increasing costs of maintaining flood defence to climate change impacts, the continued loss and deterioration of valuable habitats and inefficiencies in agricultural production (Adams et al. 2004;

Ldoux et al., 2005). At the same time we can observe growing interest amongst local stakeholders in restoring floodplains as a way of improving the quality of life with better flood protection, greater local biodiversity and more attractive landscapes, to name just a few of the potential benefits.

Given this recent surge of support for restoring floodplains among policy and research circles as well as in the public domain, it is astonishing how very few schemes for restoring functional floodplains have been put into practice in Europe to date (cf. Ledoux et al., 2005; Rohde et al., 2006). Whereas river restoration has in recent years become a widely practised form of environmental enhancement in Western Europe, floodplain restoration is still under-developed, being limited largely to a few, small-scale demonstration sites. Why is this the case when restored floodplains represent some of the most species-rich and endangered habitats in Europe, offering additional benefits in flood prevention, regional economic development, recreation etc.?

3. PAST CONSTRAINTS TO FLOODPLAIN RESTORATION

The explanation for the limited number of floodplain restoration projects lies partly in the human activities which have contributed to the loss of functional floodplains in the past, such as settlement development, agricultural land use, flood defence and navigation. The continued importance of these activities poses strong arguments against allowing floodplains to flood naturally and ecosystems typical of floodplains to develop unimpeded. There are, though, many additional factors which contribute to frustrate schemes to restore floodplains. Our policy analyses and case studies conducted in France, Germany and England have identified several of the constraints which – individually or in conjunction – prevent flood restoration schemes taking place or limit the scope and effectiveness of those implemented (cf. WWF, 2000; Adams and Perrow, 1999). The most important constraints include:

- Conflicting claims for the use of floodplains (e.g. for agriculture/forestry, settlements, hydropower, technical flood defence);
- Land ownership and the inadequate incentives for landowners/farmers to accept or promote changes in land use;
- Inadequate protection of floodplains from urban development;
- Adverse financial incentives, such as the emphasis of flood defence funding on building and maintaining defence structures or of the Common Agricultural Policy (CAP) on increasing agricultural productivity;
- The dominance of hard engineering solutions to flood defence strategies;
- Difficulties of coordination between the multiple policy fields and actor groups affected;
- Difficulties of considering the socioeconomic and ecological development of the whole catchment.

Although the intensity and significance of these constraints vary between different national and regional contexts, they are common to all the countries studied. Their combined impact has been to limit the number and scope of floodplain restoration schemes in the past. Up until the late 1990s schemes to restore floodplains in Germany, France and England were – where they existed at all – small-scale and site-based. They were typically single-issue projects, targeting environmental enhancement as a rule. They involved only a small number of actors and policy instruments, often relying on a single source of funding for the physical interventions. These characteristics applied – to a greater or lesser degree – to all three of the early generation restoration schemes studied: the Rheinvorland-Süd project on the Upper Rhine, at Bourret on the Garonne (France) and on the Long Eau in Lincolnshire, England. Still today, many floodplain restoration schemes belong to this early generation of projects of limited scope and scale.

4. NEW POLICY DRIVERS OF FLOODPLAIN RESTORATION

Since the late 1990s shifts in policy content and style in the fields of flood protection, nature conservation and agriculture at EU and national levels are, however, creating new openings for floodplain restoration of a more comprehensive, integrated kind (cf. Ledoux et al., 2005; Maltby and Blackwell, 2005; Werritty, 2006). Our research has revealed many new institutional drivers which are creating 'windows of opportunity' for floodplain restoration, encouraging the emergence of a larger number of significant schemes. These are summarised in Table 1.

In the field of flood protection our policy analyses and case studies have demonstrated how recent major flooding events in France, Germany and England have accelerated the willingness of the authorities to entertain catchment-oriented approaches and soft-engineering techniques of flood protection, creating new opportunities for floodplain restoration. The sheer cost of improving and maintaining physical flood defences, in particular in rural areas, is raising interest in alternative strategies. Water protection agencies, concerned at water pollution and shortages and motivated by the EU Water Framework Directive, are showing growing interest in water flow regimes across whole catchments and in the (disputed) potential of floodplains to improve water quality. For nature conservationists restored floodplains represent important habitats which can contribute to meeting biodiversity targets in accordance with the EU Habitats and Birds Directives. Growing political pressure for more environmentally sensitive forms of agriculture and forestry is creating new funding opportunities for extensive practices more suited to floodplain restoration. Finally, land-use planning regulations are being modified to offer more effective protection of existing floodplains and, in some instances, earmarking land for the future restoration of floodplains. Spanning these sectoral policy shifts is a general trend towards greater policy integration and stakeholder participation over schemes of this kind, informed in part by debates on sustainable development and new forms of governance.

Table 1 – Recent policy shifts conducive to floodplain restoration.

Policy field	Forces for change	Policy responses
Nature conservation	Growing concerns for the promotion of biodiversity, habitat networks and for riparian ecosystems and wetlands	EU Habitats Directive; funding programmes for functional floodplain ecosystems and wetlands; advanced instruments for the designation and management of protected areas
Flood protection	Flooding events and growing awareness of the limits to technical solutions; climate change; infrastructure costs; progress in, and growing acceptance of, soft engineering techniques; environmental quality	Flood risk management; EU Floods Directive; national legislative reforms; early steps towards river basin institutions in flood prevention
Water protection	Water quality/quantity problems; interest in flow regimes, wetlands, geomorphology	EU Water Framework Directive; catchment-oriented planning approaches and river basin organisations
Land-use planning	Growing awareness of linkage of flooding events to land use; major damage from flood events; growing pressure from insurance industry	Planning instruments for protecting and creating areas for flood retention; legislative restrictions for land use in flood-risk areas
Agriculture	Growing societal concerns for public health and environmental degradation	Agenda 2000; improved agri-environmental schemes; contractual nature conservation
Rural development	Growing spatial disparities and economic disadvantages of rural areas	EU Rural Development Regulation; integrated approaches to rural economic development

Source: Moss (2007); Moss and Monstadt (2007)

In response to these institutional drivers a new generation of floodplain restoration schemes is emerging which are of a quite different scale and scope to those of the early to mid-1990s. These schemes, three of which were investigated in detail (at Lenzen on the Elbe, La Bassée on the Seine and the Parrett Catchment Project in Somerset), set out to address some of the complex challenges to large-scale, integrated floodplain restoration outlined above. Distinctive features of the new generation schemes are their multiple objectives (covering, for instance, flood defence, biodiversity, rural development and water quality management), their wide actor engagement (including the relevant policy fields, local authorities, NGOs and the general public), their use of various instruments from different policy fields (e.g. joint funding from flood defence and agri-environment budgets) and their interaction with national policy-making, serving for instance as pilot projects for national policy development. Since these new generation schemes were only launched from the late 1990s onwards it is at present difficult to judge their effectiveness. They would at least appear to have the potential to overcome some of the principal institutional constraints to floodplain restoration which have thwarted or curtailed efforts in the past.

5. CONTRASTING DECISION MAKING IN EARLY AND NEW GENERATION SCHEMES

What implications do these two very different types of schemes – early and new generation – have on decision-making processes? What can we learn from the experiences of decision making in each case? For reasons of space I select here only the two English case studies for detailed analysis: the Long Eau floodplain restoration scheme and the Parrett Catchment Project.

Long Eau restoration scheme

The scheme to restore a floodplain on two small sites on the Long Eau River in Lincolnshire, England, was conducted between 1992 and 1996 and entailed removing embankments and creating new ones further away from the river so as to allow periodic flooding of the formerly protected floodplain. Designed originally to enhance biodiversity in an area of low conservation value, the project produced, in addition, flood protection benefits by increasing floodwater storage capacity. Typical of other early generation schemes it was small in scale and site-based. It involved a small number of actors and relatively straightforward funding mechanisms and implementation procedures. This enabled the project to be completed rapidly – in the case of one of the sites within a matter of months.

A distinctive feature of the Long Eau project was its organisational simplicity. It never had a formalised structure or procedure, but operated essentially as an informal collaborative venture. The Long Eau scheme was conceived, planned and managed by less than 10 individuals. Leadership lay, *de facto*, with three officers from public agencies: the Farming and Wildlife Advisory Group (FWAG), the National Rivers Authority (NRA) and the Countryside Commission (CC). Each was highly motivated. The FWAG officer, a farmer himself who managed land under Stewardship funding schemes, was keen to develop a project with which wetland habitats could be created in combination with less intensive forms of agricultural production. The NRA conservation officer wanted to demonstrate how ‘soft engineering’ solutions of flood protection could not only enhance the environment but also provide more cost-effective flood defence. The Countryside Commission officer responsible for the Stewardship scheme, who was new to the area, was highly motivated to conclude some good agri-environment agreements with local farmers. Together, they complemented each other in expertise and influence, quickly developing a good working rapport. They each had the backing of their superiors and enjoyed relative freedom to innovate. These three actors proved very successful in enrolling the support of other key players, notably a local NRA flood defence officer and a senior engineer of the local drainage board. The two farmers/landowners on whose land the floodplain was restored were also instrumental in the successful implementation of the project.

What was beneficial for rapid and effective decision-making proved, however, detrimental to the generation of similar, follow-up projects in the region. Although universally regarded as successful by all the participants, including the farmers, the Long Eau project was not replicated on other sites elsewhere on the river. Given the relative success and ease of implementation of the Long Eau scheme it is surprising that there was not a more concerted effort to persuade other farmers to follow suit. This reveals a structural weakness in relying too much on individuals. The freedom which the key actors required to implement the scheme so effectively was equally a freedom to move on to other issues following completion. The free rein which their organisations gave them was very valuable in encouraging innovation, but proved a weakness when it came to dissemination and follow-up activities. The failure to enrol the local community (beyond the farmers directly affected) or strategically important players at regional and national levels certainly speeded up the implementation process, but it meant that there was little knowledge of – or interest in – the project beyond the immediate project team. This suggests that some form of sensitive and un-bureaucratic monitoring of progress and potential by key public agencies is an essential pendant to providing trusted experts with the leeway they need to engage in innovative projects.

The Parrett Catchment Project

The Parrett Catchment Project (PCP) in Somerset, England, was until recently one of the flagship schemes of integrated catchment management in the UK. In a variety of ways it embodied recent shifts in opinion about how to manage rivers and landscapes. Launched in 2000 against the backdrop of bitter disputes between farmers and conservationists and severe flooding events in 1999/2000, the PCP's remit was to resolve conflicts over land and water management activities by building a broad partnership with which to develop innovative forms of sustainable flood management across the whole catchment of the River Parrett. A 50-year Action Strategy outlined the project's integrated approach to meeting flood defence needs in ways that would benefit wildlife, support the local economy and offer new opportunities for rural development. With the support of local and national policy communities it succeeded in accessing substantial funding, stimulating joint projects and initiating a dialogue between actors of the upper and lower catchment. The PCP reaped considerable praise in professional circles, winning national awards and being selected as an example of best practice for flood management nationally. Expectations of the PCP – both locally and nationally – were always high.

However, in April 2007, within just seven years of its creation, the PCP was shut down and replaced by a Somerset-wide organisation, the Somerset Water Management Partnership. Though there were broader, regional issues behind this change, it is clear that the PCP came under increasing criticism for its perceived failure to deliver. Beyond its impressive strategy documents, extensive consultation exercises and substantial external funding the PCP achieved comparatively little in terms of improvements to flood protection, wildlife and the rural economy. Many of those closely involved grew impatient at the lack of progress on the ground and questioned the viability of maintaining the broad project partnership in the absence of tangible benefits.

Critical to the PCP's performance was the sheer complexity of the project. The PCP comprised a partnership covering all the local authorities, flood defence, environmental protection and nature conservation agencies, farming organisations, wildlife trusts and regional development agencies. Decision-making in this large, diverse partnership was lengthy and laborious, even with the support of a full-time project coordinator, secretariat and steering group. Cultivating and retaining the support of all parties around the PCP's core objectives proved so central to its work that other issues – notably implementation – could not be pursued with the necessary intensity.

The case of the PCP demonstrates that the pursuit of 'catchment', 'long-term' and 'co-operation' approaches in floodplain management – though all highly laudable – present their own problems and can often be inherently conflictual. To achieve one objective, such as the management of the catchment as a whole, may not always be best served by pursuing the goals of co-operation. It may be necessary to employ more coercive measures or enrol central government support to promote catchment-level management, given the diversity of interests present within it. Similarly, it may not always be possible to maintain consensus and cooperation around a long-term vision due to the need to provide participants with visible, short-term improvements on the ground as a reward for their support. Too rigid a focus on consensus-building may, paradoxically, undermine a stakeholder partnership in the longer term. If consensus is achieved by systematically avoiding potentially contentious issues then the partnership will fail to develop the skills needed to resolve conflicts in a mutually acceptable fashion. It will be ill-equipped to deal with major issues of conflict when they – almost inevitably – arise. Apart from the importance of confronting contentious issues, the PCP experience suggests that a long-term vision – vitally important as it is – needs to be balanced by activities which can demonstrate policy delivery quickly and effectively.

6. CONCLUSIONS: THE PERSISTENT POLICY DELIVERY GAP

We conclude that recent shifts in problem awareness and problem-solving approaches in a number of relevant policy fields are creating new ‘windows of opportunity’ for floodplain restoration. At the same time there is a growing willingness amongst local and regional actors to restore floodplains as a means of addressing a variety of localised issues, ranging from flood risks and loss of biodiversity to agricultural restructuring. This interest has stimulated the emergence of a new generation of floodplain restoration schemes which target policy integration, actor engagement and the multiple functions of a floodplain from a catchment or, at least, river reach perspective. Early evidence suggests, however, that a policy delivery gap continues to exist. In particular, it appears that the sheer complexity of the tasks being tackled is posing a major problem for project management. The requirement to consult widely costs time and resources. Accessing multiple funding sources obliges restoration projects to adapt their objectives to satisfy different funding agencies. Attempts to enrol instruments from different policy fields reveal incompatibilities and inconsistencies of policy objectives. These innovative features of the new generation schemes, although each justifiable in its own right, are having the combined effect of making restoration schemes highly complex, difficult to manage and time-consuming, creating a new dimension to the policy delivery gap.

What lessons can we draw for the further development of national and EU policy on floodplain restoration? Creating policies for a more catchment-based, long-term and consensual approach does not necessarily mean that such an approach will necessarily emerge at the regional or local scale. This is not to suggest that the goals themselves are not worthy of aspiration but, rather, that there has to be greater appreciation of the importance of context, the strength of vested interests and the limitations of consensus-based forms of management. Such an approach, more modest in its expectations of success and more realistic in its capacity to meet a variety of interests, may serve to remove some of the burden placed upon actors at the project or catchment level and to focus the attention of policy-makers and the scientific community on inconsistencies apparent at other institutional levels. What, we should be asking, is the cumulative effect of specific national and European policies on actors in the catchment? How far do the various regulatory, financial and planning incentives from the policy fields of flood defence, agriculture, nature conservation and land-use planning take into consideration the day-to-day practices and perceptions of the intended addressees in their specific contexts of action? By posing questions of this nature a more 'enabling' framework for integrated catchment management may emerge. Unless institutional frameworks become more sensitive to the realities of implementation, then the rhetoric of thinking catchment, thinking long-term and thinking cooperation will remain just that and the policy delivery gap will persist.

ACKNOWLEDGEMENTS

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GEOMORPHOLOGY AND RIVER RESTORATION FEEDBACK AND OUTSTANDING ISSUE IN THE HYDROGRAPHIC DISTRICT OF THE RHONE RIVER

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1. INTRODUCTION

As a result of the increasing understanding that natural environments and healthy aquatic ecosystems can be valuable infrastructures to manage natural hazards and provide water and services in a sustainable manner, there is an increasing social demand, especially with the implementation of the Water Framework Directive, to identify, preserve and restore river corridors. Because the spatial and temporal scales concerned are now wider - managers must work with coherent geographical units of a few hundreds of km^2 or a few kilometres of river length and consider pluri-decadal trends in term of geomorphic adjustment and ecosystem evolution - the problem is more than an engineering question and includes territory management issues, public participation and interdisciplinary negotiations. In such a context, the aim of this talk is to introduce examples of geomorphological approaches for the sustainable management of river systems that have been implemented in the district of the Rhône River catchment. Shared experiences of the interdisciplinary scientific team working in Lyon in the LTER Rhône Basin platform (Zone Atelier Bassin du Rhône) will be introduced as well as the network of scientists and river managers in order to highlight knowledge needs and formulate fundamental research questions at a medium term to help practitioners in their day-to-day actions. In the geomorphological domain, there are truly challenging issues related to not only the planning of restoration and preservation strategies at the district scale but also the provision of feedback for improving pioneer restoration programs which have been performed at local scales. A few examples will be used to illustrate planning at the hydrographic network scale in terms of habitat modelling and physical characterisation, monitoring restored sites and predicting the evolution of designs involving the reactivation of former channels and sediment reintroduction, assessing the ecological quality, diagnosing the ecological problems of gravel-bed rivers, and evaluating their self-restorative capacity. Discussion points will be introduced in terms of possible limitations and the urgent need to better integrate local community wishes and social questions into the restoration projects, particularly as they are related to on the perception of landscape/aesthetics and balancing natural hazard mitigation versus ecosystem improvements. Two steps will be developed : i) key advances in geomorphology over the last two decades in the Rhône basin, ii) outstanding challenges for the provision of knowledge to support sustainable development efforts within the district.

2. GEOMORPHOLOGY AND RIVER RESTORATION: 25 YEARS OF THINKING IN AN INTERDISCIPLINARY FRAMEWORK

2.1 Scientific context

One of the major aims over the last 25 years of river management in the Rhône catchment was the reduction of the barrier between the disciplines and the creation of a common language. Previous interactions occurred between ecological (invertebrate, fish and plant communities) and geographical researchers in the 1980's, with major contributions on the understanding of the Rhône corridor and the effects of damming and regulation on riverine and aquatic environments (see Roux et al. 1982; 1986; Bravard et al., 1986; Amoros and Petts, 1993, and Petts and Amoros 1994). This first step allowed new river restoration efforts, notably related to the deepenings of former channels and the major restoration decadal plan applied on the Rhône after 1994. It also increased the interactions between geomorphologists and hydraulic engineers as they worked to better combine modelling and field observations. Significant contributions were observed on the Isère, the Ain and the Drôme Rivers in this domain. Recent development with physicists, chemists and microbiologists in order to combine understanding of sediment flux (mainly fines) with pollutants, toxics and tracers is a forthcoming effort. The observation of Rhône basin sediment is an emerging project allowing the combination of this approach over the entire reach with the joint efforts of research groups in Lyon and Aix-en-Provence. Over the last three decades, research has been actively supported by the CNRS (National Center of Scientific Research) to promote emergence of interdisciplinary teams in "environmental" (in the sense of natural) sciences. Recent understanding that the earth and natural processes are controlled by human actions, and have consequences to the long term development of human society, explains that an effort is done to promote practical output from fundamental research with two incidences : the increasing involvement of social sciences in the interdisciplinary debate and of the river managers who at the early stage simply ordered scientific studies whereas now work more in a cooperation framework with scientists.

Geomorphological contributions in this forum have provided knowledge that has influenced the way the rivers are managed today. First, a few main changes in geomorphic processes have been underlined : (i) the catchments provide less and less sediment but more and more wood. This trend will continue for a long time and is associated with different factors : excess mining in the 1970’s in a natural context providing less sediment with a disconnection of sediment sources within the hydrographic network due to slope stabilisation by spontaneous and sometimes planned afforestation, but also damming and regulation in mountain branches to prevent flooding risks. The Schumm model established in the Mississippi inner delta does not work here. Channel degradation occurred but it also narrowed. South-East France as well as other mountain areas of Europe submitted to depopulation and afforestation (Pyrenees, Italian Apennines and Alps, South Poland) and are therefore very unusual regional settings compared to many other parts of the world where deforestation is the major issue of channel evolution. This history of land use and human distribution in the environment also explains new physical processes that are emerging with the senescence of forests, notably the riparian forests and the introduction of wood in rivers. After one and a half centuries of engineering efforts on river and stabilisation of forms, new questions on the effects on ecosystems and hazard are then asked, notably in the 1990s, which were characterized by higher flood intensities.

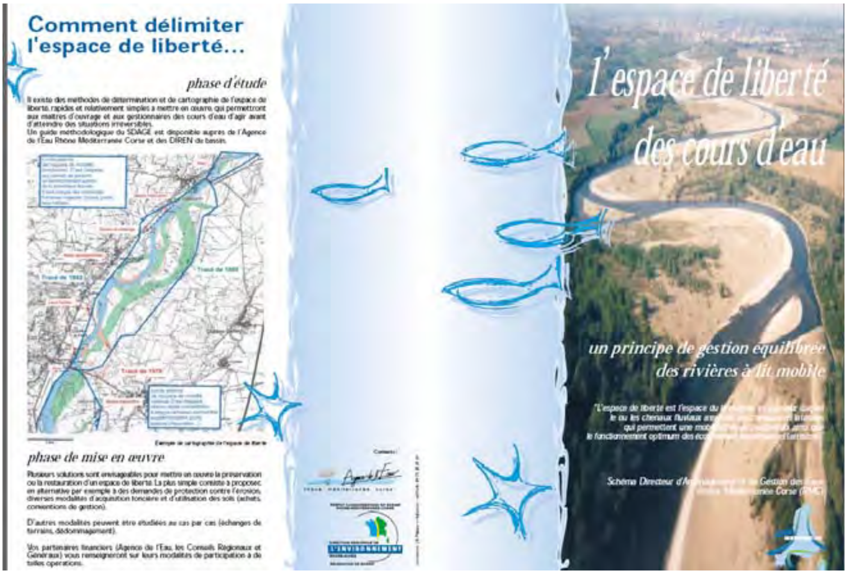
The concept of systems based on natural elements, showing both upstream to downstream interactions and also the lateral interactions between the main channel and the floodplain, and the important role of bank erosion as a critical factor for the riparian ecosystems health has had a strong influence. The introduction of humans as a key element exerting pressure on natural features and providing consequential cascading effects with complex lag times between the cause and the downstream effect has also been critical in the approach to environmental problems. It has induced research on effects of channel changes on riparian environments such as vegetation diversity, structure, ecosystem trajectory or tree growth. Geomorphic diagnosis is becoming a preliminary step in the decision-making process before identifying any management actions, as managers are now convinced that before acting we must know where the catchment is coming from, where it is going and what is its inner organisation in term of sediment cascade (do we have sensitive reaches compared to others, different environmental sub-systems, how are they structured in space?).

2.2 Applications

In the context of enlarging the temporal and spatial frameworks for supporting decision-making, the main issues in term of applications were focused on diagnosis, and then measures to promote a balance between the immediate stakes and future needs (e.g., the preservation of natural settings as a guarantee of long term satisfaction of water availability). In the 1990's the main issue was the prevention of alterations even if the restoration was becoming an increasing issue.

- Mitigation and prevention measures

All this research has contributed to the emergence of what we call now "sustainable management". The idea is to promote measures which can be efficient at a longer time scale than those proposed previously and focus more on solving collective aims rather than individual aims. Major fights occurred in the early 1990s to reduce the developments of riprap protections which were partly funded by agencies in charge of water improvements. As a pioneering sign of critical changes in environmental policy, bank erosion has been perceived as good or at least too costly to be fought where the stakes are not high enough. In this context, the idea of planning bank erosion management at catchment, or at least at a long reach scale, and identifying real risk and factors controlling erosion, is increasingly promoted as a solution adapted to the risks for the population and the prevention of erosion in order to maintain its renewal effects on riparian ecosystems. A guideline was published in 1998 to help managers to design what we called "a liberty space for rivers", a political slogan meaning the natural corridor in which society accepts and preserves bank erosion (Malavoi et al. 1998), the so called erodable corridor (Piégay et al. 2005).



Another development that has evolved deals with respecting the river bedload as a natural resource to be managed sustainably. The need for sediment continuity preservation to prevent downstream disruption is now acknowledged by river managers, and original solutions are promoted to minimise the impact of mining as much as they can. Forest services in charge of steep gradient stream regulation do not systematically clear the sediment stored upstream check-dams but push them downstream. Such actions are also now promoted in the case of derivation weirs, whereas a decade ago the gravel was extracted and sold by the owners. Some experiments of artificial channel bed design have been done to increase the transport capacity of the river so that it can output sediment from aggrading reaches to prevent further degradation downstream. Moreover, some preliminary strategic plans have been suggested so that the decision to mine sediment can be done in a more complex framework, taking into consideration both the catchment context (general deficit of sediment or not, discontinuity in sediment transport, sensitive reaches to deposits…) and the local stakes (i.e. protection). Following the mining excess and the general sediment deficit, guidelines have also been written to promote the sustainable management of sediment resources in order to preserve as much as we can the continuity of the sediment transport. Whereas the sediment deposits, the bars, are always associated with a perception of risk (too much sediment means obstruction and flooding) and are not positively viewed by the population, decision-makers in charge of policy tried to promote a much more positive view of gravel by communication strategies. As salmon is an emblematic species in the Pacific Northwest and elsewhere, some French managers worked on gravel as an emblem.

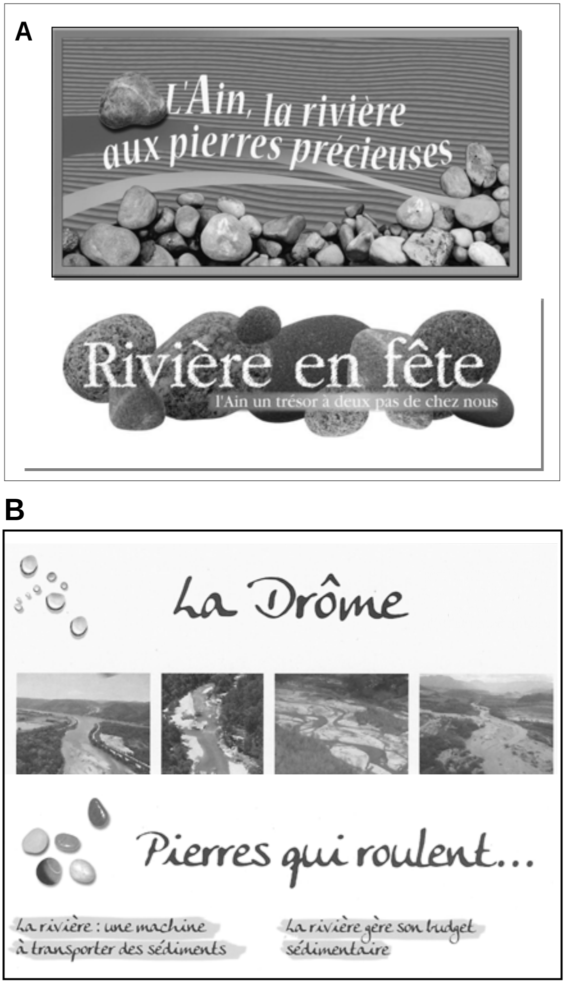
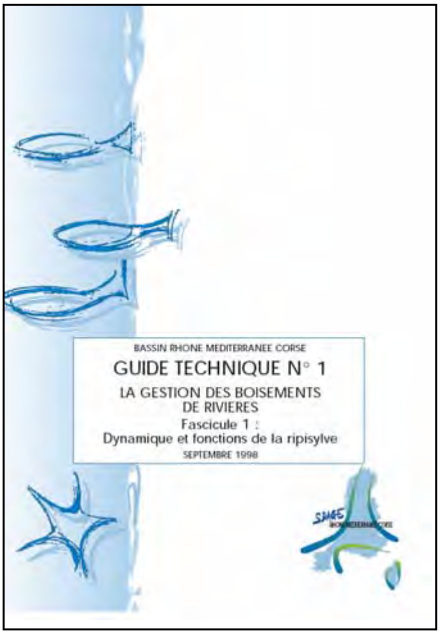


Figure 1 - Examples of communication documents created in LIFE—projects (Ain and Drôme rivers) to educate the public about the value of gravel and promote the idea of artificial sediment supply for ecological and risk management purposes. (a) “l’Ain, la rivière aux pierres précieuses”—The Ain, the River with precious stones / «Rivière en fête / l’Ain un trésor à deux pas de chez vous» - River Festival / The Ain, a treasure close to your home. (b) The river Drôme. “Pierres qui roulent” / Rolling gravel. (In Piégay et al. 2008).

“Wood is good” is another idea not shared by the population and the decision-makers in a country where the law states that wood removal and the clearing of riparian vegetation are good for aquatic and terrestrial ecosystem health. In this context, with the constant involvement of regional and district scale managers, major efforts have been done to counter-act traditional solutions and reconsider the idea that vegetation clearing must be promoted not because it is a remedy adapted to all our problems (flooding, erosion, ecosystem health, navigation) but because it answers to a specific objective. Following pioneer historical and ecological works done in western USA in the 1980's and their promotion in Europe in the 1990's amongst the river managers, an important issue has been to consider that clearing vegetation and wood removal are damaging options for the aquatic environment. Also the idea of solving flooding risk by clearing the channel is increasingly discussed in a context where wood is now widely established along the rivers and supplies them during the flood whether riparian vegetation is maintained or not. Finally, the idea of managing flooding all along the flow course is becoming popular. Wood can therefore be seen as a rough element slowing down the flow to prevent flooding downstream, as well as an ecological benefit. In 1998, a vegetation maintenance guideline was published under the auspices of the Water Agency to explain how to establish a vegetation management plan which is sectorised longitudinally according to defined objectives and which considers both wood removal and wood conservation and the different intensity and frequency of vegetation maintenance (Boyer et al. 1998). Additional measures were suggested to manage the wood in a guideline of 2004.



- Restoration options

In 1997, the basin master plan indicated 10 priorities amongst which the restoration of altered environments, notably the alluvial plains, was one. Following this first step, different local operations were funded, such as instream habitats (boulder introduction, small weirs and groins deflecting flow) and bioengineering techniques (bank revetment by vegetation), remeandering of channels, dike widening, minimum flow increase, reconnection and deepening of former channels, and finally pioneer pilot operations of sediment reintroduction. Major failures concern the reintroduction of wood. Legal limitations, low motivation of fish ecologists, and the strong opposition of society – raising the key question on the effect of human perception on decision-making – are issues explaining this blockage.

A few operations were monitored in pilot scientific studies providing feedback for improving actions. One of the major projects deals with the restoration of the Rhône with an interdisciplinary team (see the pioneer publication of Henry and Amoros, 1995). The Rhône restoration plan focused on the minimum flow increase in downstream dams and also the recreation of former channels. It is a very ambitious scientific program in which aquatic plant, fish and invertebrate ecologists, and also geomorphologists, were involved. Concerning the former channel restoration, experience acquired on the Rhône was applied on the Ain river. Two main geomorphic questions were then asked : i) which former channels can be restored considering the ecological alteration and the expected ecological gain in reference to the reach but also to the expected benefit in terms of functioning and biodiversity, and duration of the aquatic stage, ii) are the restoration measures efficient? The first question, the diagnosis step, is considered before deciding any actions and is based on both geomorphic audit of the reach to understand its trajectory of changes and long term interdisciplinary cooperation to understand physical-biological interactions in these environments. The geomorphic audit has been done on the Ain River in a Life Project. At the beginning the question of restoration was clear. Because the river is altered by a dam explaining the channel degradation and the disconnection of the former channels from ground and flood water, any re-creation of former channels is good. The local elected officials were then asked who amongst them had a former channel on his commune they wanted to restore. The geomorphic diagnosis permitted readjustment of the selection plan taking into consideration that the impact of the dam still does not affect the entire reach, but mainly affects the upper one. In this context, the selection of potential former channels has been focused on the altered reach whereas potential measures to mitigate the forthcoming alteration have been considered in the downstream one. Moreover, the selection of upstream former channels to be restored has then been based on ecological criteria using the knowledge acquired on the Rhône River. In this context, some research has been conducted in cooperation with plant ecologists to understand the set of geomorphic types and the associated hydrological functions. The level of perturbations by floods and also the influence of groundwater have been seen as critical factors in the organisation of plant communities, and specific physical environments have been identified in priority because of their rarity at the reach scale allowing there to be a focus on sites independently of political considerations (at the beginning the selection should have been based on the egalitarian idea that the restored former channels should be equally distributed on the entire reach to affect a large set of communes). Once the former channels were restored (mainly deepened in certain cases but also reconnected for reaching a given bankfull discharge in other cases) a monitoring geomorphic design was done. The main aim is to understand the short term evolution of the geomorphic characters of the restored features, and validate the expected life span of the ecological stage targeted. The monitoring surveys done along the Rhône have shown that the sedimentation which occurs at the beginning is very active, much more active than in other natural former channels with similar hydrological connections (see figure below). Such results underlined the clear need to provide long term scientific monitoring to better understand the trajectory of restored features, their recovery and the time needed to reach their steady-state stage. Short term monitoring does not really provide output on life span of the features but only on its morphological adjustment to these new geometrical conditions.

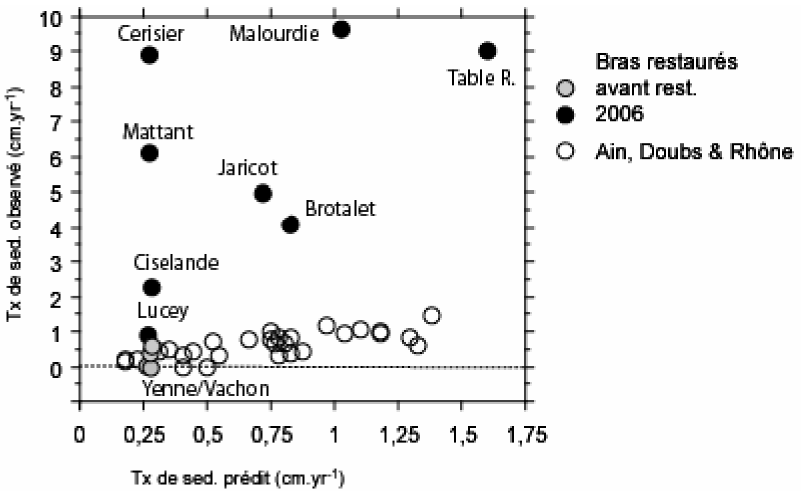


Figure 2 - Position of restored former channels (black circles) on the scatter plot « observed sedimentation rate versus predicted sedimentation rate" using the decadal

model as a function of upstream and downstream bankfull discharge. See modelling detail in Michalkova and Piégay, 2006; Citterio and Piegay, in press.

Another issue concerns sediment reintroduction downstream from dams or in hydrographic networks still connected upstream to the sediment sources. This work is naturally associated with the previous work, allowing an understanding of sediment deficit on the Rhône basin and the associated consequences for ecological assemblages and societal stakes. In the case of the Ain River, it is critical to maintain sediment sources to maintain aggrading bars, channel movement and the perifluvial habitat complexity and natural renewal of riverine ecosystems. Similarly on the Drôme, if the sediment deficit propagates downstream, then the stability of dikes is questionable and flooding may occur due to dike breakage in reaches where urban development has tremendously increased behind these dikes and communes have difficulty funding major dike restoration works. In both cases, geomorphic diagnosis studies were followed by a study of feasibility to identify possible sediment sources to be used to feed the rivers. On the Ain, the idea of coupling floodplain lowering and sediment reintroduction has been developed. Pilot sites have been identified and gravel sediment associated with the former channel deepening are being introduced in the river (see the specific talk and contribution of A.J. Rollet et al. in the Geomorphologic session). In the case of the Drôme, sediment introduction is also considered at the basin scale and two pilot sites were selected : i) a gully catchment has been deforested and is being monitored to test the gain in term of sediment delivery, ii) a floodplain has been deforested to reduce its resistance to flow and favour bank erosion and sediment transport.

After almost 30 years of geomorphic research on the Rhône basin, it is clear that restoration measures proposed are directly linked with continuous knowledge acquired through time, previous measures to mitigate the impacts, and an understanding of temporal trajectories of the physical system and its associated ecological properties. Nevertheless, uncertainties associated with these actions are significant and there are still emerging questions in term of knowledge production we must consider. In 2006, a report funded by the water agency (Biotec and Malavoi, 2006) provided the first feed-back from the previous experiments and underlined some critical issues to be considered for the implementation of the WFD. One of the main points raised was that restoration should be more highly monitored to be sure that it is valuable and to think about additional measures when it is not. Scientific knowledge is not advanced enough right now to predict the effects of the different options in all conditions and there is a clear need to promote scientific monitoring.

3. CHALLENGING ISSUES

From the evolution of research in geomorphology underlined in the Rhône district, a few challenging issues can be introduced for discussions during the conference. Three major points will be considered : i) planning at a district scale to identify priorities, ii) improving objectives for restoration design, combining ecological issues and other human stakes, risk and ecology, and iii) improving the interactions with the public.

From previous studies, it is now clear that we must admit that the idea that "restoration is good", everywhere, whatever the measures done, is not true. Following this conclusion and the risk of negative perception of these measures by the public because of failure of some previous operations, we must improve strategies before acting for the selection of appropriate sites for restoration and improvement measures. Preservation, mitigation, and restoration in addition to the prevention of alteration are complementary options that must be considered simultaneously rather than independently. The river managers, therefore, have a set of tools for acting, each of which can be applied in parallel. Restoration actions must be then reconsidered in a more general conceptual framework, rather than being a key issue in itself. Restore means that an ecological structure or function is altered in a given reach or catchment and needs to be repaired. Restoration appears as an option following a process of diagnosis, feed-backs on the evolution of the catchment of the reach and the idea that reparation is needed to provide additional values and participate to the sustainable development.

3.1 Providing data and tools for planning restoration and preservation strategies at the district scale

With the implementation of the WFD, a program of measures is being prepared for 2009. Where the measures can be applied and why are then critical issues for targeting the actions. In such evolution, the production of new knowledge is needed. Pioneer tools based on field surveys have been developed (e.g., physical quality index) but they have weaknesses (operator bias, cost for covering the entire hydrographic network, fairly static tool without considering channel adjustments in process). With the multiplication of GIS information and also the recent advance in imagery and constant increase in image resolution, new research issues are opened. A lot of work has already been done in term of ecoregion design, fish index, but also regionalization of hydrological character and pioneer prediction of habitats with regionalization of channel depth, width and grain size (see Lamouroux, 2008). Recent efforts are done to introduce information from imagery and existing DEM dealing with physical features. The first step is focused on the erodable reaches. After two decades of research to design erodable corridors and sustainably manage bank erosion at a local or a reach scale, the new challenge is providing a regional view of the shifting channels to target efforts on the most interesting reaches (see the poster of Alber et al. in the Geomorphologic session). From GIS analysis, alluvial reaches where the channel can freely move without being constrained by valley walls have been identified. In this set of reaches, additional researches are in process that will identify the main human infrastructures blocking movement and characterize bank resistance and channel energy in order to identify the potentially and effective mobile reaches. Because France is entirely covered with ortho-photos with a 50 cm resolution, it is possible to extract other data describing not only the aquatic channel and geomorphic features (pools, riffles and other aquatic units), but also the riparian assemblages, bar longitudinal distribution, confluence patterns etc. to provide a database and associated output mapping for designing a restoration/preservation policy at the district scale. Moreover, these data exist locally for at least two dates, opening also issues on channel dynamics (vegetation encroachment, bank erosion and floodplain renewal) and habitat characterisation (frequency of bar flowing, renewal of habitat features…). In the forthcoming years, it is expected that major improvements will be done on the sensors used and the resolution should increase from 50 to 20 cm (already programmed) and more, allowing the consideration of detailed features (e.g. vegetation species in the riparian corridor; grain size over a long channel network length…). Another challenge is the development of indicators of state or of evolution using the parameters extracted from imagery to help decision-makers.

3.2 Improve objective for restoration design and combine ecological issues and other human stakes

"Restoration is good" needs to be more often validated at the local scale in terms of ecological criteria but also in term of social benefits. If the society can understand that climate changes have clear consequences for its future development (infrastructure damages due to sea level rising at the scale of entire regions, water resource availability in drying environment, …), arguments to invest money for restoring environmental features at a local or a valley scale are not well understood and must be detailed, otherwise the WFD will be much less ambitious than expected. Along the Ain River, it is clear that if the French state and the EU had not supported a Life project, the locally-elected people would not have considered restoration issues, being more concerned by economical challenges such as the water availability for irrigation or the property problems associated with bank erosion. In the Rhône restoration decadal plan, the local communes are more concerned with life quality and the increase in frequentation and attractiveness of the Rhône margins than the ecological effects of the works done. In such context, it is clearly important to :

i) promote research to highlight the net benefit of restoration actions. Where and when (until which threshold of effort) does the restoration of ecological assemblages have clear benefits in term of water quality? In such context, the scientific effort cannot be only based on disciplines working on natural processes, but social sciences (economy notably) should be more involved. Ecological engineering is therefore becoming a new and promising field. Promoting studies on ecological processes and function to providing thinking and knowledge for diagnosing the ecological problem, assessing good ecological quality of gravel-bed rivers, evaluating their self-restoration capacity, and then providing future ideas for improving ecosystem quality and their associate services and benefits for the society need new research investments. When considering the disappearance of braided rivers around the Alps due to vegetation encroachment and reduction in sediment delivery, the discussion is still completely open to consider this trend as being positive or negative in term of ecological and social benefits (Piégay et al., 2006) and joint ecological/physical/social researches are still needed to provide the knowledge needed to argue the case. Can we really consider the Tagliamento as a reference system to be preserved as suggested by Ward et al. (1999) or is it a state to be restored along with other neighbouring reaches?

ii) provide feedbacks from pioneer restoration actions which have been performed at local scales and fund monitoring programs of new operations to have data to demonstrate the benefits of actions and to predict evolutions for future designs. The Rhône restoration program underlines the fact that pre-restoration data over several years is essential to show the effect of restoration measures because of long term trends of ecological features and inter-annual fluctuations. It is also relevant to have several years of monitoring to distinguish short term effects and long term benefits (Lamouroux et al., 2006). This example demonstrates it is more accurate to select a few pilot sites to cover a wide range of situations and monitor them accurately over a long period of time rather than spreading funds to monitor all the restoration sites. In such a context, a web network and database should be useful to connect operators in order to plan monitoring fundings, reduce overlaps in collective efforts and share knowledge and feedbacks.

iii) promote the sustainable management of catchments or reaches, rather than local restoration actions in which we try to maximise different benefits, such as water quality, risk management in a manner that the impacts on ecological features is minimized or in the best case their improvement is reached. This is the case of channel widening operations observed in the Alps in Switzerland or in Austria (Piégay and Habersack, 2007). In this context, the population is more concerned with solving immediate problems and is convinced that the measures implemented must now in a general sense be the least damaging for environments. The scientific debate on what is restoration versus rehabilitation and notably on the idea that historical state must be a reference, should evolve. In Europe, we are faced with cultural landscapes where the natural assemblages exist because of recent reduced human pressure and where some impacting infrastructures are needed for maintaining human activities. Sustainable management must be promoted pragmatically and consider a range of stakes in which ecological improvement (considering the past state because it provides knowledge for estimating the feasibility of future options rather than the aim to reach) and associated benefits exists. A restoration action cannot be then managed in isolation but be integrated in a wider management plan.

3.3 Improve the interactions with the civil society

There are clearly possible limitations of such evolution and an urgent need to better integrate local community wishes and social questions in the restoration projects (e.g., elements on landscape/aesthetics perception; balancing natural hazard mitigation and ecosystem improvements).

Previous researches have shown that the public does not like wood whereas the scientists have argued that wood is good. Other works done on gravel bar perception have also shown that water riverscape are much more preferred esthetically than dewatered bars. These results demonstrate how social sciences are needed in restoration studies to understand public wishes and to communicate. If we really enter in a new development strategy, working with nature rather than fighting with it, sciences must explain why new issues are critical. Environmental education is becoming a challenge for helping the society understand the recent advances in sciences and translate them into practical measures which are supported by the public. Again the cascading system of knowledge must be complexified so that the consequences of proposed measures in restoration (ecological improvement) must be more clearly translated in social benefits (water availability at a long term scale, safer environments…). Interconnecting scientists and river managers to highlight knowledge needs and formulate fundamental research is needed on the medium term for helping practioners in their day-to-day actions is another issue. Common effort in terms of planning is needed to use science output more immediately, reducing the time lag between the production of knowledge and its translation into a practical context. At a national level, the promotion of environmental education to make the population more supportive of the process is also a key issue if managers want to engage successfully innovative sustainable management options.

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ECOHYDROLOGY AS TRANS-DISCIPLINARY TOOL FOR RIVER RESTORATION

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ABSTRACT

A river is an "open ecosystem" whose dynamic is dependent on hydrological oscillations and pulses of the organic matter as far as pollutants from the catchment is concerned. This, in turn, depends on climate, geomorphology of the basin, ecosystem characteristics, urbanization, industrial pollution, agricultural practice and river valley habitat modification.

The key for efficient restoration of ecological processes, which maintain biodiversity, is a systemic approach based on the understanding of the interplay between all these components.

The three principles of Ecohydrology can be seen as a framework for river restoration.

1. Hydrological – quantification of hydrological processes and land cover patterns in the basin scale.
2. Ecological – determination on the basis of the first principle, the potential to enhance river ecosystem robustness.
3. Ecotechnological principle – provides know-how, (dual regulation) for enhancement of the river robustness – biocenosis by hydrology, and *vice versa*, shaping the biota, the hydrology – mostly water – can be improved.

Ecohydrology as trans-disciplinary science provides a new tool for IWRM, focusing on "engineering harmony" between society and freshwater ecosystems by use of ecosystem properties as complementary tools to technical solutions.

1. ECOHYDROLOGY PRINCIPLES FOR STREAM RESTORATION

The science of hydrology based on the understanding of physical processes is fundamental for the control of floods and droughts as far as the development of hydro constructions is concerned. However, over decade ago, an increasing number of empirical evidence of the world-wide deterioration of water quality and water-related ecosystem services for societies, raised the awareness of hydrologists of the urgent need for new concepts and new solutions (Dublin conference 1992). The interdisciplinary research, which has been developed in the UNESCO MAB and IHP Programmes, lead to conclusion that the *condition sine qua non* to reverse the decline of water resources in the global scale, should be the understanding of the role of biological processes in the moderation of the hydrological cycle. As a consequence, the scientific efforts to integrate ecology and hydrology into a new discipline of environmental sciences – ecohydrology - were undertaken during the UNESCO International Hydrological Programme of Phase V (UNESCO IHP V). Ecohydrology is the sub discipline of hydrology focused on ecological aspects of the hydrological cycle (Zalewski *et al.*, 1997; Zalewski, 2000, 2007; Chicharo et *al.*, 2001; Timchenko and Oksiuk 2002; Zalewski and Robarts, 2003; Janauer, 2004; Wolanski et *al*., 2004; Witte, 2001).

From the methodology of science perspective, the fundamental aspects of environmental sciences are based on empirical analysis of the structure and functional relationships between the various abiotic and biotic components of the environment. On the other hand, the key to advanced science is the distillation of the general patterns form surrounding commonalities. Ecohydrology, considering the freshwater ecosystem from the catchments perspective, contains both elements. Moreover, it defines a new target – in the face broadly understand global changes (climate, land cover, ecological processes, demography) it articulates the need for regulation of processes in the scale of hydrological mezocycle–basin. In parallel, it provides new “know how” to regulate processes from molecular to landscape level highlighting how to use, imprinted by evolution, ability to adapt terrestrial and aquatic organisms to water dynamics in the landscape, and how to use the understanding of such feedbacks for water quality improvement e.g. Zalewski et *al.* 1990. Also, *vice versa*, how by shaping biotic communities one may regulate dynamics and especially the quality of water in the terrestrial and aquatic systems (e.g. Mitsch and Jørgensen, 2004). The integration for synergy of those two aspects: river basin processes regulation (H-B and B-H) was termed “dual regulation” (Zalewski, 2006).

2. ECOHYDROLOGY OF TERRESTRIAL AND AQUATIC FASE

From the point of view of the methodology of basin/catchments research, two phases of the hydrological cycle should be distinguished: first - atmospheric/terrestrial and second - aquatic. In both, the broad range of biota appears as moderators of water dynamics. In the terrestrial phase vegetation moderates to a serious extent both water quantity and quality, and the major question is how the land cover changes are reflected in the quantitative aspects of the hydrological cycle. In the aquatic phase, much more complicated biotic interactions affect water quality to a great extent e.g. interactions at the trophic pyramid “ top down “ and “microbial loop” may up to the order of magnitude reduce or amplify the intensity of eutrophication symptoms such as toxic algal blooms.

Due to the specific methodology, the empirical component, of the terrestrial phase (EHT), has to be done by meteorologists/geophysicist, plant ecophysiologists, soli scientists, hydrologists and landscape ecologists. e.g Eagelson, 1982; Rodriguez-Iturbe, 2000; Baird and Wilby, 1999; Zalewski *et al.*, 2003.

On the other hand, in case of the ecohydrology of the aquatic phase (EHA), the interplay between dynamics of hydrology and biocenosis, reflected in the water quality, has to be based on integration of climatology, hydrology, limnology, hydrochemistry (Tundisi and Staskraba, 1999). “Aquatic EH” covers the major body of theory, the aspect of “problem solving”, by consideration as key component of the paradigm the principles of the use ecosystem properties as management tool for sustainable management of the river basin. The important way for integration and interpretation of such diversity of results is mathematical modelling Jørgensen 2002.

Up to now the both phases of ecohydrology have been developing independently, however as far as both become new necessary components of IWRM, the gradual efforts toward integrations using quantitative aspects of hydrological cycle as a template, remote sensing and GIS techniques are in progress.

3. ECOHYDROLOGY – THE NOVEL ASPECTS OF SYSTEMIC SOLUTION FOR ENVIRONMENTAL SCIENCES

In the beginning of the scientific career every environmental sciences specialist prefers to deal with the effect of a single factor on single species. However, especially aquatic ecosystems are complex entities, whose structure and dynamics are dependent on atmosphere, catchment geomorphology/land cover and human impact. This, in turn, means that if the homeostasis of such a system is disturbed, the simple sectoral solutions are usually insufficient. Thus the key to regulate such complex system performance has to be an integrative transdiscyplinary science, which not only integrates various scientific disciplines, provides joint hypothesis, which in case of EH refers to the hierarchy of regulatory factors, but considers societal needs as a reference point as well.

The three new aspects which Ecohydrology has provided to the environmental sciences are:

1/ The use the ecosystem properties as new complementary management tool harmonized with hydro technical solutions.

2/ The necessity to enhance ecosystems carrying capacity toward the UN Millennium Development Goals, by using the understanding of the established by evolution - factor response interplay between hydrology and biocenosis. The analysis of dynamic oscillations of the ecosystem performance – succession and productivity, reflected in nutrients/pollutants absorbing capacity vs. human impact specific, should be the key for the regulation of processes.

3/ The "know how" has been highlighting how to improve water resources, biodiversity and increase ecosystem services for society (expressed as carrying capacity) by use of "dual regulation".

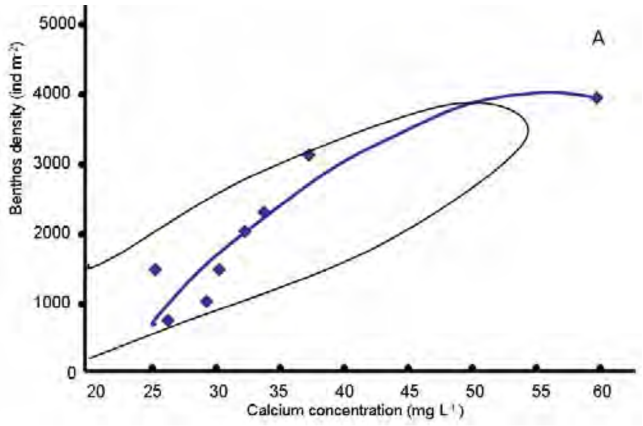
4. PRINCIPLE OF ECOHYDROLOGY AS A FRAMEWORK FOR SCIENTIFIC INVESTIGATION AND PROBLEM6SOLVING

4.1. Hydrological principle

Quantification and integration of hydrological and biological processes in the basin scale, with consideration of - as a starting point - geological structure as a determinant stream of biological productivity (Fig. 1).

This is based on an assumption that abiotic factors are of primary importance and once they become stable and predictable, the biotic interactions start to manifest themselves (Zalewski and Naiman, 1985). The most universal tool for elaboration of ecohydrological catchment characteristics is the GIS system (Magnuszewski, 2002).

The quantification covers the patterns of hydrological pulses along the river continuum (Junk et *al.*, 1989.; Vannote et *al.*, 1980) and the aspect of monitoring threats such as point and nonpoint source pollution distribution, as far as optimal regulation of processes toward sustainable water and ecosystems requires precise knowledge of the range of impact.



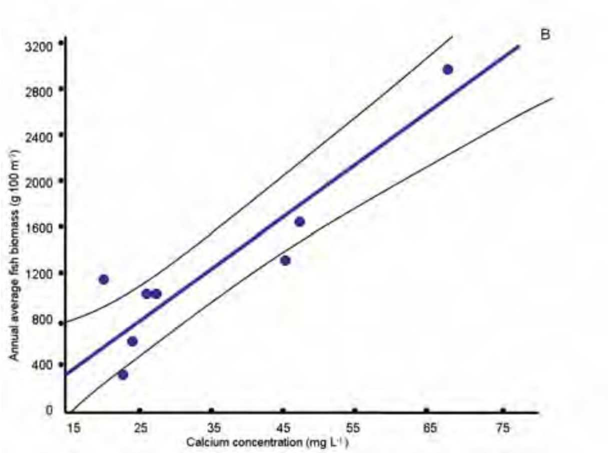


Figure 1 - The relationship between calcium concentration and (A) annual average benthos density, and (B) annual average fish biomass, (thin lines show 95% confidence limits) (Zalewski et al., 1998).

4.2 Ecological principle

Enhancement of carrying capacity of ecosystem (water quality, restoration of biodiversity, ecosystem services for society enhancement of the resilience of river ecosystem) is based on an assumption that in the face of intensive global changes it is not enough to protect ecosystems in the face of increasing population, energy material consumption and growing human aspirations. It is necessary to regulate ecosystem structure and processes toward increasing the “carrying capacity”. One of the examples is presented in Fig.2 where the effect of complexity riparian ecotones on light access to stream channel determines the fish diversity and biomass. This data indicates the importance of shaping riparian ecotones toward intermediate complexity (300-600 µE cm2s1) for stream biocenosis restoration.

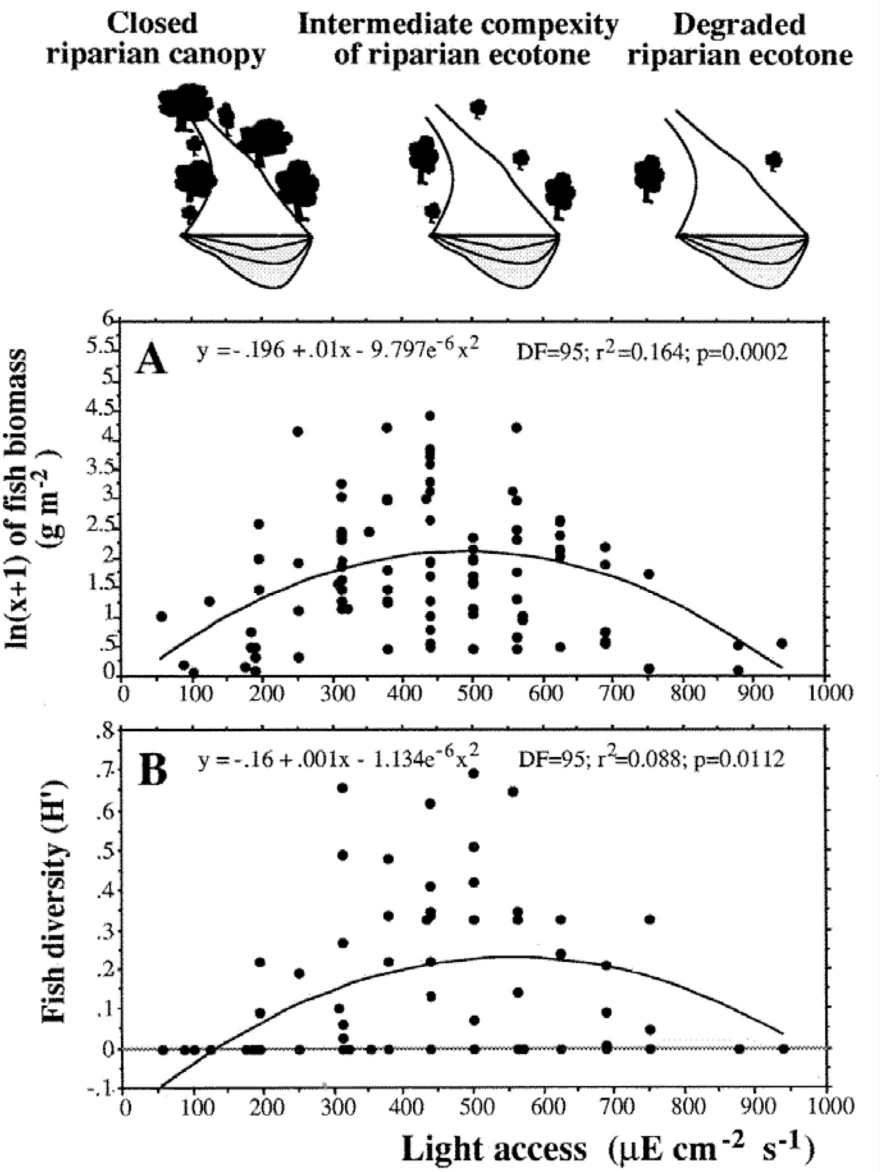


Figure 2 - The relationship between light access to habitat and (A) fish biomass and (B) fish diversity in Lubrzanka River (Zalewski et *al*., 1998).

The above data combined with long-term data from upland stream Fig.3, where strong negative correlation between fish biomass and invertebrate biomass was observed allow to formulate the hypothesis that “top down“ effect in a stream appears and potentially should be used for the regulation of nutrient spiraling toward biodiversity restoration and self-purification enhancement.

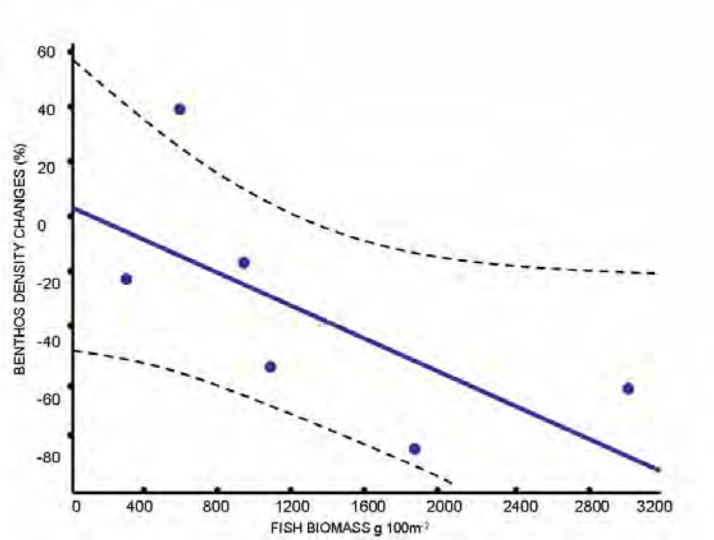


Figure 3 - The correlation between average fish biomass (g 100 m[1]) and summer decline of benthos decline (% change in numbers of individuals m[2]) (Zalewski et *al*., 1996).

4.3. Ecotechnological principle

The use of ecosystem properties as management tool has been based on the first and second principles of EH and related to Ecological Engineering (Mitsch, 1993; Jørgensen, 1996), and expressed by three implementation steps:

1/ "Dual regulation" – biota by hydrology and, *vice versa*, hydrology by shaping biota or controlling interactions.

2/ Integration at the basin scale of various types of regulations (B-H) toward achieving synergy to improve water quality, biodiversity and freshwater resources.

3/ Harmonization of ecohydrological measures with necessary hydrotechnical solutions (dams, irrigation systems, sewage treatment plants, etc.)

The integration for synergy (Fig. 4) in the basin scale mentioned and many others regulatory measures (Zalewski, 2000) have been reducing the negative effect of the excessive nutrients pollutants load in to aquatic system significantly. As every method, those solutions have some limitations. Their efficiency in general can be described by a parabolic curve, when load of nutrients and pollutants exceed the ecosystem potential absorbing capacity e.g. serious degradation of the biotic structure is accompanied by drastic modification of abiotic conditions e.g. hypertrophy, the potential of the use EH methods can be seriously diminished.

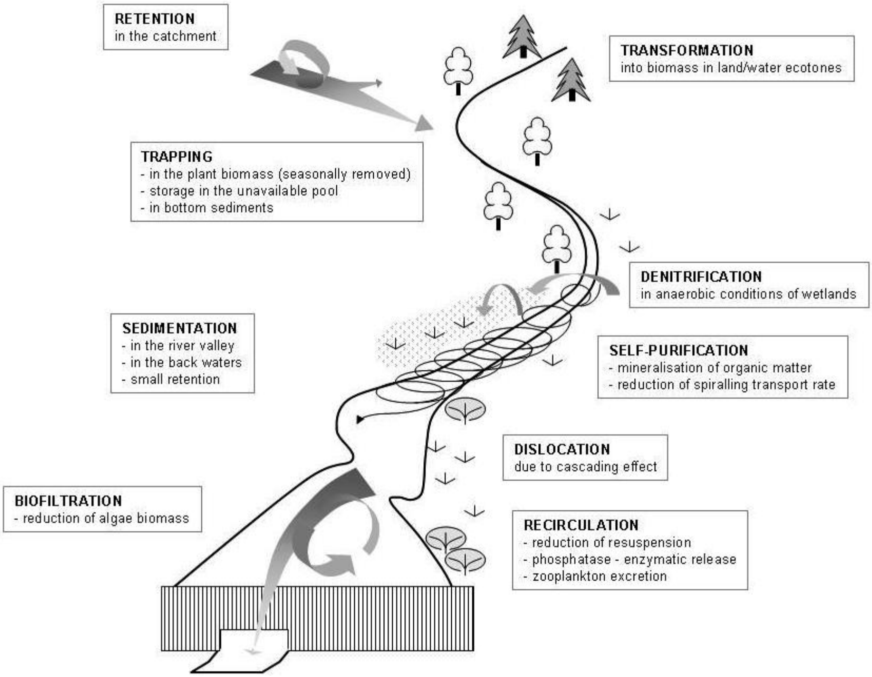


Figure 4 - The ecohydrological concept of the restoration of a eutrophic shallow reservoir, by applying various ecosystem biotechnologies as an example of catchment-scale ecological engineering (Zalewski, 2000).

Finally, the harmonization of such solutions with societal needs has been introduced in Fig. 5, where low efficiency sewage plant was enforced by constructed wetland based on the local species of willows, which were distributed according to their tolerance to flooding to increase efficiency of nutrients absorption. The conversion of Phosphorus, which instead of enriching the reservoir, stimulates bioenergy production, reduces the CO_2 emission and creates employment opportunities, is an example of ecohydrological systemic solution (EHSS). The broad range of cases such as EHSS have been under implementation on the different continents in the framework of the International Hydrological Programme of UNESCO IHP VI.

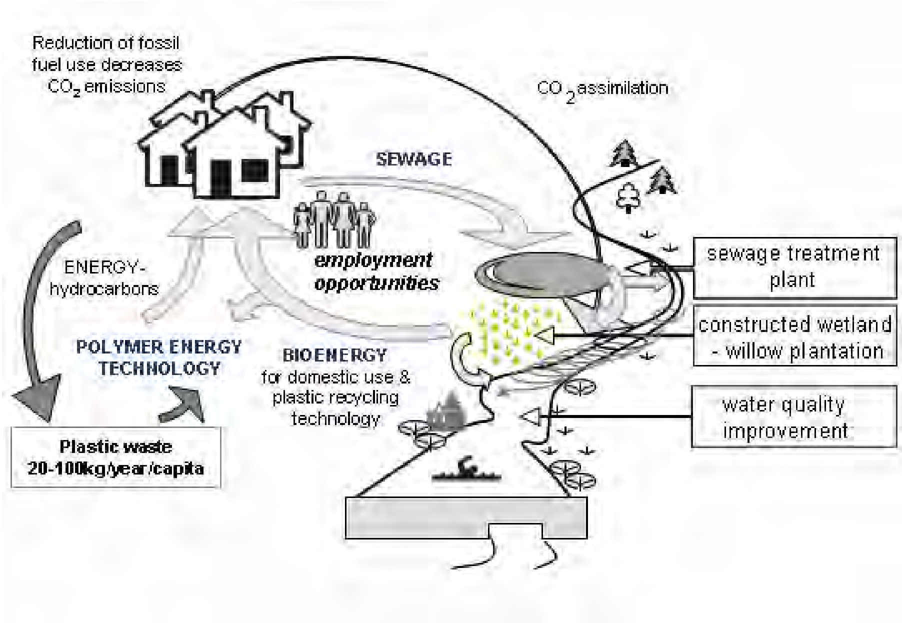


Figure 5 - System solutions - Improvement of water quality, human health and quality of life (modified from Zalewski, 2002).

The above introduced concept and examples indicate the one of the implicit but primary goals of ecohydrology is to reduce input and regulate the excess nutrients and pollutants allocation in aquatic systems toward "non-available pool" e.g. at soil, sediments vascular plant biomass or even from r toward K selected species- from algae toward zooplankton and fish. As far as a merit of biotechnology is conversion of the forms of matter using organisms, the ecological biotechnologies used in the framework of ecohydrological principles are becoming the fundamental tool for successful implementation of IWRM.

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RIVER RESTORATION: AN EUROPEAN OVERVIEW ON RIVERS IN URBAN AREAS

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ABSTRACT
With the technical and the economical growth in Europe from the second part of the 19th nineteenth up into the second part of the 20th century rivers in urban areas were sealed in concrete, habitats got lost, the hydro morphological processes within such system are even today often strongly interrupted. The technical success of sewage treatment after 1960 and the improvement of the water quality, was the basic for river restoration projects, beginning 1980. Assessments methods for chemical, biological and hydro morphological components in Europe were developed, research projects for river restoration started. Today river restoration, in connection with other projects for city development and urban planning are offering Win Win situations: to improve flood control and the ecological functions, to keep people in town, to offer recreational value and to raise the quality of living in urban areas.

Key words: History of urban rivers development, Ecological Deficits, Precondition and objectives for restoration projects, planning steps,

1. INTRODUCTION

Talking about the restoration of rivers in urban areas there are to differ: Rivers within urban areas and urban areas beside the river, mainly depending from the size of the river and its discharge. Since centuries river banks are attractive places for urban developments all over Europe. River systems are used for water supply, the discharge of sewage, they were canalized to improve land drainage, the transport of goods, hydropower and flood control. In medieval times only wealthy cities and towns have had the economic power to settle close to the river and to build weirs in large rivers for the extraction of water in channels to run mills. They could also afford the money to repair such weirs, which were periodical damaged by floods. In the rural zones, smaller towns and villages, very often kept an adequate distance from the rivers to be not endangered by floods, since they couldn't afford the costs for flood control and maintenance work. With the technical and the economical growth in Europe from the second part of the 19^{th} nineteenth up into the second part of the 20th century the feasibility for river and flood control work expanded. Urban areas were spreading along rivers and the floodplain. Along the water front of important cities representative quays were built for the promenade of people, even the water was polluted by sewage and litter. But in most parts of urban areas, in industrials as well as in housing zones the waterfront were often used as backyards with no access to the banks for the public. The water was dirty and stinky. Such rivers often were sealed in concrete, habitats for plants and animals were lost, the biological quality of such river sections even up to till today is mostly ruined. Today such sections are often designated as heavily modified water bodies; the hydro morphological processes within such a system are often strongly interrupted.

2. PRECONDITIONS FOR RIVER RESTORATION PROJECTS: ECOLOGICAL FUNCTIONS

The guideline for all restoration river restoration projects is the ecological function of the river. Rivers and streams are dynamic systems. They are formed by the natural characteristics of the drainage basin like climate, geology, tectonic, vegetation and land-use. The discharge depending from precipitation is fluctuating. The power of running water and the amount of transported solids influence the morphological process and the geometry of the river channel. This includes bank erosion and sedimentation, natural restoration of

riffle and pool and migration of the riverbed within the flood plain. The geometric features of the river channel e.g. plan form, longitudinal and cross sections as well the substrate in the river channel are depending from the conditions in the watershed area. River and floodplain are an unit.

The limitation of the hydro morphological impounded by river construction and regularly maintenance, reduced the ecological functions of the river ecosystem and changed the once dynamic river into a more static systems, causing ecological deficits. The model for restoration describes the naturally ecological function of a river system. Rivers are called natural, if they are not polluted; they can migrate freely in the floodplain. This is a continuous process in time and space. The transport of water and solids is not interrupted by weirs or bank fixation. The vegetation along the river and in the

flood plain is in natural succession, its zonation spans from pioneer vegetation to alluvial woodland. The migration of the river bed, pushed during floods, lead to a continuous restoration of typical structures. Natural river systems flood several times the year.

They are housing a mosaic of biotopes for animals and plants. This explains why natural river systems offer such a wide range of habitats and why the are today in most European countries protected by Natura2000. Their reference status is equal to the high ecological status of the WFD. Of course in urban areas the chances to bring back the described function are more or less limited, but there are chances in each project to reduce the existing deficits and to improve the ecological function of the river system.

3. PRECONDITION: WATER QUALITY AND HYDROMOIRPHOLOGICAL PROCESSES

A precondition for the discovery of the rivers and creeks in urban areas as places for recreation was the construction of sewage treatment systems after World War II. This technical success, the improvement of the water quality, was the basic for river restoration projects. Beginning in the years after 1980 there was an expanding knowledge in river morphology and river ecology, which met the interest of the public for more natural rivers. River restoration and rehabilitation projects were started. River restoration needs space to allow again the hydro morphological processes, powered by the water flow and the transport of sediments. In urban areas, were space is limited and flood protection is evident, river rehabilitation projects are common, controlling these processes. River restoration and also rehabilitation projects took many steps from the years since 1970 up till today. The first projects were very tentative, opening the banks for an easy access to the water, planting trees, shrubs and reeds, but didn’t touch the water channel. With the growing experiences in river restoration and an advanced knowledge in river ecology restoration projects it was possible to bring back the natural functions of the river system. Assessments methods for chemical, biological and hydro morphological components were developed, research projects for river restoration were started, activities which are baking up restoration projects all over Europe.

4. PLANNING PROCESSES

Today river restoration projects in urban areas integrate city planning, river engineering (including river morphology, hydro-morphology, ecology and biological engineering), nature conservation and river bounded outdoor recreation. Public hearings as well the assistance NGOs is a helpful precondition to run such projects with success. River restoration and rehabilitation projects are part of urban planning. They are also based on urban water management plans, dealing with the sewage system and also measurements to drain away surface water (rainfall). With the conversion of industrial zones and the renewing of housing projects within urban areas there are excellent chances to get the space and to change the situation along such river sections from the backyard to the water front.

The basic for river restoration and rehabilitation are planning concepts for contiguous river sections, mostly done in the scale 1:25.000. Regional river restoration concepts are helpful for the planning and communication processes with experts, communities, members of the administration, Non Governmental Organizations (NGO) and the public. Such concepts assist the transparency of the planning processes and accelerate the decisions for restoration projects. There are several planning steps:

Step 1: to develop the reference status for the river landscape,
Step 2: to asses the status quo,
Step 3: to define the deficits compare reference status with status quo,
Step 4: to show the restrictions like flood control (urbanisation e.g.)
Step 5: to develop the objectives for the restoration project,
Step 6: to place the measurements and estimate the costs.

The planning should be an interdisciplinary process integrating other plans and programs within a county or community related to the restoration project. These can be e.g. programs for urban development, for clean water, reducing the pollution from point and non point sources. Interests of stakeholders e.g. fishery, nature conservation and of land owners, especially farmers along rivers and streams have also to be reviewed (Binder, 2000).

Public Participation during the planning process supports the restoration projects. Agenda groups at regional and local level are invited to exchange ideas and to share practical experiences with experts accompanying such projects. This includes understanding for flood control, for natural retention, for ecological improvement of river systems, for nature conservation and for possibilities and limitations of outdoor recreation.

5. OBJECTIVES FOR RIVER RESTORATION

The objectives for river restoration projects are:

to improve flood control e.g. outside urban areas to strengthen the natural retention capacities,

to enforce the ecological function of the river system,

to allow the natural morphodynamic processes by giving more space to the river,

to find new techniques for mitigation to support or to limit morphodynamic processes,

to win stakeholders, residents and others for restoration projects by information and participation,

to improve the recreational value of the river especially in urban areas, like the Isar in Munich with the intentio to reduce the recreation processes in sections of the river with high ecological value e.g. in Natura2000 areas.

Today river restoration projects in urban areas integrate city planning, river engineering (including river morphology, hydro-morphology, ecology and biological engineering), nature conservation and river bounded outdoor recreation. Public hearings as well the assistance NGOs is a helpful precondition to run such projects with success. River restoration and rehabilitation projects are part of urban planning. They are also based on urban water management plans, dealing with the sewage system and also measurements to drain away surface water (rainfall). With the conversion of industrial zones and the renewing of housing projects within urban areas there are excellent chances to get the space and to change the situation along such river sections from the backyard to the water front.

6. NEXT STEPS

There are many good examples of river restoration in urban areas and much more studies all over Europe. But of course there is still much more to do. With the knowledge and experiences of the last 3o years in river restoration, in connection with projects for flood control and other projects for city development and urban planning it is possible to achieve Win Win situations. In the times of climate changes, which needs to improve flood control and the European Water Framework Directive, which demands a good ecological status for natural water bodies and a good ecological potential for Heavily Modified Water Bodies there are good arguments for river restoration in urban areas: to improve flood control, to keep people in town, to offer recreational value and to raise the worth for living.

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THE STATUS OF EUROPEAN CATCHMENTS, AND SETTING PRIORITIES FOR CONSERVATION AND RESTORATION*

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1. GENERAL INTRODUCTION

Rivers traverse our landscapes and frequently provide our major source of water for domestic, agricultural and industrial usage, power generation, navigation, fisheries and recreation. Rivers also are a source of fascination and discovery to biologists, hydrologists, geologists, geographers, and nature-lovers. As ecosystems, they are a tremendous source of biodiversity, much of which is greatly imperiled (Benke and Cushing 2005, Tockner et al. 2009A, and chapters therein). Because of the vital roles rivers play for the landscape and society, they have been described as the circulatory system of the landscape.

In spite of their undeniable and fundamental importance, there is no comprehensive treatment of the natural characteristics and diversity of European river catchments, nor of the extent to which human society has exploited them. Geographically, Europe extends to the Ural mountains in the east and the Caucasian Alps in the SE. It has a total population of 680 mill people. There are more than 150 transboundary rivers in Europe that form or cross borders between two or more countries.

The European Union has launched a highly ambiguous program, the Water Framework Directive (WFD; http://ec.europa.eu/environment/). The WFD creates a legislative framework to manage, use, protect, and restore surface water and groundwater resources in the European Union. “Good status” of all European rivers must be achieved by 2015. Hence, the WFD requires the establishment of a ‘river basin management plan’ (RBMP) for each river catchment. The RBMP is a detailed account of how environmental objectives (i.e., good ecological status of natural water bodies and good ecological potential of heavily modified and artificial water bodies) are to be achieved by 2015. Further, the European Union has set up an ambitious goal to stop the decline of biodiversity by 2010.

Here, I provide a very brief overview of the physiography, hydrology, ecology/biodiversity, and human impacts of more than 160 European catchments, including rivers in Western Russia, the Caucasus, and Anatolia (Figure 1, Table 1). These catchments cover a total area of ~8 million km2 (72% of the entire continent). Detailed information is provided by Tockner et al. (2009A).

Average runoff of European rivers is 3,100 km3/yr (8% of the world average). The 20 largest rivers (total area: 5.9 million km2) contribute 1/3 to the total continental runoff (Table 1). The average annual specific runoff ranges from 68 mm/year to 1150 mm/year. High seasonality in runoff is typical for rivers in southern Europe and Turkey, and for Boreal and Arctic rivers. Low runoff variability is characteristic for central European and Steppic rivers.

Table 1 The 20 largest catchments in Europe (including Turkey and the Caucasus). Relief: Calculated difference between highest and lowest point (resolution: 1000 X 1000 m) in catchment. Human population density: People per km2. GDP: Annual Gross Domestic Product per person and year. Protected: National parks, Ramsar sites, and other nationally protected areas and nature reserves.

	Area (km^2)	Discharge (km^3/y)	Relief (m)	Population (People/km^2)	Agricultural Area (%)	GDP ($/y)	Protected (%)	Fish (Native)	Fish (Nonnative)
Volga	1’431’296	261.8	1’536	45	49.1	2’340	5.7	66	18
Danube	801’093	202.4	3’651	102	53.6	7’007	2.4	99	32
Dnepr	512’293	42.6	411	64	63.3	1’388	3.2	29	5
Don	427’495	25.5	804	46	85.9	1’508	3.2	64	7
N Dvina	354’298	107.5	422	5	7.2	2’873	5.2	34	7
Pechora	334’367	150.9	1’604	2	0.4	2’928	12.2	34	3
Neva	281’877	79.1	390	17	13.4	6’181	5.1	43	1
Ural	252’848	10.6	1’094	15	51.6	2’205	0.9	55	1
Kura	193’802	17.1	4’816	74	22.7	1’267	5.5	33	8
Vistula	192’980	32.9	2’316	127	63.4	3’789	2.6	54	18
Rhine	185’263	73.0	3’786	313	49.6	31’822	0.4	46	25
Elbe	148’242	22.4	1’456	164	60.1	14’068	4.3	38	8
Euphrates*	121’554	31.6	3’557	57	62.0	1’535	0.0	45	1
Oder	120’274	17.2	1’468	132	61.6	5’583	1.5	42	11
Loire	115’980	26.4	1’704	67	73.1	22’196	1.5	32	26
Nemunas	98’757	17.0	354	52	53.7	2’680	5.2	46	4
Rhône	98’556	53.8	4’452	105	38.9	24’462	8.9	50	21
Duero	97’406	17.3	2’359	37	56.1	15’058	1.2	18	13
Ebro	85’823	13.6	3’104	34	48.1	19’587	1.5	29	19
Daugava	83’746	13.6	307	32	38.9	2’598	8.0	39	2

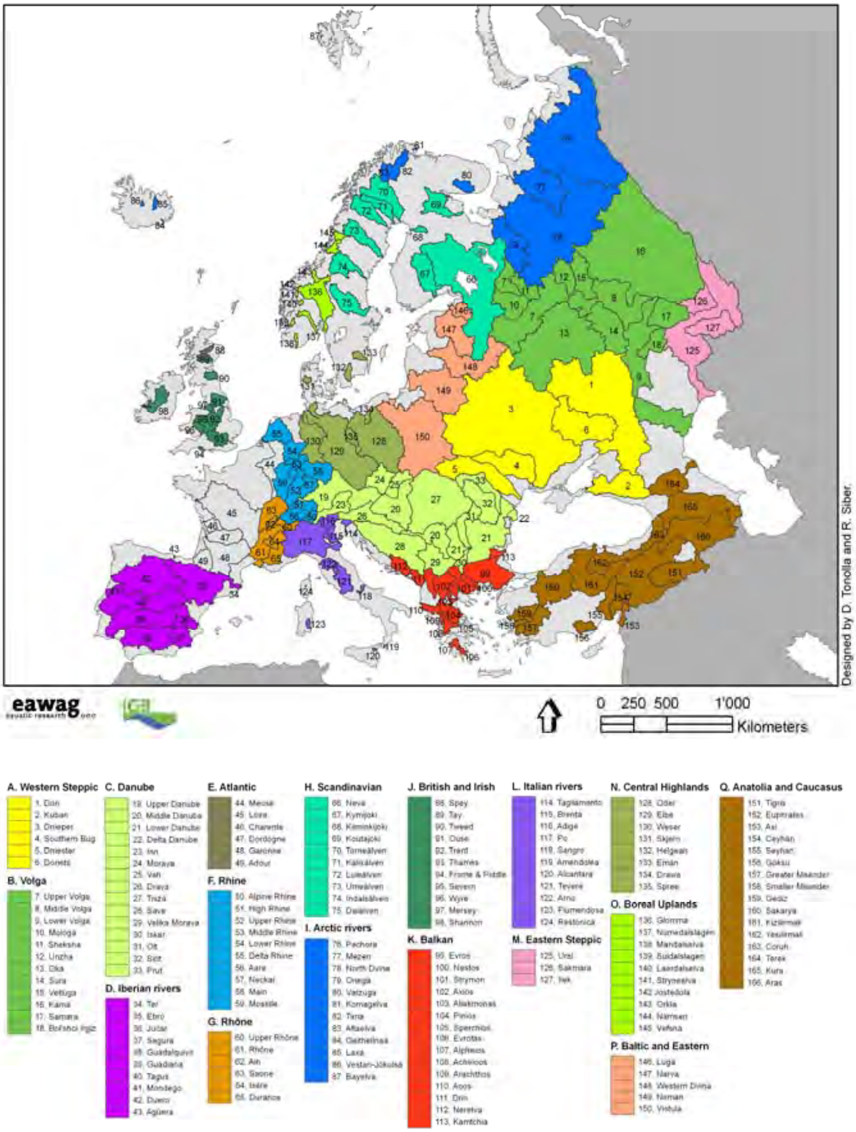

Figure 1- European catchments included in the European Catchment Data Base (after Tockner et al. 2009A,B).

2. MULTIPLE STRESSORS

Land use (proportion of developed area), river fragmentation, water stress, and proportion of exotic fish species are used to calculate an anthropogenic impact index for each catchment (Henrichs and Alcamo 2001, Nilsson et al. 2005, Peter 2006, Tockner et al. 2009A). More than 75% of the European catchments can be classified as heavily impacted; thereby threatening freshwater biodiversity. Beside high Arctic and northern Scandinavian catchments there are only few catchments in Europe that are still remaining in a semi-natural condition. These are primarily small catchments such as Frome & Piddle (UK), Tagliamento (Italy), Mondego (Portugal), Sperchios (Greece), or Sakmara (Ural Basin). These catchments may play a major role as reference systems for entire Europe. It is therefore of prime importance to preserve and actively manage those rivers that retain some of their natural functional attributes.

At the continental scale, ~50% of the original wetlands and up to 95% of riverine floodplains have been lost (Klimo and Hager 2001, Tockner and Stanford 2002). Around 60% of the European catchments have been transformed into cropland and urban area. European catchments are highly fragmented by >6000 large dams and of the 20 largest European rivers only the North Dvina in NW Sibiria is considered free-flowing. The area that will suffer from severe water stress is expected to increase from 19% today to 34-36% in 2070 (Heinrich and Alcamo 2001).

Around 60% of the combined catchment area of the 165 examined rivers has been transformed into cropland and urban area. The proportion of developed area exceeds 90% for Central European and Western Steppic River catchments. Over 70% of the European population lives in urban areas and the total number of cities with a population >100,000 is ~360.

European rivers still exhibit a wide variety of pollution problems (Van Dijk et al. 1994, Tockner et al. 2009B). Eutrophication and nitrate deposition pose the greatest challenge in western and central Europe, whereas organic matter loads, pesticides, and nitrogen inputs are major issues in southern and eastern Europe (Tockner et al. 2009B). From 1992-1996, over 65% of European rivers had average annual nitrate concentrations exceeding 1 mg/L and 15% of the rivers had concentrations >7.5 mg/L. The highest nitrate concentrations are in northwest Europe where agriculture is intense. Ammonium levels have decreased in European rivers since around 1990. Phosphorous concentrations also have generally declined since the 1990s as a result of reductions in organic matter and phosphorous loads from wastewater treatment plants and industry and of severe reduction or ban of phosphate detergents such as in Switzerland and Germany. However, micropllutants (e.g. pharmaceuticals, nanoparticles) impose increasing risks to aquatic life and humans.

The areas that face the highest human pressures, namely catchments in the Iberian Peninsula, the Balkan, and Turkey, are at the same time the areas with the highest proportion of irreplaceable species. The western Balkan is an additional area with a high proportion of threatened species, although the human pressures there are less severe (Figure 2).

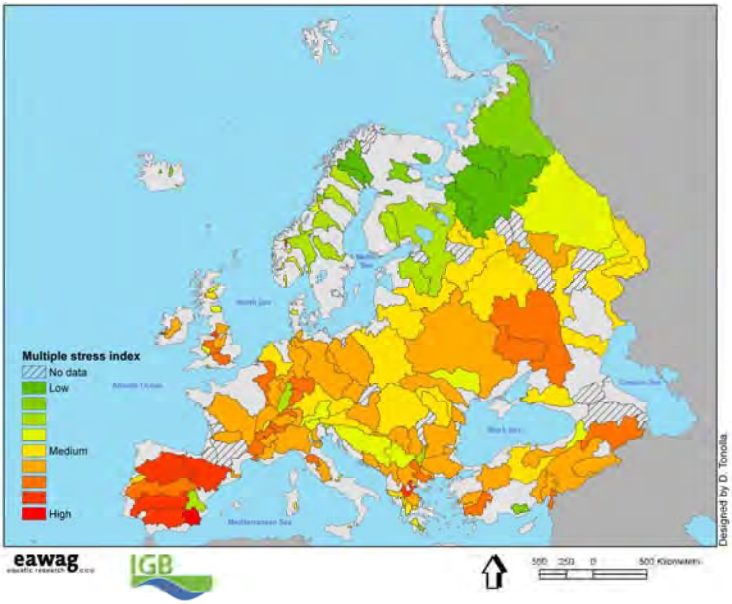

Figure 2 - Preliminary map of the multiple pressure index of the European catchments. The index is based on river fragmentation, water stress, land-use alteration, and the proportion of non-native fish species (3 classes per stressor). An index of 12 means that the catchment is highly impacted by all 4 stressors, an index of 4 means that the catchment is not affected by any of the 4 stressors (unpublished data; but see Tockner et al. 2009A).

3. BIODIVERSITY PATTERNS

The most up-to-date global inventory of freshwater animal biodiversity lists ~126,000 freshwater species; about 10% of the global diversity (http://fada.biodiversity.be). Nevertheless, European freshwaters are relatively species poor compared to other continents. European waters provide habitat for <4% of the global freshwater fish fauna (Kotellat and Freyhof, 2006).

At present, data on freshwater fish, amphibians, wetland birds, odonata, and crayfish are included in the European Catchment Data Base at IGB (Leibniz-Institute of Freshwater Ecology and Inland Fisheries; www.igb-berlin.de). For example, the number of freshwater fish per (sub)catchment varies from 1

(Geithellnaá; Iceland) to 70 (Lower Danube). If only primary catchments (draining into the sea) are considered, the Danube contains more than a quarter of all European native fish species (Peter 2006). While less than 5% of all native freshwater species are reported extinct at the continental scale, up to 40% of the former fish species already dissappeared at the catchments scale. At the subcatchment scale, the proportion can be as high as 75% (e.g. Upper Rhône in Switzerland). A total of 19 species has lost between 20% and 66% of their native catchment range; five species of them belong to the family Acipenseridae (sturgeons). The highest proportion of irreplaceable species, i.e. species with a limited geographic distribution, can be found in catchments of the Iberian peninsula, the southern Balkan, and Anatolia. These are at the same time the regions that will face the highest human pressures in the near future.

The proportion of nonnative fish species can be higher than 40% in some catchments. On average, about 17% of all species per catchment are introduced species, with exceptionally high proportions for Iberian rivers, Shannon in Ireland, the Loire and Garonne (both France) and rivers in the southern Balkans. Rivers with no or few nonnative fish species only occur in northern Europe; however, a distinct latitudinal gradient in nonnative species richness was not found (Peter 2006).

An even more pronounced pattern can be found for crayfish species. Figure 3 shows the distribution of native and nonnative crayfish species in European catchments. While the number of native species per catchment is 3 at the maximum, the number of nonnative species can be as high as six per catchment. Several catchments that contained none or very few native species today are dominated by nonnative, and often invasive, species.

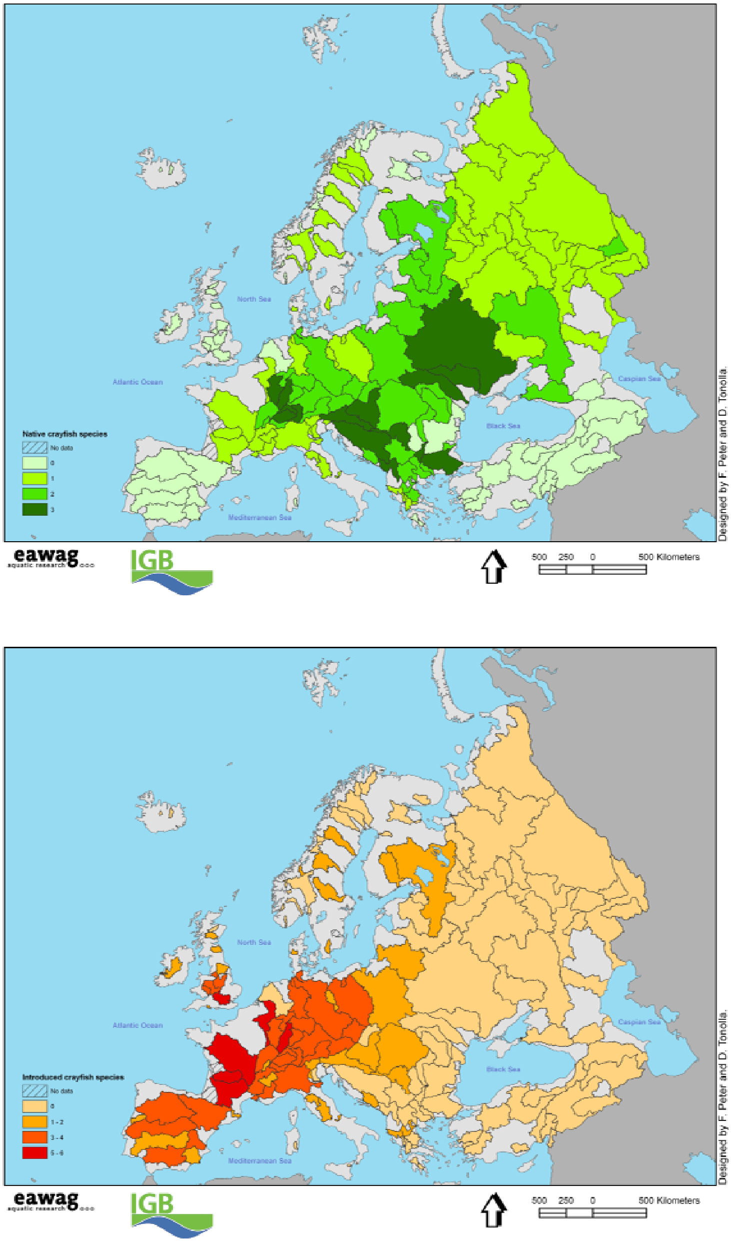

Figure 3 - Crayfish diversity (A: native and B: introduced species) in European catchments. Information is derived from Souty-Grosset et al. (2006), from unpublished sources, and compiled by F. Peter (European Catchment Database).

4. VEGETATED ISLANDS AS KEY ECOLOGICAL NODES

Vegetated islands are key riparian nodes along river ecosystems. Vegetated islands are (were) common landscape elements along river corridors and provide key instream riparian habitats for both aquatic and terrestrial communities. Vegetated islands increase the ecotone length, create important aquatic and terrestrial habitats for a rich and unique fauna and flora, are pivotal stepping stones for the dispersal of aquatic and terrestrial organisms along river corridors, and serve as important retention and transformation areas for organic matter and nutrients. Further, the proportion on nonnative species is much lower on islands compared to the adjacent riparian zone. In a recent survey, the distribution and condition of islands along 12 European rivers were investigates. A total of >1700 islands were mapped covering an area of 1700 km^2 (unpubl. data). Results demonstrate that islands are in general in much better environmental conditions than adjacent riparian floodplain areas. At the same time, islands are among the first landscape elements that disappear as a consequence of flow, sediment, and morphological alterations. Therefore, islands can serve as sensitive indicators of river/riparian ecosystem health; and may serve as key "nodes" for the development of future conservation and restoration strategies.

5. SETTING PRIORITIES FOR CONSERVATION AND MANAGEMENT

Based on the analysis of the European catchments it is becoming clear that the Mediterranean area, in particular the Iberian Peninsula, southern Italy, the Balkans and Turkey deserve the highest priority for conservation and restoration. Further, Eastern European rivers are morphologically often more intact than Western European rivers. It seems to be a paradox that in Western Europe heavily channelized rivers carry water of good quality while in Eastern Europe morphologically more intact rivers carry highly polluted waters. Hence, different management strategies are required in both parts of the continent. If we want to set priorities for restoration and conservation at the European scale, we need to focus on these areas of high conservation value and of high (reactive approach) and low (proactive approach) human pressures. However, the majority of restoration and conservation projects are most likely carried out in Scandinavia, UK, and Central Europe, areas that are mostly outside of these key priority “hot spot” areas.

It is also crucial to link the different European directives such as the WFD with the Habitat Directive. At present these two directives are implemented parallel rather than jointly. Most important, however, is that the remaining relatively pristine catchments, in particular those in sensitive areas such as the Iberian Peninsula, Greece, Turkey, the Steppic area, or in the Baltic zone, are maintained and conserved. The actual rapid spread of small hydropower plants posses a great threat for many still near-natural catchments. The boom in biofuel production may transform our landscapes more rapidly than we have experienced in the past decades, with potentially detrimental impacts on freshwater and coastal ecosystems. Finally, the extensive navigation network in Europe supports the rapid spread of nonnative species. While catchments still can be clearly delineated hydrologically, they become more and more connected biologically. Today, most large rivers, from the Rhône in the west to the Volga in the east, are connected by navigation channels; and there exist major plans to extent and improve the present navigation system. Therefore, there is an urgent need to develop sustainable management strategies for navigation that include mitigation strategies against wave action, noise pollution, or the spread of nonnative species.

6. RESEARCH PRIORITIES

Based on this catchment analysis, we may identify, among others, the following key research priorities for the near future:

(i) improving the catchment data base by a careful quality check of the data and by incorporating additional data on social and natural pressures as well as on biota (e.g. other macroinvertebrate groups). The catchment must be considered as the key spatial unit to understand and manage ecosystem processes and biodiversity patterns. However, biological information is mostly available at the country rather than the catchment level. In addition, available data are unevenly distributed across Europe, which constrains potential comparability.

(ii) establishing a network of experimental monitoring catchments across Europe. We urgently need a network of reference ecosystems against which the deviation of catchments and their biodiversity can be assessed; and we need long-term data sets to understand trends of both the environmental drivers and the response variables. Without being able to understand the functioning of near natural ecosystems, we will not be able to manage and restore rivers and their adjacent floodplains in a sustainable way. Further, presently it remains almost impossible to quantify the decline or change in biodiversity. Therefore, ambiguous goals such as "halting the biodiversity loss by 2010" can not be achieved because we even do not know how fast biodiversity changes; at least for freshwaters!

(iii) applying functional indicators to assess the ecological status of European catchments. While conservation planning is primarily driven by the number of native, endemic and endangered species (so-called „hot spot" areas), there is an urgent need to incorporate other ecosystem aspects such as the evolutionary potential of the system and it's capacity to perform key ecological processes in conservation and restoration planning. We need a function-based approach to assess river ecosystems. For example, ecosystem metabolisms, stable isotope data and modern molecular tools for a fast screening of biodiversity offer novel opportunities to assess the quality of river ecosystems.

(iv) linking socioeconomic and ecological catchment conditions. Europe is characterized by a high cultural variety (e.g. more than 100 languages are spoken) and by a distinct gradient in economic conditions (GDP varies over two orders-of-magnitude across the continent). It is therefore crucial to quantify to which extent socioeconomic conditions within a catchment are a cause or a consequence of water scarcity, environmental stress and alteration in biodiversity.

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A FRAMEWORK FOR EVALUATING DISCIPLINARY CONTRIBUTIONS TO RIVER RESTORATION

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ABSTRACT

As river restoration has matured into a global-scale intervention in rivers, a broader range of technical disciplines are informing restoration goals, strategies, approaches, and methods. The ecological, geomorphological, hydrological, and engineering sciences each bring a distinct focus and set of perspectives and tools, and are themselves embedded in a larger context of social, economic, legal, and historical drivers. Restoration practices carried out in different countries and cultures reflect this context. Ecological concerns drive much of the current restoration activities in the United States, while re-introducing and re-engineering rivers for more natural functions and processes is a hallmark of European restoration. Some examples of river restoration around dams and reservoirs from the Pacific Northwest of the U.S. reveal the interplay among various disciplines, and point to more and less successful disciplinary mixes. Projects focused on dam removal, retrofitting dams to modulate downstream water temperatures, and adding gravel back to rivers below dams also demonstrate different ways that science itself is used in river restoration, and point to how best incorporate a scientific perspective in future activities.

Keywords: river restoration, international perspectives, effects of dams, dam removal, gravel, river management

1. INTRODUCTION

A revolution in river restoration is under way. In the past two decades river restoration has evolved from the application of a limited set of tools and concepts guided almost exclusively by ad hoc experience in scattered regional settings of mostly developed countries, to a worldwide and sophisticated enterprise. Today it is a global industry involving multiple technical disciplines, and an annual investment of billions of dollars, 1 billion dollars is spent in the U.S. alone (Bernhardt et al., 2005).

As the palette of river restoration strategies has evolved, interesting country-to-country and region-to-region differences in objectives, approach, techniques, and style of restoration have also emerged. Such differences tend to be rooted in past histories of river modifications and interventions, differing legal and cultural expectations for rivers, and different blends of technical disciplines involved in restoration activities. Beyond these differences lies the broader consideration of the extent to which river restoration in any particular cultural setting draws on the scientific method as the basis for testing new methods and approaches, and directing future activities. The goal of this short paper is to foster an appreciation of both the cultural and technical context of current restoration strategies, offer modest insight into strengths and weaknesses of various restoration schemes, point the way towards future developments.

2. A MULTI-DISCIPLINARY RIVER RESTORATION FRAMEWORK

A working definition of river restoration should include the full suite of actions done to improve river function to meet specific objectives. This intentionally broad definition makes no distinction between structural and non-structural interventions, riparian or groundwater strategies, etc. The Examples of restoration activities include: 1) increasing flows to dilute water contaminants; 2) removing levees to promote off channel storage of water and sediment; 3) adding gravel to a river to increase hyporheic flow; or 4) controlling invasive species to improve native ecosystems. These examples illustrate the range of technical disciplines that form the nucleus of restoration activities as currently practiced: hydrology, engineering, geomorphology, and ecology. Individual restoration projects typically draw on one or more of these disciplines to provide technical guidance for the project and the overarching objectives of the restoration itself. The multi-disciplinary universe underlying and guiding restoration can be envisioned as a tetrahedron, with the four disciplines located at the vertices (Fig. 1). Any project is represented within this universe as a point corresponding to the proportional contribution of each discipline to the objective or implementation. Increasing flows or removing levees, for example, are primarily hydrologic or engineering interventions respectively. Most restoration projects will involve a mix of technical approaches.

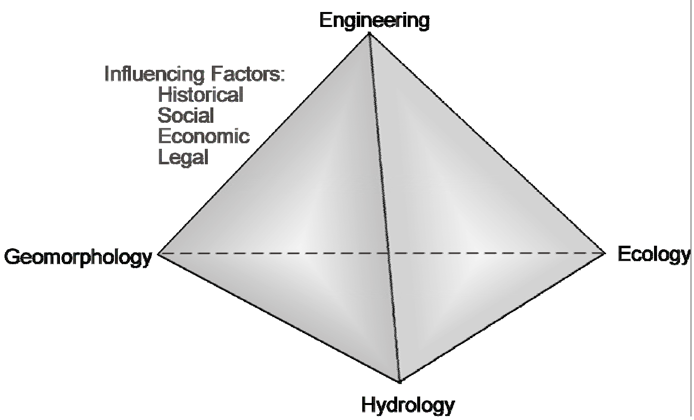

Figure 1 - Conceptual framework for restoration.

Restoration activities are themselves embedded within a broader cultural context that includes legal, economic, historical, and social issues and drivers (Fig. 1). For example, a major driver of restoration activities in the western U.S. is the Endangered Species Act, a national law intended to protect imperiled species and the ecosystems on which they depend. In Europe, a major driver of river restoration is the Water Framework Directive of the European Union, which sets the ambitious goal of achieving a “good status” for all of Europe's surface waters and groundwater by 2015. Beyond these legal directives lie a complex set of culturally defined historical and social expectations for rivers that also strongly influence the extent and types of restoration strategies employed.

From a global perspective, there has been tendency for restoration practices within different countries and regions to emphasize or be motivated by particular disciplinary foci. In the Pacific Northwest salmon example above, ecological considerations motivate restoration activities, which include a wide range of projects such as riparian planting, adding large woody debris back to streams, gravel augmentation to improve spawning habitat, etc. In southern Europe, on the other hand, a century of gravel extraction and extensive river engineering for erosion control has promoted dramatic channel incision (Liébault and Piégay, 2002; Rinaldi et al., 2005). Here, restoration activities principally involve engineering or geomorphic approaches designed to add gravel back to rivers by promoting active bank erosion in degrading reaches, building control weirs to check bed erosion, and actively trenching channels and floodplains to promote gravel transport from gravel rich to gravel poor zones (Piegay et al., 2006). Other examples include re-engineering of channels to promote meandering, as in Switzerland and Japan.

Restoration practices tend to evolve over time in response to changing societal expectations and collaboration among practitioners around the world. Such evolution can shift the disciplinary mix towards other vertices over time. For example, there is a growing utilization of engineering approaches in the United States, and increasing use of non-structural geomorphically- and ecologically-based approaches in countries such as Japan (Nakamura et al., 2006).

3. SOME EXAMPLES FROM THE US PACIFIC NORTHWEST

I now offer a few brief, heuristic, and undoubtedly biased examples of how this framework can potentially be useful in understanding the strengths and weaknesses of river restoration activities. These examples are drawn from some recent restoration projects in the U.S. Pacific Northwest that illustrate some salient aspects of current restoration thinking. In particular I emphasize the interplay and relative degree of integration among different technical disciplines involved in restoration activities, and the overall role of science in informing restoration strategies. These examples are offered not so much to critique specific projects as to compare the consequences of utilizing different disciplinary mixes with an eye to encouraging a more rigorous scientific basis for river restoration.

I focus specifically on river restoration examples involving dams, since dams represent some of the most significant human interventions in rivers worldwide (Nilsson et al., 2005). The three examples represent different restoration strategies to different aspects of this problem: dam removal to improve fish migration, dam retrofitting to improve river temperatures, and evaluating potential gravel augmentation below a dam for temperature benefits. The details from each of these examples have been published elsewhere and cited below; here I focus on how successfully were the technical disciplines involved and with what consequences.

Removal of Marmot Dam, Sandy River, Oregon

Dam removal has been widely viewed as an important river restoration strategy and interesting scientific opportunity, the latter because it represents a real-time, full-scale field experiment on fluvial adjustment (Grant, 2001; Doyle et al., 2003). Removals offer an excellent setting for validating analytical models of sediment transport and morphologic change, and testing our capacity to predict short- and medium-term channel evolution in response to changing water and sediment transport regimes. Most dam removals have involved relatively small structures and modest releases of sediment stored in pre-removal reservoirs. The largest instantaneous and uncontrolled release of sediment accompanying a dam removal occurred with the breaching of the Marmot coffer dam on the Sandy River in Oregon in October 2007 (Fig. 2).

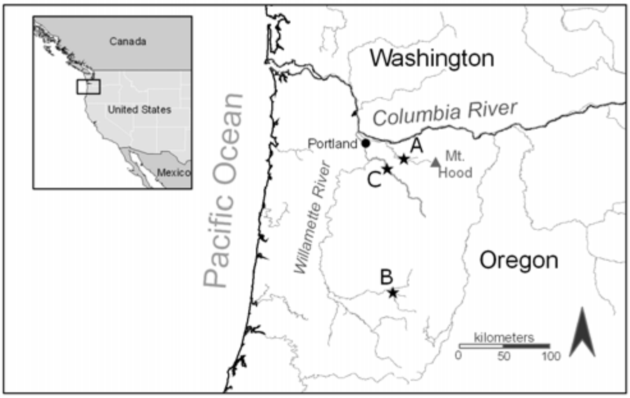

Figure 2 - Location Map showing A. Marmot Dam, Sandy River, B. Cougar Dam, South Fork McKenzie River, and C. River Mill Dam, Clackamas River.

Marmot Dam was a concrete diversion dam built in 1913 as part of a larger hydroelectric project that located on the Sandy River approximately

45 km upstream from its confluence with the Columbia River near Portland, Oregon, U.S. The Sandy River is an energetic river that naturally carries copious quantities of volcanic sand and gravel, because it drains the western flanks of Mt. Hood, an active stratovolcano. At the time of removal, the reservoir upstream of the dam was completely filled with 750,000 m^3 of sediment. The river below the dam includes bedrock gorges, mixed bedrock/alluvial reaches, and alluvial reaches with well-developed gravel and sand bars.

The decision to remove the dam was motivated by a combination of increasing maintenance costs and an unfavorable future economic return due to the necessity of installing expensive fish passage facilities to meet relicensing requirements. The dam's owner surrendered the license in 1999, and removal commenced in summer, 2007. To remove the concrete structure, a temporary coffer dam was constructed out of river bed and reservoir sediment upstream. The main structure was dynamited in July 2007, but the combination of high stream power during even modest flows and high natural sediment fluxes was a key factor in the decision to allow the river to naturally breach the coffer dam and erode the remaining impounded sediment during the first fall storms. Physical modeling helped project engineers design the breach scenario (Grant et al., 2008).

A multi-agency initiative organized to conduct pre-, during, and post-event monitoring of channel evolution and sediment transport. Individual study elements included event-based measurements of suspended sediment and bedload, repeat surveys of channel cross-section and planform change, reservoir incision, and repeat LIDAR surveys to capture three-dimensional changes. High-resolution time-lapse photography recorded changes occurring during and subsequent to the breach. These data have provided and will continue to provide a treasure trove of measurements useful for evaluating models of sediment transport and geomorphic change that are applicable not only to future dam removals, but to a wide range of geomorphic problems, including the fate of landslide dams and river response to changing base level (Major et al., 2008).

The specific set of external issues driving removal of Marmot Dam involved a combination of legal, economic, and social factors. Engineering played a major role in the design and construction of the coffer dam and removal of the main structure. The scientific focus was on geomorphic response of the river, and involved a coordinated set of numerical and physical models, sediment transport and discharge measurements, and geomorphic surveys. The resulting data offer rich geomorphic insights.

On the down side, however, is the relatively poor integration of ecologists and measures of ecological response following removal. This is an unfortunate consequence of limited funding and the rather grassroots organization of the studies; basically the disciplines represented are those that chose to show up. A "top-down" approach might have yielded stronger cross-disciplinary integration, but there was neither the funding nor the institutional home to effect this.

Retrofitting Cougar Dam to improve downstream temperatures for fish

Large flood control projects that store and release water at different times of the year can change the natural temperature regime of a river, depending on timing and temperature of water influxes and discharges. These shifts in temperature can affect the timing of triggers for key stages of resident and anadromous fish, such as spawning and migration. Retrofitting dams to permit water to be withdrawn from multiple levels within a temperature-stratified reservoir is an emerging, though expensive, strategy to restore and manage temperature regimes downstream of large dams.

Cougar Dam on the South Fork McKenzie River, Oregon., USA, is a multi-purpose dam and reservoir impounding 270 million cubic meters of water (Fig. 2). The reservoir becomes thermally stratified in summer, with warmer, less-dense water near the surface and colder, more-dense water at the bottom. A low-elevation outlet in the dam resulted in the release of relatively cold water from near the bottom of the reservoir in mid-summer. As the reservoir was drawn down in autumn to make room for winter floods, warmer surface water was released as well. This altered temperature pattern was potentially causing problems with the timing of migration, spawning, and emergence of juvenile salmonids. In order to restore the temperature regime, the dam owner modified the intake structure at Cougar Dam to permit extraction of water of different temperatures from different reservoir levels. These modifications, which were constructed from 2002 to 2005, allow operators to release colder water during the winter, and warmer water during the summer, to improve habitat conditions for threatened bull trout and spring Chinook salmon.

In order to carry out work on the intake tower, Cougar Reservoir was lowered below minimum pool elevation in April 2002, thereby exposing deltaic and lake bottom sediments to reworking by the South Fork McKenzie and other reservoir tributaries. The incision and reworking of these sediments resulted in a prolonged discharge of turbid water from Cougar Reservoir that was highly visible for kilometers downstream and even affected the turbidity of the Willamette River below the confluence of the McKenzie (100km downstream). Although turbidity was predicted to increase during the drawdown, the magnitude, timing, and duration (4 months) of the problem was underestimated, prompting concern that sediment contained within the turbidity plume might intrude into river gravels, with potentially negative effects for fish and other aquatic biota.

Follow up studies focused on both the source of the sediment giving rise to the turbidity and whether fines had intruded into the coarse gravel bed below the dam. The latter studies showed that significantly higher concentrations of fines in the gravel bed downstream of the dam than above it, but these could not be conclusively tied to the drawdown and subsequent erosion. A key finding of the sediment studies was that the source of the clays that caused the turbidity was not delta incision, but erosion of the toe of a large landslide complex that had entered the reservoir subsequent to dam construction. Erosion of the toe caused extremely fine clays with very low settling velocities from this landslide to become resuspended in the reservoir; these turbid waters were then released below the dam.

This example highlights how focus on one aspect of a restoration strategy – in this case the dam retrofit with the temperature control structure – to the exclusion of other potential effects (erosion and resuspension of fines) can result in unintended consequences (turbid water releases and possible impacts on gravel quality). While the restoration itself was clearly motivated by ecological considerations, and involved extensive temperature modeling and re-engineering of the dam, there was little attention paid to potential geomorphic effects of the drawdown itself. A more integrated approach might have incorporated a geomorphic perspective that evaluated the potential for the drawdown to remobilize turbidity-causing sediments. Fortunately, the long-lasting ecological impacts from this incident appear to be minor.

Evaluating potential thermal benefits from adding gravel below dams

Reintroducing gravel to rivers whose sediment supply has been reduced or depleted by dams and reservoirs is emerging as a new approach to river restoration. Although gravel augmentation is primarily used to allow rivers to rebuild bars, riffles, and other habitat features, it may also help mitigate the thermal effects of reservoirs by increasing hyporheic exchange, where surface water enters the riverbed and flows along subsurface paths before returning to the main channel. In theory, gravel augmentation could increase hyporheic exchange by increasing total gravel storage in a depleted river reach and by promoting lateral migration. Increased hyporheic flow, in turn, could have temperature benefits, because this exchange promotes mixing of waters of different ages and temperatures in the subsurface, thereby potentially reducing maximum temperatures.

As part of a dam relicensing on the Clackamas River, a large gravel-bed river in northwestern Oregon, US (Fig. 2), the dam owner is considering a substantial gravel augmentation that may involve adding thousands of cubic meters of gravel annually to the river. This augmentation is primarily intended to create habitat for spawning fish and to restore channel morphology and sediment transport interrupted by the River Mill dam complex, but may also have ancillary benefits for mitigating temperature effects of the upstream dams and reservoirs, which is a legal requirement of the new operating license. Determining the magnitude and timing of temperature changes that might result from gravel augmentation is challenging. No current models address both hyporheic flow and heat exchange in rivers, and there is little field data. Because of this, the dam owner funded a set of preliminary and anticipatory studies to evaluate the magnitude of the potential effect through a coordinated set of modeling, experimental, and field studies.

We examined the relationship between hyporheic exchange and temperature along a 24-km reach of the lower Clackamas River (Burkholder et al., 2008). Hyporheic exchange was primarily identified by temperature anomalies, which are patches of water that demonstrate at least a 1 °C temperature difference from the main channel. These anomalies were located through field investigations and thermal-infrared-radiometry (TIR). Anomalies were associated with specific geomorphic features, primarily bar channels and bar heads that act as preferential pathways for hyporheic flow. Detailed field characterization and groundwater modeling showed that hyporheic discharge from anomalies comprises a small fraction (−1%) of mainstem discharge, resulting in almost negligible main-stem river-cooling. However, the presence of cooler patches of water within rivers can act as thermal refugia for fish and other aquatic organisms.

First, multiple disciplinary perspectives underlay the motivation for this study: to investigate whether an engineering manipulation (gravel augmentation) could effect a geomorphic change (bar growth), leading to hydrologic change (development of more hyporheic flow and temperature anomalies) that in turn would result in peak temperature reductions, thereby improving ecological habitat for threatened fish species. Stated in this way, these different disciplinary perspectives form a chain of logic or causality that provided the framework for the research. Second, this work was done in anticipation of a future action – adding gravel to the river – and represented the direct application of a scientific process to guide a management decision. The research results revealed that while the direct temperature benefits from gravel augmentation were likely to be small, the effects were large enough to potentially have other, more localized, benefits to habitat. In this way, the science helped guide future actions on the part of the dam owner and river managers towards more effective strategies.

4. REFLECTION AND IMPLICATIONS

The lessons that we draw from these examples highlight some recent developments in river restoration, including emergence of new approaches and methods, and the overall maturation of river restoration as a sophisticated and deliberate set of actions aimed at improving river function. But perhaps most importantly, they demonstrate different ways that scientific disciplines and the scientific process itself is (and is not) being incorporated into river restoration. Both the Marmot and Clackamas River examples illustrate how science is being used in an anticipatory fashion: to test hypotheses, operational strategies, and potential outcomes prior to full implementation. The physical modeling of the breach scenarios on the Sandy River helped design the actual breach scenario. Field and modeling studies on the Clackamas helped steer river managers away from a particular path of speculation towards other more fruitful areas. On the other hand, absence of certain key studies and perspectives in the case of Cougar Dam may have contributed to undesirable consequences. Incorporation of the broader landscape context (in this case, the geomorphic setting and history of the reservoir itself) might have forestalled the fine sediment erosion, or at least allowed project engineers to anticipate it and possibly change the drawdown schedule to accommodate it.

These examples point to the conclusion that river restoration projects that explicitly incorporate a scientific process of stating then testing hypotheses at all stages of project development are likely to be more effective and efficient in the long run. Such a process is capable of identifying the most effective strategies in particular situations, including what is likely not to work. Projects underlain by this type of information will inevitably be better situated to adapt to changing environmental conditions or societal expectations.

Although not all restoration projects require the perspectives of multiple disciplines, the examples presented here suggest that restoration that draws on more than one scientific discipline may be more successful in the long run. Each discipline brings with it a certain set of methods, approaches, and ways of evaluating larger contexts within which restoration activities sit. The hydrologic sciences offer rigorous means of characterizing river flow and hydraulic regimes, the ecological sciences provide the context of understanding the interplay between individuals, species, communities, and ecosystems, the geomorphic sciences emphasize understanding physical processes and watershed history over broad spatial and temporal scales, and the engineering disciplines help define what is doable within a rigorous context of risk analysis. With the world's rivers changing in response to human interventions and climatic trends, river restoration will require the perspectives and tools of all of these disciplines in order to be successful.

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CHAPTER 2

Session 1

Biodiversity and restoration of hydromorphological processes

Chairpersons

B. GUMIERO, K. BOYER, S. GREGORY

Introduction
BIODIVERSITY AND RESTORATION OF HYDROMORPHOLOGICAL PROCESSES

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The European Union's Water Framework and Habitat Directives require all rivers to be considered in terms of their ecological quality, defined partly in terms of "hydromorphology". Downs and Gregory in 2004 articulate two major components of modern river management: conservation-based management and "design with nature". Considering that rivers and streams are open ecosystems, one of the key issues for addressing their ecological quality is the importance of maintaining a dynamic flow of physical (water, sediment), and biological (flora, fauna, wood, carbon, nutrients) elements laterally, longitudinally, and vertically throughout a river's network from headwaters to the sea. Restoring hydrological and morphological connectivity is thus an important strategy for river restoration.

The most important contribution of interdisciplinary river management is the recognition that physical riverine features influence habitat quality and quantity and its consequent contribution to biodiversity conservation, in terms of "good ecological quality" in rivers, and the hydromorphological component of this quality. Effective river restoration requires interdisciplinary information at a range of scales from catchment to microhabitat.

The objective of this session was to exchange experiences and findings about the linkages between habitat restoration and biodiversity. Thirteen oral presentations and 12 posters were given in the session (25 total contributions). One oral presentation (Elso et al.) gave a broad overview of biodiversity conservation within a management plan. However, in this session we focused mainly on lateral and longitudinal connectivity that correspond respectively to 1) floodplain conservation-restoration and 2) in-channel restoration.

1. During the first half of the session, 5 oral presentations (Stammel et al., Corenblit et al., Negri & Casotti, Davies, Vietto et al.) and 5 posters (Groves, Ortiz-Arrona et al., Badarau & Ticalo, Scholl et al., Leummens & Tkachenko) were contributed. Three of these presented tools, mainly models, and their potential applications to river management and restoration (Davies, Negri & Casotti, Groves). Two posters were focused on wetlands as important habitats for sustaining biodiversity of river ecosystems (Badarau & Ticalo and Leummens & Tkachenko). Stammel et al. reported on a project which restored 2,100 hectares of riparian areas along the Danube floodplain. The objective of the project was to restore the hydrological and morphological dynamics for conservation of typical floodplain habitats and species. Scholl et al. provided monitoring data on zooplankton in a restored floodplain of the Danube. The changes in zooplankton abundance and diversity during different flow conditions provide insights useful for large river restoration. Ortiz Arrona et al. provided a Mexican example of integrating activities between stakeholder practices along rivers and riparian zone restoration. Vietto et al. underlined the important role of black poplar in the initial stage of development of floodplain forests. Lastly, Corenblit presented detailed findings on the effects and responses of pioneer plants within fluvial corridors and applications for developing an integrated approach of river ecosystem dynamics as a conservation strategy.

2. The second part of this Session was comprised of 7 presentations and 4 posters regarding the effects of stream restoration on aquatic biota, including benthic macroinvertebrates, bivalves, fish, and periphyton. All presentations emphasized the need to restore ecological-physical structure and functions of streams and floodplains to increase habitat complexity and connectivity. Important contributions came from Denmark with 2 presentations and three posters validating the importance of long-term monitoring and ecological and economic efficiency of river restoration projects. Kronvang et al. described the short and long term effects of re-meandering projects implemented in different Danish stream types by monitoring different biological indicators. Pedersen and Kronvang presented results of a major effort by Denmark to re-meander channelized streams, and re-introduce gravels for improving spawning habitat for *Salmo trutta*. Another example of stream restoration effects on fish fauna was presented by Vehanen et al. from Finland.

Kail presented previous evidence of a “spreading effect” of upstream reach conditions on downstream biodiversity. Elosegi presented preliminary data on the effects of re-introducing large wood to the channel of a montane stream. Rechendorfer et al. discussed the significance of riverbanks and reciprocal resource subsidies on biodiversity in Austrian streams and rivers.

Munoz reported on restoration efforts to increase longitudinal connectivity in the Negro River of Spain for threatened pearl mussels. Lastly, with his poster, Pini Prato showed a methodology for a mesohabitat characterization.
Three other posters presented different aspects of river restoration: Sileri et al. reported on the effects of hydropeaking on biota, Kralova et al. reported on the use of monitoring data to determine locations for restoration, and Studenov et al. presented a case study on fish habitat conservation related to a diamond mine construction.

The main conclusions from this session are:
1. There is an urgent need to develop innovative tools for river restoration at multiple scales.
2. It is very important to conduct long term monitoring to better understand river restoration techniques and the response of aquatic biota.
3. It is not enough to improve hydrogeomorphology to enhance biodiversity. The positive and negative upstream effects should be considered in stream restoration and management in addition to local habitat quality and catchment land-use pressure. Moreover the positive effect of near-natural upstream reaches on local ecological condition is of special interest in urban streams. The work of Kail and Hering (in press) indicates that restoration of upstream reaches can positively influence or improve the condition of downstream reaches in urban areas.
4. *Salmo trutta* fry monitoring indicated that gravel-enhanced streams increased potential for spawning success and influenced Young-Of-Year preferred microhabitats of stream margins. Furthermore, excessive sediment transport found in many lowland Danish streams should be minimized before restoration of spawning grounds to minimize the risk of failure (Pedersen et al. in press).
5. Actions should be taken to restore the natural abundance of large wood in stream channels where this will not increase flood hazard. Adding wood increased channel complexity, as indicated by changes in flow patterns, in addition to retention of sediments, nutrients, and organic matter. The response of the stream biota to the wood additions will be forthcoming.
6. Plan at catchment scale, implement at those scales where the opportunity to restore ecological-physical structure and functions of streams and floodplains is most likely. Enhancing habitat complexity and connectivity will contribute to the conservation of biological diversity.

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RESTORATION OF RIVER/FLOODPLAIN INTERCONNECTION AND RIPARIAN HABITATS ALONG THE EMBANKED DANUBE BETWEEN NEUBURG AND INGOLSTADT (GERMANY)

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ABSTRACT

In the 19th century the Upper Danube was embanked and straightened and nowadays it flows in embankments without any contact with its floodplain except during very high floods. Additionally, in the 1970s large dams which supply hydropower stations were built, negatively influencing the river continuity and the groundwater level of the floodplain. The goal of the presented river restoration project is to create new dynamics to the floodplain (water, groundwater, and morphological features) which is the key process to foster floodplain habitats and species richness. The project 'Restoration of riparian areas on the Danube floodplain between Neuburg and Ingolstadt (Bavaria/Germany)' takes place in an area of 2,100 hectares of riparian forests. Despite the altered conditions, a high biodiversity mainly of species of the hardwood riparian forest has been conserved. The project consists of three actions: 1) A permanent flow of water (up to 5 m^3/s) bypassing the dam upstream of the hydropower station. The new river will develop on the floodplain partly flowing in old oxbows, but partly eroding its way naturally. 2) Controlled (ecological) flooding (up to 30 m^3/s) of parts of the floodplain during peak discharge of the Danube (600-1,100 m^3/s; as average two to three times per year). 3) Temporary drainage of the floodplain in summer, where the groundwater level is constantly too high due to the dams. The project, conducted by the Free State of Bavaria and the the Bavarian Water Authority, started in October 2006. By summer 2009 the construction works will hopefully be finished, and the first water will run through the riparian forest. The Aueninstitut (Floodplain Institute) Neuburg was founded in January 2006 to document the hydrological, morphological and biological changes in the project area. A comprehensive monitoring program including vegetation, hydrological and morphological data collection was established and will be presented.

Key words: Floodplain habitats, monitoring, vegetation, hydrology, geomorphology

1. INTRODUCTION

Like most rivers in Europe and North America (cf. Schiemer et al., 1999), the Danube and its floodplain have been considerably affected by land use and changes in its catchment. People wanted to control the frequent flooding, reduce soil erosion and use the nutrient-rich floodplain for settlement and agriculture by embanking and straightening, which had already started at the beginning of the 19th century. But because of these actions, floodplain was disconnected from their rivers. In the mid of the 20th century, the rivers were affected again by a series of new projects: impoundments were built to operate hydropower stations. Due to these impoundments, the groundwater level of the floodplain was changed dramatically to either permanently too high, or too low, but not to the typical shifting level. The changes of the River Danube along the study area since the 19th century can be seen in Figure 1. In the 1970s two additional hydropower stations ('Bergheim' in the west and 'Ingolstadt' in the east) were built.

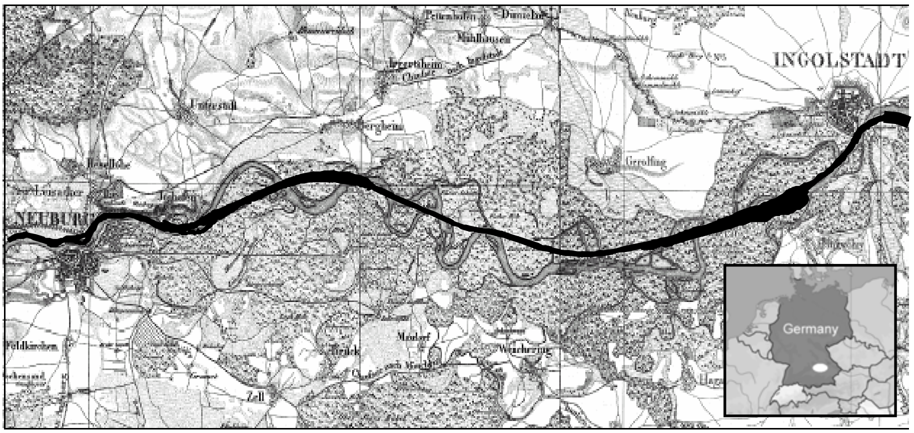

Figure 1 – Historical map of the River Danube in the project area (white ellipse in small map), present watercourse sketched in black. Mosaic of maps of the Topographic Atlas of Bavaria, scale 1:50 000, Page Neuburg (1823) and page Ingolstadt (1819).

Due to these changes occurred in the past, today the typical floodplain habitats are highly endangered. In the last 150 years 75 % of the Bavarian floodplain areas were lost due to human activities (cf. Margraf, 2004). In the study area, however, 2,100 ha of riparian forests and riparian habitats have survived as relicts of the former floodplain. Margraf (2004) found 536 plant species, 80 of them listed on the Red List of Bavaria. But the author also recorded a strong change in vegetation types due to changes in the abiotic conditions due to the construction of the hydropower plants: the loss in water and soil dynamics and the changed groundwater level. Without any restoration measures, these isolated alluvial relicts will disappear or their biodiversity will decline constantly (Margraf, 2004, cf. Ward et al., 1999).

To conserve the species diversity of the floodplain and to restore the typical floodplain habitats, the project presented in this article aims to restore the natural dynamics and the interconnection of river and floodplain, notwithstanding the still-existing impoundments (Cyffka and Haas, 2007). We present the action planned in the project, the recently started monitoring program regarding soil, hydrology, and vegetation features, which were the content of the oral (S1_8) and poster (S5A_15) presentations.

2. THE RESTORATION PROJECT 'NEW DYNAMICS'

The Danube is one of the main drainage systems in Europe, running from Germany to the Black Sea. The project area is situated at the upper reaches of the Danube (river kilometre 2472 to 2464) where the river is still small and the catchment area is 20,000 km^2. The mean annual discharge is 313 m^3/s, lowest mean annual discharge is 131 m^3/s, mean annual flood discharge is 1,130 m^3/s. A discharge up to 500 m^3/s can be used by each hydropower stations. The discharge is strongly influenced by rivers running from the Alps (Iller, Lech), therefore more frequent and stronger flooding occurs in early summer due to snow-melt. But only floods higher than 1,300 m^3/s (with a return period of 10 years) reach the floodplain, lower ones remain in the embanked Danube (WWF, 1997) .

The objective of the project is to restore the key hydrological and morphological dynamics which are the precondition for the conservation of typical floodplain habitats and species (cf. Schiemer et al., 1999). The floodplain should be reconnected to the Danube water gradually by stepwise measures. If one is able to use water as an adjusting screw, many other related features (e.g. vegetation) will adjust themselves after a certain period (Cyffka, 2006). Therefore, in order to restore the water and soil dynamics in the floodplain, the implementation of three measures is planned (Fig. 2).

2.1 The new floodplain river

To improve the groundwater and soil dynamics not in the whole floodplain, but in a small corridor and to rebuild the longitudinal connectivity for aquatic organisms a new permanent floodplain river will be built bypassing the dam of Bergheim. The water from the Danube will be discharged into a new river bed using old, but disconnected meanders, varying between 0.5 and 5 m^3/s, according to the discharge of the Danube itself. Today, in the first 3.5 kilometres of these meanders there is no running water throughout the year. Passed this restored reach, the water course will run through an existing temporary waterbody, i.e. an existing brook not originating from the floodplain (Zeller Kanal), and finally through a backwater, called 'Alte Donau' (Old Danube). The water will return into the Danube after running for a total length of 8 km.

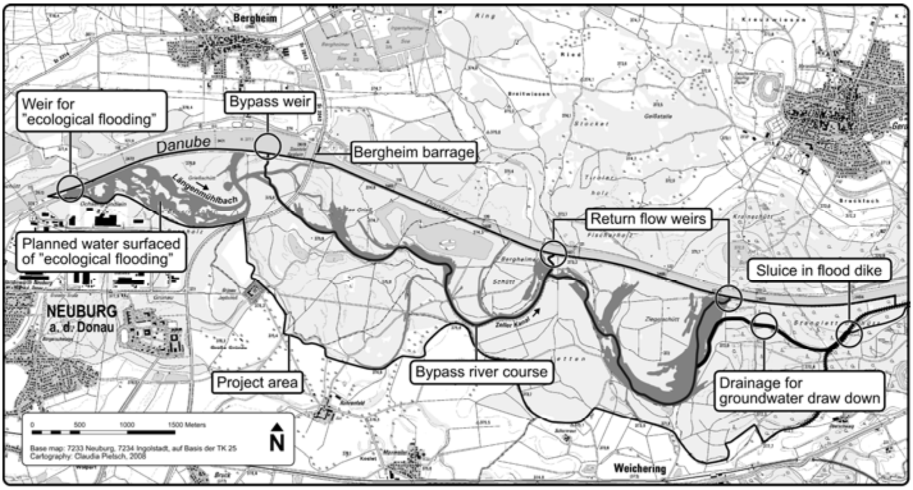

Figure 2 – The actions of the restoration project: new water course, ecological flooding and temporary drainage.

2.2 Ecological flooding

Due to embankments, the Danube floodplain is currently only flooded when the Danube reaches the discharge of 1,300 m^3/s. Therefore, the project aims to bring back a higher flooding frequency and variety to the area, according to the changes in the Danube water level. A controlled water discharge will be carried into the floodplain (a maximum of 30 m^3/s) during the Danube peak discharge (600-1,000 m^3/s), which as average occurs 2-3 times per year and lasts for about 5 days. Because only 500 m^3/s of water can be used by the hydrological power plant Bergheim, no financial loss will occur. At 1000 m^3/s, the ecological flooding will be stopped to keep the floodplain as retention area of floods with higher discharge (> 1,300 m^3/s). The main course of the ecological flooding will be along the new watercourse through the riparian forest and will flow into the Danube downstreams of the new watercourse.

2.3 Drawdown of permanent high groundwater

Due to the dam at 'Ingolstadt' and the storage area downstream of it the groundwater level in the eastern part of the project area is permanently high, favouring wetland species in contrast to floodplain species. Therefore, the third measure of the project aims to bring back the typical dynamic of the groundwater. A new channel will be created to drain the groundwater of the area into the area upstream the dam 'Ingolstadt' where the water level of the

Danube is lower (Fig. 2). The hydraulic gradient will be 5 meters. The canal will connect the new river/Zeller Kanal and the existing Aich Creek behind the dike where a new sluice will be constructed. In periods of low water discharge of the Danube, the weirs at the two confluence points of the new river and the Danube can be closed and the groundwater will be drained by the sluice in the dike into the area upstream the dam 'Ingolstadt'.

3. MONITORING CONCEPT

A monitoring programme should document and analyse the changes in the floodplain. The results will allow to adjust the amount of water both flowing in the new river and during ecological flooding in order to reach the restoration goals, and provide suggestions for new similar restoration projects. Thereby the monitoring plan covers the main driving variables, such as water and soil dynamics. On the other hand, effects on the vegetation will be monitored as vegetation is good indicator of the achievement of restoration goals.

3.1 Fluvial geomorphology/soils and hydromorphology

The new river banks are prone to lateral erosion and new undercut slopes will develop. From the beginning of the flooding a new morphological activity will begin. To archive the *status quo* of the new river channel several investigations were carried out. The main goals of these investigations were to collect as much knowledge of the channel topography and sediment distribution in the channel as possible. Methods ranged from standard granulometric analyses over cros-profile measurements to highly sophisticates terrestrial laser-scanning. Figure 3 shows the western part of the project area and the locations of the investigation sites.

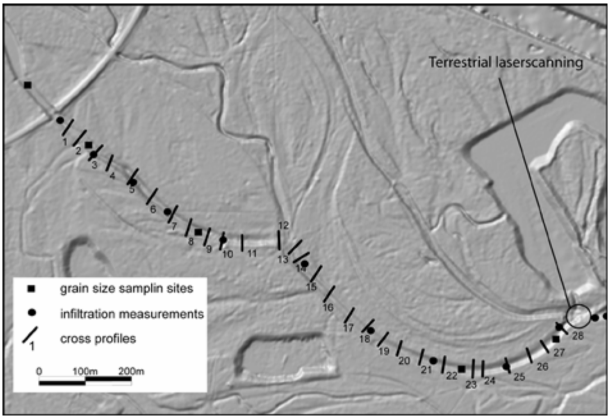

Figure 3 – Positions of grain size sampling sites, cross profiles, infiltration measurement sites and terrestrial laser scanning sites. Background: analytic hillshade of the DTM.

Measurement of cross-sections

In the western part of the newly-built bypass river a total amount of 28 cross-profiles sites have been defined for long term monitoring. The cross-profiles are measured with a Leica Total Station (TPS 1205). In order to carry out repeated surveys, the starting points and the end points were precisely marked. By means of regular and event-related measurements at the cross-profiles, an accurate recording of any changes of the bed morphology, of bed erosion and accumulation is possible.

Terrestrial laser scanning

Figure 4 shows the so called ‘Wetterloch’ as part of the new channel. Erosion was initiated there by the centennial flood of 1999 and from then on, the area has been subject to morphological activity. Stretches like these are important sources of debris, and must be measured precisely and frequently. At this site and at other undercut slopes, as well as at potential accumulation areas (sand and gravel banks) a terrestrial laser scanner (Riegl LMS Z420ii) will be used for high-precision measurements. This relatively new method allows fast and highly precise surface measurements, and thus eroded or accumulated material will be quantified easily.

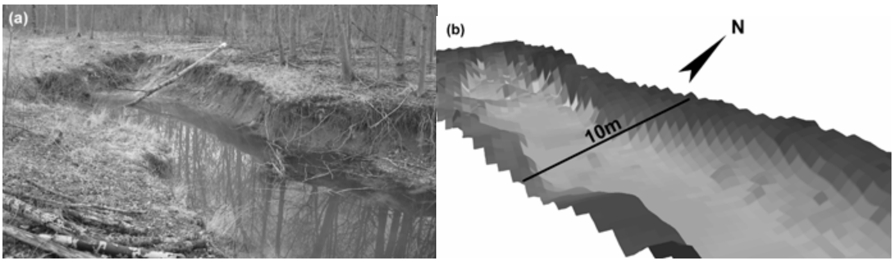

Figure 4 - Photo of active channel erosion at ‘Wetterloch’ (photo: F. Haas, 2007) (a), and 3D-view of ‘Wetterloch’ area, based on terrestrial laser scanning data (b).

Grain size and infiltration capacity as an indicator for change

For first characterization sediment samples were collected from the bottom of the future river channel. Additionally, infiltration measurements were carried out in the same sites to identify highly permeable areas where surface water infiltrates into the aquifer.

The grain size distribution of the channel material differs clearly between the sample sites due to the activity the River Danube in former times as far as oxbow generation and migration are concerned. Therefore, the future river channel will run across a range of sediment composition. The areas where such composition changes, e.g. from sand to silt or clay (mostly alluvial clay from the mediaeval times) are subject to erosion. Therefore, it is necessary to identify such areas, especially where they coincide with a change in channel direction. At these areas erosion will be most severe and the undercut slopes will develop into a real oxbow.

Infiltration capacity was measured using a Guelph Permeameter (Reynolds and Elrick 1986) at 12 wells to a depth of 60 cm. According to the sediment size distributions, the infiltration capacity differs from very permeable (0.0241 cm*sec^{-1}) to very impermeable (0.0001 cm*sec^{-1}).

Regular aerial survey of the project area

In order to record morphological changes in the channel and to identify the flooded areas (ecological flooding) at a large scale, aerial photographs of the project area were taken from a helicopter. The photos were taken with a calibrated SLR camera (Canon EOS 350D), so they are suitable for stereoscopic analyses, as far as surveyed ground control points are present. This aerial survey will be carried out regularly and event-related (during and after floods).

3.2 Vegetation ecology

Permanent plots in alluvial forest

The effects of the restoration project on the vegetation of alluvial woods will be studied by a system of stratified permanent plots. The following four different parameters were selected to define the strata (Tab. 1).

(1) Actual level of surface- and groundwater and planned measures: due to the two dams in the project area, the groundwater level increases from the west to the east. Additionally, there are different water typologies in the floodplain (temporary, lotic, lentic). Further, the three planned measures will be implemented in different areapects, the project area was divided into 6 sectors from east to west (Fig. 5).

(2) Flooded area: on the base of a hydrologic model by which ecological flooded areas were calculated, the 6 sectors were divided into flooded and non-flooded.

(3) Probability of flooding, correlated to the elevation: lower or higher than 1.25 m above the thalweg (compare Bock et al. 2006).

(4) Distance from the new water course, as a declining influence of the new water dynamics with increasing distance can be assumed. Two classes were defined: along a corridor of 25 m, or at a further distance.

To classify the study area by these parameters a digital relief analysis by a GIS-software has been conducted. The vertical distance of a site to the river bed was calculated with module ‘Vertical distance to channel network’ of the Open Source GIS SAGA (Bock et al. 2006). The defined strata plots of 200 m^2 were randomly placed on the map, but were examined in the field to check whether they fit the definition of a semi-natural forest. Parameter (2), (3) and (4) allowed 8 combinations, but only 7 were found in each sector (1) of the project area (Tab. 1). For each stratum, 3 replicates were selected, so a total amount of 126 permanent plots will be surveyed (Fig. 5). Additional plots with special soil conditions and land use (e.g. calcareous grasslands, semi-natural pine forests) were chosen. Vegetation monitoring was started 2008 with relevés conducted two times (spring and summer) by the Londo scale (1976) and will be repeated in the first year after the restoration than every 2 to 5 years.

Table 1 – Possible parameter combination (strata) in which the permanent plots for vegetation monitoring were chosen.

(1) Sector	(2) Surely flooded	(3) Height above water course	(4) Distance water course	Present in study area
For each of the 6 sectors (see Fig. 5)	Yes	< 1,25 m	< 25 m	Yes
			> 25 m	Yes
		> 1,25 m	< 25 m	Yes
			> 25 m	Yes
	No	< 1,25 m	< 25 m	No
			> 25 m	Yes
		> 1,25 m	< 25 m	Yes
			> 25 m	Yes

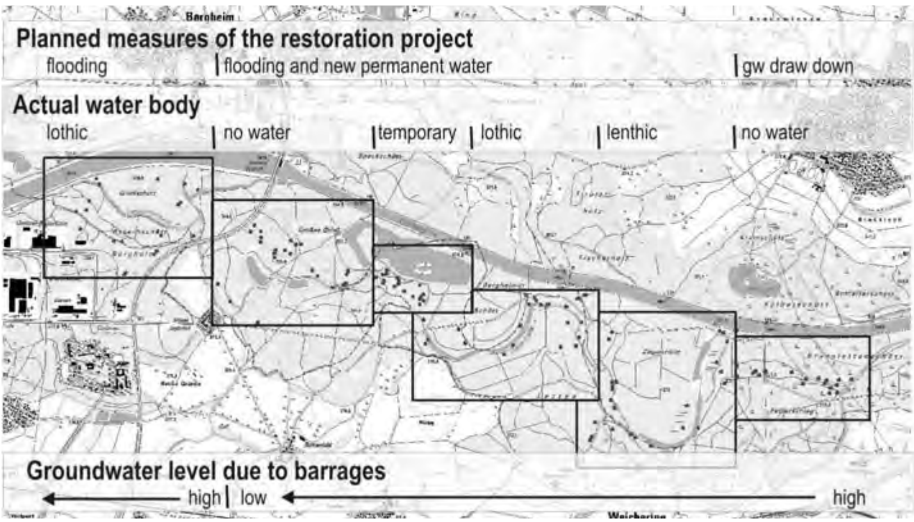

Figure 5 – Site map of all permanent plots (black rectangles), separated in the 6 sectors. Factors influencing the classification listed. Base map: TK 25, 7233 Neuburg, 7234 Ingolstadt.

Vegetation mapping along the new river

The biggest changes in vegetation were assumed to occur along the new permanent watercourse where the ecological flooding will take place, due not only to changes in hydrology, but also in geomorphology (see 3.1). Therefore, the vegetation of the aquatic and riparian habitats will be mapped using floristic-structural units. In 2007, we conducted a first mapping in those sectors where waterbodies were already present; 11 units were identified and documented by vegetation relevés in sample plots. The four investigated sectors showed strong differences in the composition of vegetation units and species, therefore the effects of the restoration will probably differ within sectors. This will be examined by yearly mapping after the restoration will take place.

Transects along the riparian habitats

To gain a better insight into the changes of vegetation types along the new watercourse, a second monitoring system was additionally installed on a smaller scale: 15 transects 50 to 100 m long depending on the cross section of the floodplain were installed, 3 in each of the first five sectors. In each transect, relevés of 1 m^2 were conducted. First data were recorded in 2007, but relevés will be repeated in summer 2009, as vegetation in aquatic habitats can differ strongly between years.

4. CONCLUSIONS

In autumn 2009, the first water is expected to run through the floodplain. By then, we will have gained a consolidated knowledge about the existing situation at the beginning of the restoration by the baseline monitoring. But even if some changes can be anticipated (like the trend of vegetation from terrestrial forests or wetland habitats to riparian habitats) others cannot be foreseen.

What will happen when the sediment budget is in balance? What will happen when the maximum discharge of the bypass river and the 30 m^3/s from the ‘ecological flooding’ will have no effect anymore because all sediment which is erodible by this discharge and velocity of water is gone? Will bed erosion stop? This is to be assumed because energy for bed erosion will be missing. But what about the lateral erosion and the migration of oxbows? If this stops, one objective of the project will not be achieved, in fact the project planned to create should be dynamic and ever-lasting changing conditions on this part of the floodplain.

As the hydrological processes were assumed to be the key process for the restoration success, not only the time-span but also the spatial dimension of the project is of great importance. Main questions concern at which distance from the new river the effects are readable in the vegetation, and which part of the 1,200 ha of the floodplain can be restored by the comparably small waterbody represented by the new bypass river. But even more interesting is the question whether there are enough diaspores of the target species remaining in the floodplain to re-colonize the new habitats. Hopefully, the restoration project is not coming too late for some species, as a diaspore input from the outside is rather unlikely: floodplains in the upper Danube that are rich in species are fairly isolated, the exchange between them is hardly possible due to the many weirs present in the river.

Furthermore, abiotic conditions and vegetation are only a small aspect of the restoration project, the study area is also very important for threatened animals. In cooperation with other institutes, further research and monitoring will be conducted, hoping to improve the habitat conditions for typical plant and animal floodplain species.

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HYDROBIOLOGICAL SURVEYS IN SPECIFIC HYDROLOGICAL SITUATIONS AT THE GEMENC FLOODPLAIN OF THE DANUBE (HUNGARY)

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ABSTRACT

The Gemenc floodplain lies between the 1498th and 1469th river-kilometres of the River Danube and it is an integral part of the Hungarian Danube-Dráva National Park. The floodplain (30 km long and 5-10 km wide) is one of the largest in Europe with an area of 18000 hectars (Natura 2000). It contains various characteristic side arms and backwaters, which are in different conditions.

The main arm and a typical parapotamal side arm (Rezéti-Holt-Duna, 15 km long) were chosen to demonstrate the effects of water level fluctuation on the chemical characteristics of the river and the composition of zooplankton assemblages. The water level fluctuation in the main arm influenced the stream velocity of the side arm. We observed a clear relationship between this phenomenon and several abiotic parameters and the diversity and abundance of zooplankton assemblies. At extremely low water levels in the main arm, the side arm acquires a lentic character. As a consequence, remarkable differences can be observed in water chemical characteristics as well as ecological parameters of zooplankton assemblages between the side arm and main arm. At normal water levels, when flow in the side arm is permanent, these differences decrease, except in the lower reach of the side arm. When the Danube's water level is high, the water chemical characteristics and zooplankton assemblages of the side arm and main arm become similar, because of the homogenizing effect of the flood.

Key words: floodplain, water level fluctuation, water chemistry, zooplankton

1. INTRODUCTION

The importance of floodplains has risen in the last decades as potential retention areas for floods, but also as valued natural wetland areas with high diversity (Berczik and Buzetzky, 2006). The goals and methods of conservation and restoration possibilities for river-floodplain systems are inadequate. Therefore, investigation of the rivers and their remaining floodplains is an important task, especially under the current conditions of growing human interference, with most adverse effects (e.g. regulation, water-use, pollution) (Tockner et al., 2000). The importance of retentive inshore habitats and adjacent floodplain water-bodies for the growth and abundance of lotic zooplankton is well known (Baranyi et al., 2002; Reckendorfer et al., 1999; Zimmermann-Timm et al., 2007). The quantitative and qualitative influence of floodplains on their zooplankton community depends on the abiotic (flow velocity, physical and chemical parameters) and biotic characteristics (competition, predation, presence of macrophytes) of each tributary. Most of these parameters are defined by the overall discharge of the main arm, which varies over time (Lair, 2005). The Danube is the second largest river in Europe with an overall length of 2860 km and a catchment area of about 817000 km^2. The floodplain of Gemenc covers 18000 hectars, making it the only notable floodplain of the Middle-Danube in the Carpathian basin. It is also one of the largest in Europe, with unique natural value (Zinke, 1996). As it lies completely within the dam-system, the characteristic hydrological processes of the river-floodplain system still occur undisturbed. We can observe in the area every characteristic “functional unit” (eu-, para-, plesio- and paleopotamal) of an ecological succession, providing a great opportunity to compare them simultaneously (Guti, 2001).

As a result of the regulation of the Middle-Danube in the 19^{th} century, the length of the riverbed decreased, and its shape became stabilized. In long term this caused most of the adjacent floodplains to become unflooded areas outside the dams. The increased flow velocity at the shortened reach of the river caused significant erosion in the riverbed, which led to the drying up of the floodplains and to the weakening of the lateral interactions (Guti, 2001). With the goal of increasing the knowledge of the ecological and hydrobiological functions of the floodplains, the Hungarian Danube Research Station of the Hungarian Academy of Sciences has started the Gemenc Research Project, which also covers the investigation of zooplankton assemblages (Dinka and Berczik, 2005; Dinka et al., 2006; Kiss, 2006; Schöll, 2006).

The aims of our study include the hydrobiological (hydrology, water chemistry, zooplankton assemblages) comparison of the main riverbed with the adjacent floodplain side arm, and the assessment of the dynamic interchange between the river and affluent arms.

2. METHODS

2.1 Study area

The Gemenc floodplain lies between the 1498th and 1469th river kilometres, on the right bank of the Danube. It is 30 km long and 5-10 km wide. In this reach of the Danube the mean annual discharge is 2400 m^3s^{-1}, with a minimum of 618 m^3s^{-1} and a maximum of 7940 m^3s^{-1}. Total amplitude of water level fluctuation reaches 9 m. The water level fluctuation are monitored by the water-level gauge at Baja (1479 rkm) (Fig. 1). The stream gradient is about 5 cm km^{-1} in the main arm, with a 0.8-1.2 m s^{-1} flow velocity at mean water level The river starts to overflow into the floodplain after it reaches a water level of 500 cm at Baja in the main riverbank.

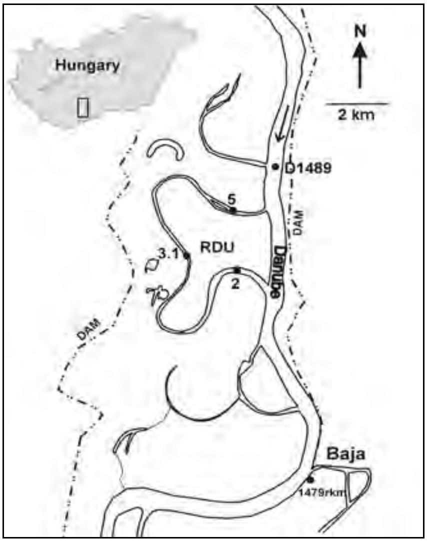

Figure 1 - The investigated area (water level gauge: 1479 rkm).

2.2 Sampling methods and data analysis

In order to compare the main arm and a typical parapotamal side arm on the floodplain, our sampling covered the main arm (D1489) and the 15 km long side arm, Rezéti-Holt-Duna (RDU) (between 1488-1485 rkm) in which 3 sampling sites were marked out (Fig. 1). Sampling was carried out between 2002 and 2004 (Tab. 1). The results were divided into three groups based on the actual water level of the Danube (1479 rkm): low (<210 cm), mean (350-430 cm) and high (>480 cm).

On each samplig site hydrophysical and hydrochemical parameters as well as hydrological conditions of the water bodies were monitored.

Table 1 - Sampling date and water level at Baja (1479 rkm).

2002		2003		2004	
Sampling date	Water level (cm)	Sampling date	Water level (cm)	Sampling date	Water level (cm)
08.04.2002	484	07.05.2003	321	14.04.2004	404
02.05.2002	429	08.07.2003	188	27.05.2004	387
13.06.2002	511	16.09.2003	173	01.07.2004	424
02.07.2002	308	27.10.2003	174	26.08.2004	209
20.09.2002	261			27.10.2004	180
12.11.2002	622				

Water temperature (ºC), conductivity (µS cm^{-1}), pH, dissolved oxygen (mg l^{-1}) and oxygen saturation (%) were measured in situ with WTW Multi 340i or Hydrolog 2100 instruments. Water samples were analyzed for Na^+, K^+, Ca^{2+}, Mg^{2+}, NH_4^+, Cl^-, NO_2^-, NO_3^-, PO_4^{3-}, SO_4^{2-} with a Dionex DX-120 ion-chromatograph after filtration (Chromafil filter, 0.2 µm pore size). Suspended matter, CO_3^{2-} and HCO_3^-concentrations were determined titrimetrically using standard analytical methods (Golterman et al., 1978). From 2003, dissolved organic carbon (DOC) was measured by Liquitoc analyser.

Zooplankton samples were concentrated by filtering 20 L (Rotifers) or 50 L (Crustacea) of water collected from the surface of the water bodies through 40 µm (Rotifers) or 70 µm (Crustacea) mesh sized nets.

All statistical analyses were performed with the Statistica 7.0 software package (Statsoft, 2005). From the quantitative data the Shannon-Wiener diversity (H) and dominance (D) of zooplankton assemblages were calculated.

3. RESULTS AND DISCUSSION

The water supply of the Gemenc Floodplain is almost completely derived from the main arm of the Danube. The physical-chemical characteristics of the water change after it enters the side arm. In general, these values depend on the residence time of the water in the side arm (and the weather conditions). The residence time of the water bodies is determined by the hydrological characteristic (length of the side-arm, gradient conditions, riverbed morphology), and by the hydrological conditions of the examined period (Talling and Rzoska, 1967; Gruberts et al., 2007; Hein et al., 2001). The results presented below show the effects of water level fluctuations in the main arm on water chemistry and zooplankton assemblages of the 15 km long side arm. These results summarize the data recorded during a three-year (2002-2004) project, while the Gemenc Floodplain experienced different flow regimes (low, mean and high flow).

Table 2 – Water chemical characteristics at different water level (Danube and side arm RDU).

sampling site		temp. °C	pH	O_2 mg/l	O_2 %	cond. uS/cm	susp.m. mg/l	HCO_3^- mg/l	Cl^- mg/l	NO_3^- mg/l	PO_4^{3-} mg/l	SO_4^{2-} mg/l	Na^+ mg/l	K^+ mg/l	Mg^{2+} mg/l	Ca^{2+} mg/l	DOC mg/l
Low water level																	
D1489	**mean**	**17,12**	**8,20**	**8,04**	**81,62**	**386,00**	**17,90**	**249,63**	**21,29**	**5,86**	**0,25**	**31,16**	**17,60**	**2,77**	**13,18**	**48,91**	**2,79**
	sd	*5,40*	*0,46*	*3,19*	*26,91*	*40,83*	*9,50*	*25,72*	*6,97*	*1,36*	*0,17*	*1,26*	*3,21*	*0,36*	*1,43*	*8,52*	*0,14*
RDU3.1	**mean**	**15,73**	**8,12**	**12,04**	**118,23**	**555,50**	**25,00**	**342,75**	**22,17**	**1,46**	**0,18**	**30,78**	**15,39**	**2,86**	**23,31**	**75,36**	**4,29**
	sd	*5,72*	*0,44*	*4,44*	*46,01*	*87,76*	*0,00*	*0,00*	*5,81*	*1,91*	*0,19*	*13,31*	*1,45*	*0,71*	*5,89*	*13,43*	*0,00*
RDU2	**mean**	**17,36**	**8,20**	**10,45**	**106,52**	**423,20**	**27,25**	**251,08**	**25,76**	**2,09**	**0,24**	**39,30**	**18,29**	**3,91**	**17,09**	**54,54**	**5,08**
	sd	*5,88*	*0,42*	*3,69*	*31,03*	*50,64*	*10,75*	*44,56*	*3,77*	*1,95*	*0,20*	*20,41*	*3,39*	*1,48*	*1,52*	*12,00*	*0,45*
Mean water level																	
D1489	**mean**	**15,68**	**8,40**	**9,96**	**102,15**	**427,75**	**30,73**	**238,21**	**22,37**	**6,80**	**0,06**	**30,76**	**16,88**	**2,66**	**14,59**	**53,11**	**3,49**
	sd	*3,42*	*0,22*	*3,28*	*35,79*	*61,12*	*10,31*	*18,46*	*6,07*	*2,32*	*0,08*	*5,12*	*4,37*	*0,33*	*2,13*	*6,58*	*0,38*
RDU5	**mean**	**15,90**	**8,40**	**12,22**	**125,28**	**406,00**	**32,67**	**236,28**	**21,99**	**6,87**	**0,05**	**31,73**	**17,44**	**2,68**	**14,89**	**54,35**	**3,38**
	sd	*3,60*	*0,26*	*5,67*	*59,08*	*45,61*	*7,83*	*28,26*	*6,01*	*2,42*	*0,07*	*4,51*	*4,65*	*0,16*	*1,35*	*6,41*	*0,41*
RDU3.1	**mean**	**17,00**	**8,43**	**12,65**	**134,15**	**404,25**	**24,83**	**237,01**	**21,44**	**6,53**	**0,04**	**32,64**	**17,48**	**2,54**	**14,81**	**51,01**	**3,52**
	sd	*4,26*	*0,29*	*5,40*	*60,14*	*45,78*	*5,02*	*35,05*	*6,73*	*2,45*	*0,06*	*4,88*	*4,66*	*0,31*	*1,28*	*8,43*	*0,48*
RDU2	**mean**	**17,43**	**8,54**	**12,38**	**134,70**	**405,75**	**22,92**	**243,28**	**21,19**	**6,06**	**0,07**	**31,28**	**17,50**	**2,70**	**14,78**	**51,97**	**4,38**
	sd	*4,70*	*0,29*	*5,41*	*62,45*	*50,23*	*10,87*	*28,45*	*5,84*	*2,40*	*0,11*	*4,38*	*4,64*	*0,18*	*1,11*	*8,39*	*0,11*
High water level																	
D1489	**mean**	**12,33**	**8,50**	**10,91**	**105,60**	**411,33**		**220,00**	**18,37**	**10,41**	**0,00**	**32,33**	**12,32**	**2,42**	**15,57**	**64,33**	
	sd	*4,97*	*0,20*	*3,34*	*40,91*	*36,02*		*0,00*	*0,00*	*0,00*	*0,00*	*0,00*	*0,00*	*0,00*	*0,00*	*0,00*	
RDU5	**mean**	**12,23**	**8,46**	**11,31**	**108,73**	**413,67**		**210,72**	**16,10**	**9,89**	**0,00**	**36,79**	**11,23**	**2,67**	**15,46**	**61,11**	
	sd	*5,18*	*0,14*	*3,80*	*46,88*	*36,15*		*15,28*	*2,64*	*0,48*	*0,00*	*4,16*	*1,36*	*0,18*	*0,03*	*1,09*	
RDU3.1	**mean**	**12,57**	**8,52**	**10,14**	**97,30**	**412,67**		**201,36**	**13,40**	**9,44**	**0,14**	**28,71**	**9,78**	**2,84**	**12,46**	**60,47**	
	sd	*5,37*	*0,19*	*3,11*	*37,73*	*36,57*		*0,00*	*0,00*	*0,00*	*0,00*	*0,00*	*0,00*	*0,00*	*0,00*	*0,00*	
RDU2	**mean**	**13,23**	**8,53**	**10,49**	**104,40**	**411,00**		**210,72**	**14,94**	**9,44**	**0,00**	**29,57**	**10,41**	**2,74**	**12,92**	**58,84**	
	sd	*6,04*	*0,25*	*3,46*	*46,03*	*36,18*		*15,28*	*2,34*	*0,36*	*0,00*	*1,25*	*1,06*	*0,09*	*1,00*	*1,99*	

3.1 Physical-chemical characteristics

At very low water levels (170-210 cm, measured at Baja) there is no water flow in the Rezéti-Danube. During such periods only the RDU2 and RDU3.1 sampling sites are accessible, as water is only present in the lower part of the side arm (Fig. 1). Conductivity, temperature, oxygen content and saturation of the water in the side arm are always higher than in the main river arm (Tab. 2). The content of suspended matter in the water is similarly two times higher than in the main arm. Due to the high content of suspended matter, transparency of the water is low. The depth of light penetration is about 1 meter, compared to 1.5-2 meters in the main arm (Dinka, unpublished data). Among the examined parameters, the concentration of NO_3^-, K^+ and Ca^{2+} ions differs significantly between the RDU and the Danube itself. In RDU the concentration of NO_3^- ions decreases with decreasing distance from the main riverbed.

In the low water period, there is a correlation between the content of suspended material and DOC ($Y_{DOC} = 0.0649X_{susp.matter} + 2.955$; R^2=0.6689).

At mean water level (385-430 cm, measured at Baja) the flow in the side arm is continuous, flow velocity increases together with water levels, while the retention time of the water decreases. The flow velocity in the side arm is about 40% of the flow velocity in the main arm. The temperature of the water in the side arm gradually increases with increasing air temperature and because of the longer residence time in the side arm, the water temperature is usually 1.5-4.0 °C higher than in the Danube (in winter the opposite effect can be observed, with lower temperatures in the side arm than in the main arm).

The conductivity and the concentration of NO_3^-, PO_4^{3-} and cations in the side arm are comparable with the values measured in the Danube (Tab. 2). At the beginning of the summer dissolved oxygen was 210% in RDU and 136% in the main arm and phytoplankton production was usually higher in the side arm, as a result of slower water flow and fluctuation in temperature and light conditions, occasionally accompanied with increasing pH and oxygen content in the side arm (Tab. 2) (Dinka, 2003; Kis,s 2005). Suspended solids were partly deposited in the side arm, resulting in an increase in the depth of light penetration compared to the main arm conditions (Dinka, 2003).

At high water levels (>500 cm, measured at Baja) the water flow is strong in the side arm. There were no significant differences in the examined water parameters between the side arm and the Danube, on the basis of examinded hydrochemical parameters, during the sampling period (Tab. 2). Light penetration was 2.0-2.5 meters in both the side arm and the Danube (Dinka 2003). The water flow carries away the lighter fractions of the sediment, thus

„cleaning up” the river bed, and inundating the floodplain, with the side arm becoming part of the flooded area.

3.2 Zooplankton

During our 3 years investigation (2002-2004) in the main arm (D1489) we recorded 12 Cladocera, 2 Copepoda, 1 Ostracoda and 32 Rotifera taxa, whereas in the side arm (RDU) 18 Cladocera, 9 Copepoda, 5 Ostracoda and 45 Rotifera taxa were found.

The zooplankton communities of the side arm differed remarkably in terms of abundance and diversity from the main arm. The same phenomenon was previously reported for the Danube, and also for the Rhine and the Meuse (Baranyi et al. 2002; Van den Brink et al. 1994).

At extremely low water levels, the abundance, species richness index (S) and Shannon-Wiener diversity index (H) of rotifer assemblages was higher, whereas the dominance index (D) was lower in the RDU than in the main arm (Tab. 3).

Table 3 – Ecological parameters of zooplankton assemblages at different water level

Site		Rotifera				Crustacea			
		Taxa *S*	Abund. *ind 100L^{-1}*	Shannon *H*	Dom. *D*	Taxa *S*	Abund. *ind 100L^{-1}*	Shannon *H*	Dom. *D*
Low water level									
D1489	**mean**	**3.8**	**925**	**0.90**	**0.50**	**4.8**	**40**	**0.98**	**0.52**
	sd.	*3.3*	*1480*	*0.69*	*0.31*	*2.9*	*46*	*0.66*	*0.30*
RDU3.1	**mean**	**4.7**	**9906**	**1.37**	**0.25**	**5.8**	**514**	**1.28**	**0.34**
	sd.	*3.7*	*7476*	*0.51*	*0.22*	*2.5*	*821*	*0.22*	*0.08*
RDU2	**mean**	**7.2**	**7785**	**1.58**	**0.25**	**5.6**	**538**	**0.99**	**0.49**
	sd.	*1.8*	*5682*	*0.29*	*0.07*	*1.1*	*706*	*0.38*	*0.20*
Mean water level									
D1489	**mean**	7.2	**4386**	**1.55**	**0.28**	**5.2**	**149**	**0.87**	**0.56**
	sd.	*2.6*	*5828*	*0.51*	*0.16*	*1.3*	*183*	*0.41*	*0.22*
RDU5	**mean**	**8.0**	**1945**	**1.73**	**0.22**	**4.3**	**80**	**0.92**	**0.49**
	sd.	*2.8*	*1566*	*0.43*	*0.11*	*1.9*	*171*	*0.41*	*0.22*
RDU3.1	**mean**	**7.3**	**1582**	**1.63**	**0.26**	**3.5**	**9**	**1.02**	**0.44**
	sd.	*2.7*	*1662*	*0.35*	*0.11*	*0.9*	*3*	*0.18*	*0.09*
RDU2	**mean**	**8.2**	**2821**	**1.65**	**0.26**	**3.8**	**12**	**0.97**	**0.49**
	sd.	*1.7*	*3004*	*0.31*	*0.13*	*1.8*	*8*	*0.55*	*0.28*
High water level									
D1489	**mean**	**6.5**	**340**	**1.71**	**0.21**	**6.0**	**16**	**0.27**	**1.51**
	sd.	*0.7*	*352*	*0.06*	*0.04*	*0.0*		*0.00*	
RDU5	**mean**	**7.7**	**323**	**1.84**	**0.18**	**3.0**	**16**	**0.52**	**0.72**
	sd.	*1.5*	*298*	*0.15*	*0.03*	*2.0*	*24*	*0.52*	*0.32*
RDU3.1	**mean**	**7.3**	**494**	**1.70**	**0.22**	**3.8**	**4**	**1.01**	**0.39**
	sd.	*2.5*	*404*	*0.24*	*0.03*	*1.4*	*2*	*0.45*	*0.16*
RDU2	**mean**	**6.0**	**277**	**1.57**	**0.24**	**3.3**	**5**	**0.40**	**1.03**
	sd.	*0.0*	*175*	*0.02*	*0.11*	*1.4*	*3*	*0.39*	*0.14*

The correlation between water level of the main arm and rotifer abundance in the side arm was negative (R: -0,81, t: -8,14, p: $6*10^{-9}$). In contrast, correlation between water temperature and abundance of rotifers was positive (R: 0,47, t: 3,10, p: 0,018). When water level is lower in the main arm, the slower flow in the side arm has less effect on rotifer assemblages. At higher temperature the reproduction is faster (Galkovskaya, 1987). The abundance of planktonic crustaceans was also higher in the side arm than in the main arm. The diversity and dominance indices for crustaceans were similar in the side arm and main arm. The abundance of rotifers was high both in the main arm and the side arm (Tab. 3) (Lair, 2005).

At mean water levels, the rotifer abundance was similar in the RDU and the main arm. The occasionally difference in abundance is low. The diversity indices did not differed significantly between the main arm and the RDU. The abundance of crustaceans was slightly higher in the main arm, but the diversity and dominance were similar. Rotifer abundance was always higher than crustacean abundance (Tab. 3). Abiotic factors like retention time and water temperature are the main parameters controlling zooplankton abundance (Zimmermann-Timm, 2007).

At high water levels, the zooplankton assemblages were similar in the main arm and the RDU. The abundance, diversity and dominance did not differ. Rotifers were more abundant than planktonic crustaceans (Tab. 3). The impact of biotic control decreases due to turbulence and advection (Baranyi et al., 2002; Pollard et al., 1998).

4. SUMMARY

The water characteristics and zooplankton assemblages were investigated at specific hydrological situations in the main arm and in the longest (15 km) side arm of the Gemenc floodplain. The flow trough the side arm can also have important effects on zooplankton communities of the main arm, as the side arm can act as an inshore retention area (Hein et al., 1999).

At low water levels in the Danube (170-210 cm), the side arm (RDU) has a lentic character, the retention time is longer. Due to the increasing importance of local effects, differences with the main arm can become significant (Dinka, 2003; Berczik & Dinka, 2005; Van den Brink et al., 1994). The favourable conditions lead to eutrofication. Accordingly the concentration of suspended matter is high, while the concentration of nutrients decreases because of the higher phytoplankton biomass (Dinka et al., 2006; Kiss, 2005). Zooplankton abundance in the side arm is higher than in the main arm, due to the absence of flow and the increased availability of food (Schöll, 2006; Zimmermann-Timm, 2007).

At mean water levels, the flow in the side arm becomes faster and the retention time decreases. The production in the slow flowing side arm is higher than in the main arm, but high trophity and low water transparency does not occurr. Zooplankton abundance is higher in the side arm than in the main arm, but the differences in diversity are low.

At high water levels (>500 cm) the retention time in the side arm is short, the water begins to inundate the floodplain. The differences between the main arm and side arm are low, caused by the „homogenizing” effect of the flood (Thomaz et al. 2007).

The fluctuations of hydrological-biological interactions highlight the high spatio-temporal variability of the floodplain. The hydrological, chemical and biological relationships of the side arm are essentially determined by the water level of the Danube (Heiler et al., 1994; Hein et al., 2004).

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RIPARIAN VEGETATION, STAKEHOLDER USES AND MANAGEMENT PRACTICES: ELEMENTS FOR RESTORATION BASED ON EXPERIENCES FROM THE AYUQUILA WATERSHED, MEXICO

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ABSTRACT

Riparian vegetation in the Ayuquila watershed is highly degraded, especially in the agricultural floodplains, where most of it also has been eliminated. Degradation is caused by agro-industrial farming practices (especially sugarcane and livestock production), deforestation and municipal sewage system inflow. The main goal of the project is to characterize both local ecological conditions and stakeholder uses and management practices of the riparian zone, and to develop a restoration program in priority riparian zones, all to be considered as small-scale experimental sites.

Thirty-six riparian fragments (600 m^2 each) along 90-km of the Ayuquila river were sampled. In addition, interviews of the farmers about their management actions indicated they actively use and manage riparian zones, with different intensity depending on stream and bank width as well as agricultural production methods.

The results of the riparian assessment and interviews were used to develop on-going restoration activities. Priority plant species for restoration were identified using a scoring system based on tree plant diversity, structural components, and farmer use and preferences. Ten experimental plots were established on the riverbank zones, planting selected tree-species and involving surrounding farmers. The paper concludes with a discussion of the possibilities and challenges for restoration in the Ayuquila watershed from the sustainability perspective.

Key words: Riparian vegetation, socio-ecology, restoration, Ayuquila watershed.

1. INTRODUCTION

Nowadays, it is recognized that watersheds all over the world are subjected to strong anthropogenic pressures, often resulting in natural resource degradation, water pollution, biodiversity loss, land productivity reduction, increased vulnerability to drought and flood events, increased risks of natural disasters and loss of quality of life. In Mexico, such conditions occurs as well, and today a lot of attention is being given to restoration with combined production and conservation objectives, as part of the sustainable management of watersheds (Martínez, 1992). Based on our long-term experience in western Mexico, it has become clear that restoration initiatives within a watershed require an understanding of both ecological and related social aspects (Ortiz-Arrona et al., 2004; Martínez et al., 1999). At the same time, it is also important to consider landscape interactions between highlands (where the water is produced) and lowlands (where water is used for domestic needs, industry, and agriculture, and other uses).

This research addresses restoration activities from a socio-ecological perspective, based on an ongoing research project in the Ayuquila watershed. The Ayuquila is a highly degraded watershed, especially in the agricultural floodplain, where most of its natural vegetation has been eliminated. Degradation is caused by agro-industrial farming practices –especially sugarcane and livestock–, deforestation and municipal sewage water releases. The main goal of the project is to characterize both local ecological conditions and stakeholder use and management practices of the riparian zone to develop a long-term participatory restoration strategy for the Ayuquila watershed.

2. STUDY AREA

The Ayuquila-Armeria watershed is located in the states of Jalisco and Colima, in western Mexico, with a surface of 3900 km² and a length of 150 km. It is considered the second most important river in the state of Jalisco for its biodiversity, as source of drinking water and irrigation, as well as due to the presence of the Sierra de Manantlan Biosphere Reserve (SEMARNAP, 2000; CONABIO, 1999). Our study area, that lies in the middle of the Ayuquila watershed, is formed by ten municipalities, and located at approximately 900 m above sea level (Fig. 1).

A high complexity of environmental conditions characterizes the watershed, due to variations in altitude and relief. Seasonally dry tropical forest is the dominant forest type associated with the river and its tributaries. The Ayuquila River is especially important for the conservation of aquatic fauna (fishes, crustaceans, reptiles and mammals), including endemic and threatened species, such as the otter (*Lontra longicaudis*) (Santana et al., 1993). Fishing is an important economic activity for the watershed's rural communities.

The current, degraded state of the Ayuquila River is caused by human activities such as water storage and diversion, channelization, irrigation of the agricultural fields –mainly sugarcane-. Discharge of the urban and industrial –sugarcane- residual water into the river is one of the main problems; however, the improvement of the sewage systems has been recently included in the municipal agendas. Another immediate threat to the river is the elimination of the riparian vegetation and clearing of native vegetation from steep slopes within the watershed. The riparian vegetation is highly degraded, especially in the agricultural floodplains, where most of it has been eliminated.

Socio-economic and political conditions are also complex; the lower part of the watershed is formed by ten municipalities with a total population of about 120,000 inhabitants. About 60% of the population lives in the cities of Autlan and El Grullo, the two main agriculture-industrial urban centers in the valleys, and the rest is dispersed between small communities (Gerritsen et al., 2005). The subsistence farming communities in the lower valley are dependent on the river and disproportionately impacted by the water pollution that originates upstream.

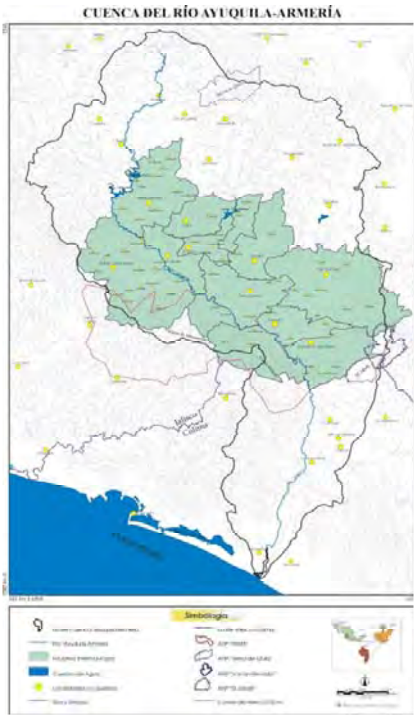

Figure 1 – Location of the Rio Ayuquila watershed, western Mexico.

3. RESEARCH DESIGN

The design of our project is based upon three components: 3.1) ecological characterization along the Ayuquila river, 3.2) farmer´s use and management of the riparian areas and 3.3) on-farm reforestation initiatives.

3.1 Ecological characterization

Thirty-six riparian fragments (600 m^2 each) were sampled along a 90- km segment of the Ayuquila River flowing between the Municipalities of La Laja (upstream of the Corcovado diversion dam) and La Taza, downstream of the confluence of the Ayuquila and Tuxcacuesco rivers. This segment of the Ayuquila-Armeria River has been monitored for water quality since 1996 (Martinez et al., 1999). The river corridor was divided into two stream reaches: valley and mountain. Sampling sites were established close to water quality monitoring points, where vegetation appeared well preserved and the area was accessible.

All woody vegetation over 2.5 cm diameter was identified, for each plant the height was estimated, and the distance from the riverbank and vigour recorded Seedlings of woody vegetation were also counted within the sampled area. General data collected included slope, aspect, wetted width of the river, width of riparian vegetation, approximate width of floodplain, and degree of use by people and livestock, the latter estimated from the visible signs of grazing and soil compaction. The Shannon- Wiener diversity index ($H^{'}$) was applied. The Jaccard´s coefficient was used to measure species similarity among landform classes (reaches).

3.2 Use and management of riverbank vegetation

During the same period of the riparian vegetation assessment, 75 farmers who were owners or users of riparian parcels were surveyed. Information collected in the survey included land tenure, agricultural activities in riparian areas, perception of the river and riparian vegetation, and interest in reforestation.

3.3 On-farm experiments

As a result of the vegetation assessment, ten experimental plots of about 2,000 m^2 each were established on the riverbank zones, planting selected tree- species and involving surrounding farmers.

4. RESULTS

4.1 Ecological characterization

The riparian corridor of the Ayuquila River and associated tributaries shows differences with respect to vegetation diversity and structure. A total of 118 woody plant species were recorded. Leguminosae family was predominant. *Salix humboldtiana*, *Asthianthus viminalis* and *Phitecellobium dulce* were the most abundant and frequent woody species. Three species with special status were recorded: *Enterolobium cyclocarpum, Sideroxylon capiri,* and *Guaiacum coulteri.*

The highest diversity was found along the Manantlan, a tributary river and Zenzontla ($H^{\prime}$: 2.9). Other sites with good diversity were El Guamuchil ($H^{\prime}$: 2.5), La Taza and La Yerbabuena ($H^{\prime}$: 2.4). These sites are less impacted by human activities due to their difficult access, location in little-populated areas, and either have a more natural hydrological regime, or have fences that exclude cattle and other human impacts. In general, the more diverse sites were found on steep slopes, with the exception of site La Yerbabuena, a fenced site that is one of the only remnant patches of riparian forest on an unregulated tributary in a wide agricultural valley. Despite sharing similar geomorphology and location within wide valleys, site El Aguacate and La Yerbabuena have no similarity. The latter is the fenced site with highest diversity.

Certain structural attributes of the riparian vegetation, specifically the presence of large, abundant and diverse tree species, could indicate desirable ecosystem functions, such as ability to reduce water temperature by shading the river, create habitat for wildlife, increase landscape diversity, and provide areas where the local people can recreate. Some of the species with these characteristics were *Asthiantus viminalis*, *Salix humboldtiana*, *Ficus insipida*, *Enterolobium cyclocarpum* and *Phitecellobium dulce*. Some species like *Brosinum alicastrum* -a very valuable non-timber specie in the region- , *Vitex mollis* and *Guaiacum coulteri* were lees common or rare.

4.2. Use and management of riverbank vegetation

Farmers use and manage riparian zones actively. The study shows that the interplay of social and physical factors influences the farmers' mode of production. As a consequence, there are fewer opportunities for sugarcane cultivation in surrounding slopes than in the valley Autlan –El Grullo; farmers living on the slopes are more oriented towards livestock production, and therefore their activities impact riparian vegetation differently. The farmers with livestock on the slopes make use of the riverbed and riverbank for pasture for their cattle and trees are useful for the shade, fodder, pole wood, and firewood they provide. In the sugarcane valley, the burning of the plants before harvesting often causes the destruction of trees on the riverbank.

In general, six factors that influence the use, management and conditions of the riverbank vegetation can be identified (Snoep, 2004): the width of the riverbed and riverbank, the slope of the riverbank, transformations in agriculture, diversification of agricultural practices, channelization and irrigation of the agricultural fields and the overall farming objectives. Regarding the farmers´ perception, they consider important to conserve the vegetation of the riverbanks. The main reason is the protection of the products and services they deliver. Another reason is the belief that the presence of vegetation attracts the rain.

4.3 On-farm experiments

Research results were used for developing on-going restoration activities, and a scoring analysis to select priority species. This scoring analysis was based on the following social and ecological criteria: 1) usefulness of the plant to farmers, 2) species protected by farmers, 3) preference for planting, 4) usefulness of the plant to wildlife and ecological criteria: importance value due to abundance, frequency and dominance, and 5) special status as a threatened or endangered species.

Table 1 – Priority species for reforestation based on socio-ecological aspects (Rodriguez, 2006)

Species	Social aspects				Ecological aspects		Level of importance
	Used and managed by farmers	Protected by farmers	Preference for planting	Important for wildlife (farmers opinion)	Structural characteristics (Index)	Protected or threatened	
Enterolobium cyclocarpon	1	1	1	1	1	1	6
Pithecellobium dulce	1	1	1	1	1	0	5
Salix humboldtiana	1	1	1	1	1	0	5
Tabebuia chrysantha	1	1	1	0	1	1	5
Ficus insipida	1	0	1	1	1	0	4
Acacia farnesiana	1	1	0	1	1	0	4
Brosinum allicastrum	1	1	1	1	0	0	4
Asthianthus viminalis	1	1	1	0	1	0	4
Sideroxylon capiri	1	1	0	1	1	1	4
Guaiacum coulteri	1	1	0	0	1	1	3

As part of the on-farm experiments, fourteen experimental plots of about 2,000 m^2 each were established on the riverbank zones. Planting was done using about 9 woody native species (Tab. 1) and involving surrounding farmers. Seedlings were produced in the region using seed or vegetative segments. The seed planting period occurred during the rainy season (at the beginning of July) and the planting of stakes after the rainy season (October-November) to avoid loss by flooding. Weeds were controlled on all planting plots during the first and second year. Survival and growth of plants were monitored to assess species performance. Finally, reforestation activities were coordinated with environmental education groups to facilitate the participation of volunteers.

5. CONCLUSIONS

Due to the specific characteristics of our project, basic and applied ecological and sociological knowledge now serves as a scientific base for the design and implementation of restoration activities in Ayuquila watershed. Our results indicate that ecological and sociological heterogeneity should be considered as starting points for defining restoration strategies. Factors such as species selection and preferences, plot design, and stakeholder rights and responsibilities in the follow-up phase should be discussed with the involved local stakeholders. In this respect, on-farm experiments serve to generate information about responses of the species and how to involve farmers into the project. However, a strategy is needed to protect intact, functional riparian fragments that still exist as these sites are important as reference sites and for monitoring ecological processes.

ACKNOWLEDGEMENTS

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MATCHING THE NEEEDS FOR THE EUROPEAN BLACK POPLAR (*Populus nigra* L.) GENE CONSERVATION AND RIVER RESTORATION: CASE STUDIES IN ITALY, BELGIUM AND GERMANY

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ABSTRACT

Riparian forests are among the most important habitats along river stretches and European black poplar is probably the most representative tree of the old European natural floodplain forests. As a result of many centuries of exploitment, severalof freshwater habitats have disappeared and the natural tree composition has often been replaced by more productive hybrid poplar stands. Therefore *P. nigra* is considered on the verge of extinction in Europe, and that many programs have been undertaken to protect its germplasm and to implement conservation strategies (EUFORGEN Programme, Scattered Broadleaves Network). Black poplar is extremely important to restore riparian woodlands as natural corridors. It is a better pioneer species than willow, being heavily dependant on the hydro-morphological processes of the river for its natural regeneration, well-adapted to the water dynamics, and able to colonize bare, moist soils on river banks through seeds, cuttings or root fragments. Therefore, black poplar plays an important role in the initial stage of development of floodplain forests. River restoration projects aiming to restore riparian habitats contribute to create new opportunities for the survival and conservation of the species. Three case studies of black poplar rehabilitation projects are discussed: one along the river Po in Italy, one along the river Meuse in Belgium and one along the river Oder in Germany. The results can be used in other similar situations by riparian ecosystem managers.

Key words: River restoration, *Populus nigra*, gene conservation, riparian forests, introgression, EUFORGEN

1. INTRODUCTION

The restoration of floodplain forests is one of the main objectives of river restoration projects, not only for natural flood control but also because the river banks serve as corridors through which larger forest areas are connected. The European black poplar, *Populus nigra* L. (Family Salicaceae), is a tree of ecological importance as a key species in the development of riparian woodlands. Poplars initiate the hydromorphological processes of island formation and riparian forest development and they host a large number of threatened and common species that are associated with poplars or depend on them (Rotach 2003). Nonetheless, due to the alteration of its natural habitat, overexploitation and potential gene flow with cultivated relatives, black poplar is considered on the verge of extinction in Europe. Many initiatives have been undertaken to protect its germplasm and to implement conservation strategies (EUFORGEN Programme, Scattered Broadleaves Network) (Smulders et al., 2008).

Several river restoration activities have recently begun in many European countries which contribute actively to the conservation of the European black poplar and the restoration of floodplain forests. Restoration and reforestation projects have been carried out recently on the Morava River (Czech Republic) (Pospiskova and Salkova, 2006), the Common Meuse River (Belgium), the Oder River (Tautenhahn et al., 2007), the Rhine and Elbe rivers (Germany) and the Po River (Italy) (Vietto and Chiarabaglio, 2004). We discuss here several practical aspects related to black poplar restoration actions carried out in Italy, Belgium and Germany, such as the choice of the plant material, site preparation and planting, management strategies and limitation of the risks of inbreeding and gene introgression. These experiences provide useful technical recommendations on how to restore floodplain forests using native poplars. These recommendations might be used in other similar situations by riparian ecosystem managers.

2. GENERAL SETTING

2.1 The Po River

The Po River originates at 2022 m. a.s.l. on the slopes of Mount Monviso in the Cottian Alps in northwest Italy near the French border; it runs eastwards past Turin, Piacenza, Mantua and Ferrara, and flows into the Adriatic Sea (Fig. 1). As well as being the Italian longest river (652 km long, with 141 tributaries), the Po has the most densely populated basin of Italy: a total of 15.764.600 inhabitants live in its basin, the greatest density being in the region south of Milan metropolitan area. The Po River is characterized by complex and varied hydrogeological conditions and shows a snow-melt and rain-fed mixed regime, with discharge peaks in spring and autumn. The restoration activities have been carried out on the upper-mid Po River catchment, in the Piedmont, a region dominated by the Alps which are close to the Mediterranean Sea and thus determine a complex climatic and hydrological regime. The upper basin is characterized by a number of fast-responding tributaries from the Alps and the Apennine, whereas the lower basin is moderately flat, with meandering, wide floodplains, sandy and cobbled river bed. The soil is alluvial, unconsolidated, sandy and gravely, with neutral pH and it is often subject to partial or total flooding during autumn and spring. The restoration site on the Po River has a temperate/sub-humid climate; the annual average temperature is 12.7 °C with 827 mm/year rainfall, with minimum values in summer. This area was affected from repeated changes due to fluvial forces which caused erosion and sedimentation over the entire area.

Figure 1 – The Po River catchment and the Po River Fluvial Park area.

2.2. The Meuse river

The river Meuse originates at an altitude of 409 m above sea level on the plateau of Langres in the northeast of France and, after running for about 900 km, discharges into the North Sea in the Netherlands (Fig. 2). The Meuse is typically rain-fed, with a resulting regime of low flows in dry periods and high flows in periods with strong precipitation, mostly in winter time.

Figure 2 – The Meuse river catchment and the Common Meuse area.

This study focuses on the Common Meuse reach, the free-flowing middle course of the river where the river forms the natural border about 50 km long between Belgium and The Netherlands. Here the river consists runs on a gravel substrate with a loamy alluvial cover. The river Meuse arrives in this section from the south of Belgium, it is forced into a narrow valley with high rocky slopes which widens again in the Common Meuse with a width varying from 300 to 2500 m. The floodplain was traditionally used in agriculture as meadows. Despite the absence of flow regulation and navigation on the Common Meuse river stretch, bank reinforcement and former gravel mining in the river bed resulted in a strong decline of the morphological activity and of bars and islands (Micha and Borlée, 1989).

2.3. The Oder river

The river Oder originates in the Czech RepublicT, flows through western Poland, forming 187 km of the border between Poland and Germany, and discharges into the Baltic Sea (Fig. 3). It is a predominantly rain-fed river. The study area is located in the floodplain of the lower stretch of Oder River in the Brandenburg Federal State, and is part of the Lower Oder Valley National Park which extends in the floodplain of 35 km long river reach. This floodplain area is disconnected from the river by dykes creating a polder system. Most of the floodplain is artificially flooded annually from November 15th until April 15th by weirs in the dykes. During the last century and due to hydraulic management including river channelization and dyke construction, the original length of the river and the natural flooding area were reduced by 22.7% and 23%, respectively. Nowadays, the Oder River is characterized by unnatural short and high floods and periods of very low flow accompanied by low water table levels (LUA, 1998).

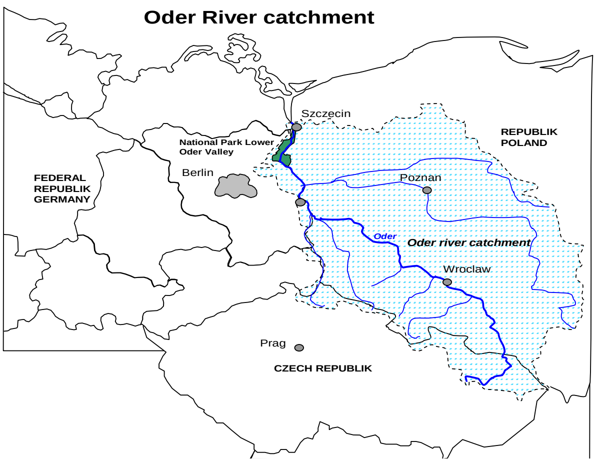

Figure 3 – The Oder river catchment and study site (green colour).

3. RIVER ASSESSMENT AND RESTORATION STRATEGIES

The objective is to establish black poplar stands that are able to produce seeds of good genetic quality and quantity in order to initiate regeneration and contribute to the evolution of local genetic resources and conservation of the species. Restoration of black poplar riparian populations have been carried out on three European rivers stretches representing three different situations:

1. a site where the current river dynamics produce favourable conditions for black poplar regeneration, but where there is a lack of significant mature trees Po River);
2. a site with lack of ecosystems dynamics and lack of significant adult trees to produce seeds (Common Meuse River);
3. a site with lack of ecosystems dynamics but with presence of scattered flowering trees (Oder River).

3.1 The Po River case study

Ever since the Hydro-Geological-Settlement Plans was adopted in 2001, the river has been considered as an organic unit and the general objective was: i) to guarantee the entire Po River basin an adequate level of security from hydraulic and hydro-geological damages by restoring hydro-geological and environmental balances, river banks and water ecosystems, ii) provide solution for flood defence through, stabilization and consolidation of land, iii) restorate an adequate level of security as regards hydraulic and hydro-geological damages fluvial areas for recreation.

The site on the Po river is classified as “A zone” (i.e. land where normal flood flows) and it is included in zones with severe limitation of agricultura activities. It suffered from continuous changes due to fluvial forces which caused erosion and sedimentation over all the area. Floods that occurred in 1993, 1994 and 2000 had disruptive effects on agricultural land; erosion created deep gullies, holes and deposits of gravely material. As a result of floods the area is heavily infested by exotic species such as *Sycios angulatus*, *Heliantus tuberosus*, *Solidago gigantea* and *Humulus scandens*.

Historical and naturalistic records demonstrate the presence of oak and elm together with native poplars, willows, hazel and ash. In the studied river stretch, native poplars are very scarce. During the last century, natural environments were substituted by gravel mining and specialised poplar cultivation. Since the last years, rice cultivation covered the surrounding areas resulting in the pollution of the water table with nitrates and residual pesticide compounds.

Since 2000, the CRA-PLF together with State–run organizations like the “Parco Fluviale del Po tratto vercellese/alessandrino e Riserva naturale dell’Orba” (Po River Fluvial Park) carried out several pilot trials to convert areas dedicated to conventional crops or poplar cultivation into floodplain forests and to recover areas previously damaged, on the upper part of the Po River basin; activities related to the EUFORGEN strategies (Lefèvre et al., 2001) are still in progress.

The main aim of the project is restoring floodplain forests for recreational purposes, and to contribute actively to the conservation of native poplars genetic resources, black poplar in particular, creating a network of artificial in-situ gene conservation units to support a dynamic evolutionary process in a short time. These "minipopulations" once they have been created on suitable habitat conditions, may serve as founders to establish new populations over rather large distances, as a source for gene flow into neighbouring natural stands, and lastly as a seed sources for material used for restoration activities. Genetic, demographic and ecological factors have been considered for restoration. In particular, the origin of the material available in national collection (adaptation to local environmental conditions), the genetic variability (proportion of unrelated genotypes, number of pollen donors, balanced sex-ratio), the pattern of planting (mosaic of clonal plots and clonal mixtures); the high number of trees are all factors which will limit the inbreeding level and increase the likelihood of effective regeneration. Over 6400 black poplar poles have been planted in three main sites, Crescentino, Valenza and Palazzolo (Fig. 4); from 2000 to 2008, 24 hectares were restored via pole plantings; over 43000 poles and seedlings of *P. alba*, willow, hardwood and shrubby species were used to afforest more 30 hectares. Maintenance procedures included sheltering the trees, mechanically controlling the weeds and were conducted during the first 2-3 years to ensure planting success (ranging around 80% depending on the soil conditions and summer droughts).

Figure 4 – Overview of a restoration site on the Po River (Palazzolo).

3.2. The Meuse river case study

Severe flood events in the Common Meuse valley during two consecutive winters of the mid-nineties caused a lot of damage to houses, industries, agriculture and infrastructures. These events stimulated the development of a transboundary river restoration plan for the Common Meuse that was adopted by an international Commission in May 1995. This transboundary master plan aims to stop further degradation of the floodplain natural heritage and to minimize the risks of flooding for the local people. The main objective is to create a wide

riparian forest corridor, allowing the development of natural river banks, gravel bars, forested islands (willow and poplar woodlands) and restored floodplain meadows and forests (Van Looy, 2006). Current activities include bed widening, bank lowering and side channel reconnection.
The restoration of the river dynamics along the Common Meuse will provide new opportunities for the black poplar, one of the most endangered forest trees in Belgium. Natural black poplar populations have disappeared completely along the Common Meuse valley and the species is represented only by ten scattered, very old relict individuals. Due to lack of gene flow between these last individuals combined with the presence of introgressive hybridisation with cultivated poplars, black poplar is susceptible to extinction in the Common Meuse valley (Vanden Broeck et al., 2004). In order to prevent the extinction of black poplar, a reintroduction programme was started up following the technical guidelines produced by EUFORGEN (Lefèvre et al., 2001),

Figure 5 – Restoration activities on the Meuse river.

The project started in April 2002 and a reforestation programme is still ongoing. A total of 600 trees were planted over 2 ha.. Success rate varied between 20 and 80 % depending on the water availability in the first growing period. Plant material originated from the national gene bank collection, controlled crosses with local material and with populations from neighbouring regions. In winter 2008 a new area of about 15 ha will be restored with black poplar on the same river reach. Management measures will include re-planting of poorly growing or dead clones, new additions from the gene bank and from neighbouring regions and removal of unsuitable clones due to the threat of introgression. Cultivated non-native poplars including *P. nigra* cv. *Italica* that are present in the nature development area will be removed to limit the risks of introgression. New restoration sites of black poplar will be established in order to create a network of different restored patches of different age, scattered across the river. In this way, the exchange of genes between restored populations by pollen or seeds should be made possible and the risk of loosing a restored population through a single catastrophic event is limited.

Management measures such as thinning will be carried out if necessary in order to promote flowering. When the first offspring will be created from the restored populations, genetic analyses will be carried out to check the quality of the seedlings and to monitor introgression.

3.3. The Oder river case study

Black poplar is an endangered species in Brandenburg as well as in Germany. Because of the degradation of rivers and catchment areas, the residual black poplar stands on the German side (westbank) along the Oder river are estimated to consist in no more than 1.000 individuals, most of which (400) are located on the southern part of the Kuestrin-Kietz island. Their age is estimated to be 50-60 years (Joachim, 2002). So, due to both the age of the trees and to the lack of natural regeneration, the existence of the population is highly endangered (Kätzel et al., 2005); the same situation occurs in the Lower Oder Valley where only a few mature trees remain. The main cause is the loss of river dynamics which results in lack of open areas suitable for seed germination. Other relevant factors are, the extreme fluctuations of the groundwater level in the floodplains after spring flooding, and cattle's grazing on trees and shrubs.. Based on a scientific study, a technical guideline for floodplain forest restoration was compiled (MLUR, 2003) which identified a total area of 53.1 hectares suitable for black poplar restoration.

The project "Initiation of floodplain forest with black poplar (*Populus nigra*) in the Lower Oder Valley National Park" has been set up in cooperation between the Landesforstanstalt Eberswalde, a Brandenburg state forestry institute responsible for protection of endangered tree species, and the Lower Oder Valley National Park Administration, responsible for restoration of floodplain forest on the Oder.

The project was carried out from January 1st 2005 to June 30th 2007 by Stiftung Wald in Not (supervision, funding), Landesforstanstalt Eberswalde (administration, genetics, scientific contribution), Nationalparkverwaltung Unteres Odertal (support, ecology, scientific contribution), Naturschutzfonds Brandenburg (field work, maintenance) and Deutsche Bundesstiftung Umwelt (funding).

The aim was to combine in-situ conservation of autochthonous black poplar and floodplain restoration into suitable ecological settings to support natural regeneration.

Over 4000 black poplar poles and seedlings (half-sib families from relict mature trees) were planted in four places(16 hectares of restored area) in 2005 (Fig. 6). After planting, management and cultivation practices were carried out (fencing, weed control, watering), and success rate was around 50% after the first year.

Figure 6 – Planting black polar on the Oder floodplain.

5. CONCLUSIONS

The results of the three case studies show that native poplars can be successfully used in restoration of floodplain forests, which are considered to be one of Europe's most threatened natural ecosystems. Black poplars can be successfully planted in fluvial ecosystems and floodplain forests can be re-established over a short time period. Particular attention should be paid to the genetic origin of the plant material, site preparation, after planting care, (weed control, fencing), water availability and potential introgression with cultivated hybrid poplars. Reforestation activities result in artificial populations that act as a seed-source and might contribute to the dynamic gene conservation by supporting (semi-) natural regeneration in appropriate sites. In this way, they contribute in a positive way to the evolutionary potential of the species by improving genetic connectivity of isolated populations in a fragmented landscape via pollen or seed transport.

However, conservation activities of black poplar will never be successful when the conservation of its associated habitat is not considered. For the long term survival of populations, the suitable habitat and environmental conditions for seedling establishment should be available. It is therefore important to combine reforestation activities with river restoration. In flooded environments characterized by the presence of invasive infesting species, the final results of reforestation can only be guaranteed by cultural operations over the first three years after planting.

The importance of international collaboration is becoming more and more apparent, both for exchange of genetic material and of field experiences.

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THE MOSAIC EVALUATION SYSTEM (MOS.E.S): A GIS BASED TOOL TO SUPPORT FLOODPLAIN RESTORATION

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ABSTRACT
Many rivers and floodplains have been modified where urban and industrial areas and agricultural land has replaced riparian forest. River restoration is not just a question of enhancing the river channel: it must include the floodplain system as a crucial part of the river ecosystem, as it performs several functions such as flood mitigation, nutrients reduction, ecological corridor, biodiversity niche.

The understanding of the structure and functioning of a floodplain needs a specific tool that can evaluate, manage and restore a part of territory which is often a combination of natural, semi-natural and artificial patches. The Mosaic Evaluation System (Mos.E.S.) is a useful decision support tool for planning and assessing floodplain restoration plans.

Mos.E.S. is a GIS based assessment method of the fluvial corridor which can interpret and elaborate land-use maps and field survey data. Land cover analysis associated with restoration potential coefficients produces thematic mosaic maps that highlight the vulnerability and strength of the territory and the most suitable areas for floodplain restoration. Mos.E.S can be also applied in post-restoration evaluations to carry out a cost-benefit analysis and a success evaluation The method can be used at different scales from a stream reach to the whole length of a river as the mosaic tile dimension can be chosen to match the aims of the project. Mos.E.S. was successfully applied to several river and wetland restoration projects and a case study will be used to demonstrate the applications and effectiveness of the method.

Key words: river restoration, G.I.S. tool, floodplain, project evaluation

1. INTRODUCTION

Territory fragmentation caused by human intervention has produced “several natural islands” that are often surrounded by quite altered areas. This process can be particularly noticed along rivers where the riparian forests have been drastically reduced. The EU Habitats Directive in fact (92/43/EEC) includes in the natural habitat of community interest:

- Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* (*Alno-Padion, Alnion incanae*, *Salicion albae*)
- Riparian mixed forests of *Quercus robur, Ulmus laevis* and *Ulmus minor, Fraxinus excelsior* or *Fraxinus angustifolia*, along the great rivers (*Ulmenion minoris*)

Anthropogenic alternation of river corridors and floodplains significantly modified the structure and function of landscapes and led to extensive loss of wetlands (Burt, 1997).
It must also be highlighted that the floodplain is a valuable ecosystem that can support high biodiversity, especially in large floodplain rivers (Naiman & Decamps, 1997), protect the main channel from temporal changes and large disturbances (Whiting & Pomeranets, 1997), and provide refuge and food for wildlife (Negri, 1997).
Because restoration processes are in most cases artificial, the results depend from the skills of the planners and the degree of human interference with the natural context of a floodplain wetland. Mitsch and Gosselink (2000) therefore proposed two fundamental concepts for restoring wetlands: understand wetland ecology and minimize artificial input. In addition, ecological restoration in riparian systems should attempt to reconnect the organisms and their environment. In other words, the restored floodplain wetlands should fit the regional context of landscape and land use development (Siligardi et al., 2005).
Finally, to ensure that the restored floodplain wetlands are functional and self-sustaining, restoration plans should be integrated with the economic, political, and cultural viewpoints deduced from local to state-wide collaborations.
There is often a lack of financial resources for river restoration scheme and, as the EU life project "Wide Use of the Floodplains" (www.floodplains.org) has described, a lack of guidance on methods for evaluation of the effects of restoration and management options.

2.1 Indexes based on land use information: a brief overview

Landscape ecology is the science and art of studying and improving the relationship between spatial pattern and ecological processes on a multitude of scales and organizational levels (Wu 2006, 2008; Wu & Hobbs, 2007). To understand the distributions of plants and animals in a landscape, it is important to understand how they interact with each other, and with their environment. The resulting networks of interactions make the ecosystems highly complex. The complexity of the territory can be assessed using relevant and suitable indexes that normally include land cover data, vegetation and fauna information. An example on a European scale is the Net Landscape Ecological Potential, that is a macroindicator derived from Land and Ecosystem Accounts (European Environment Agency, 2006). Spatially distributed over 1 km² grids, NLEP enables connecting ecological potentials and human pressures via land use, and detect impacts in a systematic way. There are several other indices that can have a valid application around Europe (Blaschke & Petch, 1999; Gergel et al., 2002; Herzog et al., 2001) but there are just few examples of specific tools that are designed for river, floodplain and wetland restoration (Rohde et al., 2004; Brooks et al., 2006).

2. PAPER OBJECTIVES

The aim of this paper is to describe a GIS-based tool that, alongside other methods and evaluations (of biological, economical and social issues) can bring a clear understanding of the ecological potential of the floodplain, supporting decision making and planning processes. In the flowing chapters we will show how the Mosaic Evaluation System (Mos.E.S) can determine the most important ecological areas of a very fragmentised floodplain, and give clear maps of the most environmental values to be restored.

3. THE MOSAIC EVALUATION SYSTEM (MOS.E.S)

3.1 Introduction

Basic site characterization and data collection are the first steps in inventorying a river and its floodplain. Characterization may include information on water quality, geochemistry, hydrology, fluvial geomorphology, substrate condition, flora, and fauna, and, to the greatest extent possible, identification of stressor sources in the watershed. All this information must be categorized and summarized in an accessible and understandable way for the decision making process and for all the stakeholders involved in the restoration scheme. (HarmoniCOP, 2005)

Floodplain land use can be surveyed using appropriate land cover data (such as Corine) and with site visits. The land use map, divided in different categories according to the types of cover, can not easily display the strength and the weaknesses of the territory. In fact, different cover typologies are very patchy and not homogeneous, and it may be difficult to identify the areas which are more suitable to be restored. For this reason, a method was developed that can help to prioritize the river restoration using the land use cover information.

3.2 Method description

The Mosaic Evaluation System (MOS.E.S) is inspired by the botanic value map used by the Park and Forest Service of the Autonomous Province of Trento (1996) and the wetland classification produced by the Natural Historic Museum of Verona (1982).

M.O.S.E.S is based on the GIS technology. Firstly a 50x50m square grid is superimposed on the land cover map. The grid dimension may change according to the dimension of the river and the area investigated. For each square, the percentage of area of every single cover type is calculated. A potential value, based on the natural state of the river and its ecological role and defined by an expert judgment is assigned to each cover category. These values (potential coefficients) vary from -3 and +3. The negative values are assigned to cover types that may negatively influence river restoration schemes such as agricultural or urban areas. An example of these potential values is showed in the following table:

Table 1 – Example of potential corfficients associated to cover types

Cover type	Potential coefficient
Macrophytes	3
Reeds	3
Riparian trees	3
Riparian bushes	2
Other vegetation	1
Grass	0
Soil	-1
Poplar cultivation	-2
Urban areas	-3
Agricultural areas	-3

Of course, it is possible to add new cover types, according the land use map and the field surveys of the site. The calculation of the potential values follows this procedure:

For each square:

$PVi = \Sigma i(\%cover_i * pc_i)$

Where:

PVi = potential value for the i-square
%cover = percentage of the i-cover type of the total area
$pc_{i:}$=: potential coefficient for the i-cover type

The calculation is repeated for each square that is part of the investigated river. The final score may vary from -3 to +3. Each square tile is then associated a river restoration potential score. The score is divided in 4 different classes as it is shown in table 2.

Table. 2: The restoration potential is divided in 4 classes. The cell colour corresponds to the layout of the tiles in the mosaic map (see fig. 2)

Restoration potential class		
Potential score	**Judgment**	**Brief description**
3.00 – 1.50	High	The area already has important ecological elements. The restoration requires small intervention and limited measures.
1.50 – 0.01	Sufficient	The area has some ecological elements (i.e. riparian vegetation, small wetlands, reeds) that must be integrated with measures to improve the general habitat value and diversity.
0 – -1.51	Scarce	The area contains just few ecological elements. The restoration scheme may require great intervention and measures.
-1.50 – -3.00	Bad	The area does not have any interesting ecological elements .It is required a total restoration of the site

The final result of this procedure is a restoration potential map which looks like a mosaic – hence the name Mosaic Evaluation System (MOS.E.S). The map highlights (with the colours seen in tables 2) the areas where the river and its floodplain have already a certain ecological quality and where it is probably more worthwhile to carry out a river restoration scheme. All the MOS.E.S process is described in figure 1 and an example of MOS.E.S. map can be seen in figure 2.

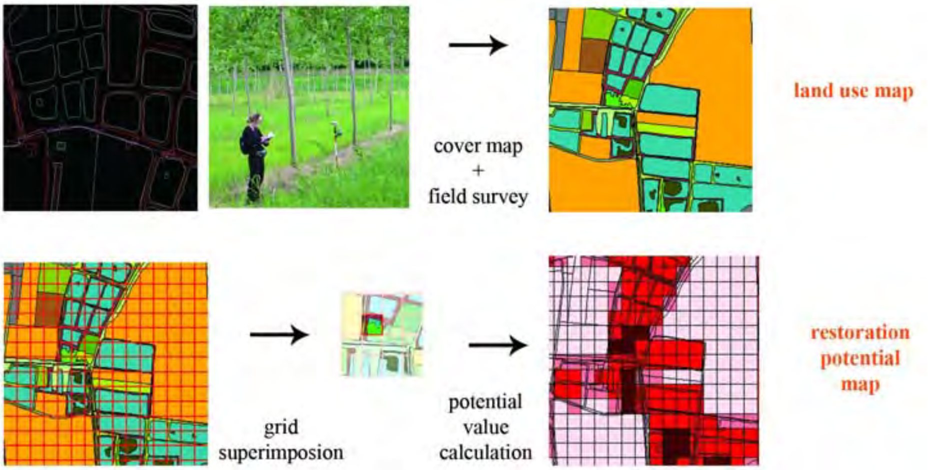

Figure 1 – The diagram show the scheme procedure for the MO.S.E.S approach.

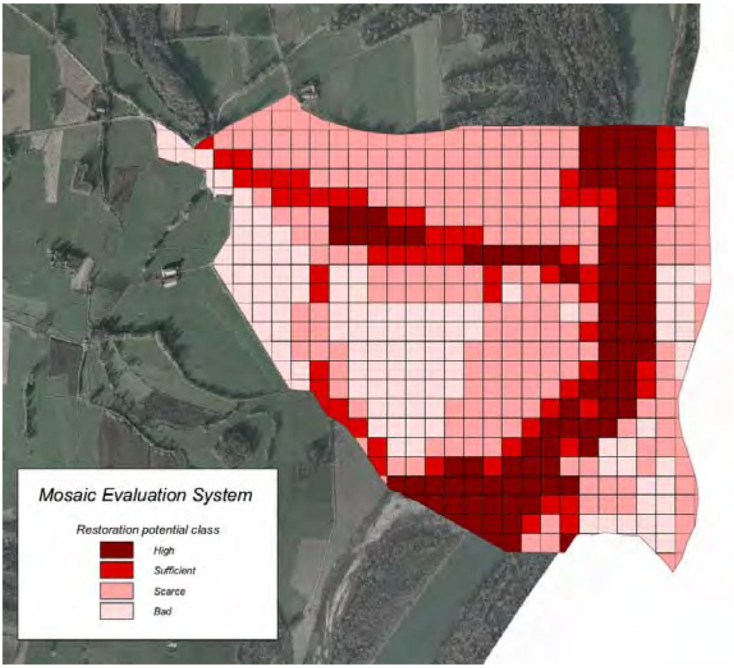

Figure 2 – An example of MO.S.E.S output on a stretch of the River Ticino (Italy)

3.3 Mos.E.S. in practice: wetland restoration near Verona (Italy)

Mos.E.S was developed and applied for the first time in 2005 for a wetland restoration project of 130 hectares in Ronco all'Adige close to Verona (Italy). The results are shown in figure 3. After carrying out field surveys of flora and fauna, the Mos.E.S results have been used to identify hydraulic connections between some high potential areas (Fig. 4). The foreseen measures for this areas are represented only by: deepening the soil in order to create water circulation and faunal corridors especially for amphibians and small mammals. In this way there was no need to apply expensive and complicated measures, thus saving funds for other areas that need more interventions. It is expected that the deepening will lead to natural restoration as the new corridors will create new microhabitat and dispersal of vegetation seeds.

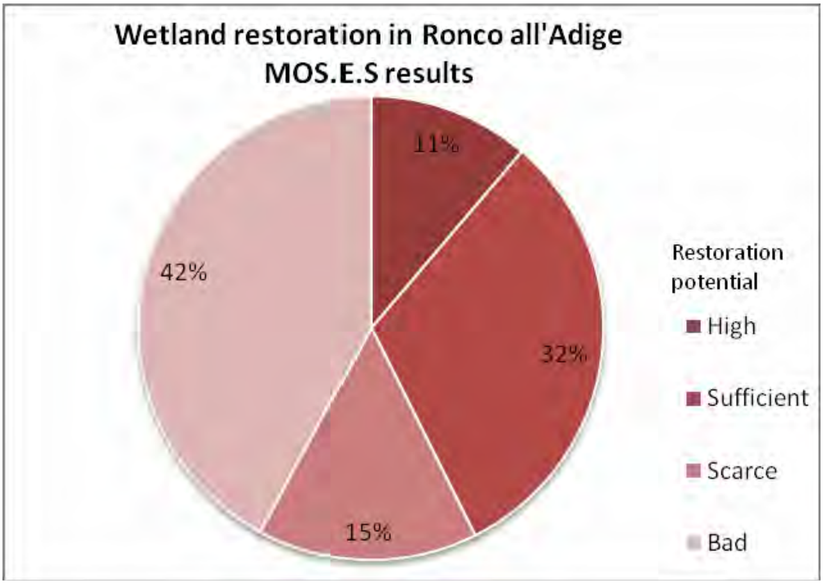

Figure 3 – The graph highlights the different percentage of restoration potential after applying MOS.E.S in Ronco all'Adige (Italy). The majority of the mosaic tales is classified from scarce to bad. The restoration plan aims to connect the areas with the highest restoration potential.

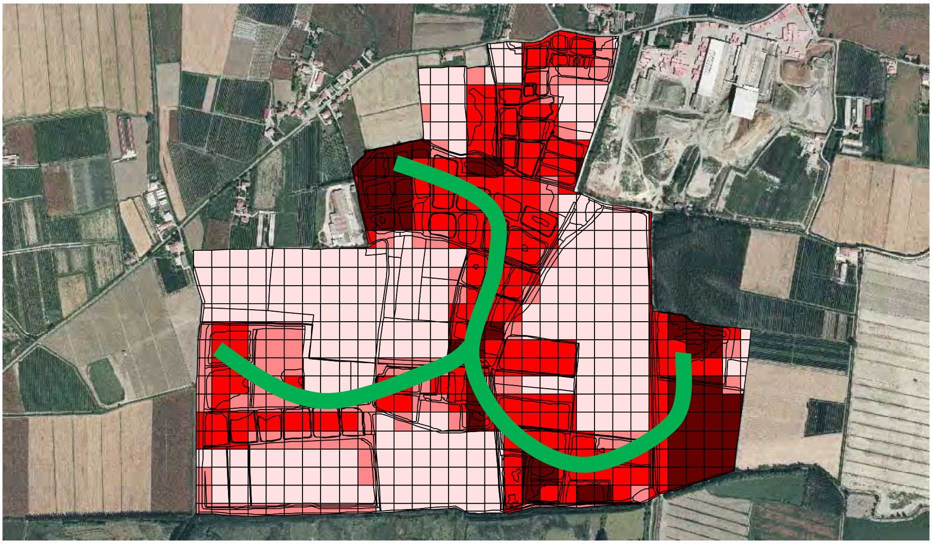

Figure 4 – The MO.S.E.S output on for the wetland restoration project in Ronco all'Adige (Italy). The green strips highlight the corridor connections between areas with high restoration potential.

4. CONCLUSION

The Mosaic Evaluation System is a quick but valuable method that helps to classify and assess land use, providing basic information to prioritize a river restoration scheme. The MOS.E.S. approach can therefore be a useful tool to support the decision process especially as it defined the areas which are more suitable for restoration. This clear information can be used also for the participation processes with stakeholders that do not have a special technical background. The MOS.E.S method is also particularly useful when evaluating different option as allows to identify the areas that already have a certain restoration potential.

MOS.E.ES can also be use to assess river restoration conditions before planning and to forecast possible post restoration scenarios, verifying how the ecological potential of the project area can change according to the design and the objectives of the project.

From the practical point of view this can lead to a better allocation of the financial resources and hopefully to more successful restoration schemes.

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A MECHANISTIC MODEL OF FLUVIAL SEED DISPERSAL

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ABSTRACT

Secondary seed dispersal by water can be important for many native and alien riparian species, both herbaceous and woody. However, there is limited understanding of the dynamics of seed distribution in river systems. Accordingly, we have developed a mechanistic model of seed dispersal by water that predicts the parameters of the dispersal kernel. The model is based on aerial dispersal and hydrological approaches with the core parameters being a function of velocity. Calibration of the model has been carried out in the Wingecarribee River and two of its tributaries, in the Southern Highlands of New South Wales Australia, through the use of seed mimic releases. The model simulates the dispersal curve for both the main river and its tributaries, with strong overall model correlations ($R_2 > 0.80$). This model increases our fundamental understanding of seed dispersal along rivers, and is a tool that can be calibrated to different rivers using local parameter values to help predict seed dispersal of native and alien plant species along waterways.

Key words: riparian, hydrochory, sustainability, seed dispersal, mechanistic model

1. INTRODUCTION

For a long time there has been an interest in understanding seed dispersal in ecology, as it is seen as one of the main drivers in structuring vegetation (Levine and Murrell, 2003). Most research has focussed on quantifying and modelling the dispersal kernel of both anemochory (wind dispersal) (Levin et al., 2003), and zoochory (animal dispersal) (Abe et al., 2006). Relatively little research has been conducted on hydrochory (fluvially dispersed seed) (Andersson et al., 2000; Hampe, 2004; Johansson and Nilsson, 1993; Riis and Sand-Jensen, 2006), though recently seed rain has been shown to be a main limiting process in structuring riparian vegetation (Hampe, 2004; Levine, 2001; Levine and Murrell, 2003; Merritt and Wohl, 2006). To improve our understanding of riparian vegetation structure we need to be able to use the main drivers of hydrochorous transport to predict the dispersal kernel of fluvially dispersed seed.

Hydrochory is primarily driven by the local flow regime (Andersson et al., 2000; Danvind and Nilsson, 1997; Hampe, 2004; Merritt and Wohl, 2002; Middleton, 2000; Nilsson et al., 2002; Pettit et al., 2001; Riis and Sand-Jensen, 2006), with channel roughness (Andersson and Nilsson, 2002; Levine, 2003; Merritt and Wohl, 2002; Naiman and Decamps, 1997; Nilsson and Svedmark, 2002) and life history traits of seed (Middleton, 2000; Nilsson et al., 2002) playing lesser roles. Velocity, and its variation between reaches, has been found to be the major driver behind seed suspension and deposition. Merritt and Wohl (2002) found a significant difference in seed deposition between low flow areas, such as pools and slack waters, compared with high velocity areas, such as straight reaches and cut banks. Andersson et al. (2000) similarly established velocity to be the only significant factor that influenced seed deposition in an unregulated river in Sweden. Alternatively, other studies have shown that micro-environmental factors, such as large woody debris (Johansson and Nilsson, 1993) and sinuosity (Schneider and Sharitz, 1988), can also influence seed deposition, although these links are not as apparent (Andersson et al., 2000). Even with the influence of micro-environmental factors in a fluvial environment, the general distribution of fluvially dispersed seed closely resembles that found in anemochory, where velocity is the main driving force (Greene and Johnson, 1989; Johansson and Nilsson, 1993; Levine, 2003; Nathan and Casagrandi, 2004).

Previous hydrochory models have used mainly an empirical approach to describe seed transport. Campbell et al. (2002) produced a two-phase dispersal model, with the second phase being hydrochorous. To predict the fluvial dispersal curve they used a negative exponential equation, which predicted that most of the seed would be deposited close to the release point. A similar empirical approach was used by Levine (2003) to predict the distribution of herbaceous plants and their communities. However, using an empirical method such as this gives a generalised distribution of seed, but it does not take into account changes in the flow regime, it is also difficult to use in non parameterized catchments. Alternatively, the flow regime was used in Australia as the main dispersal mechanism in a concept model describing hydrochory (Pettit and Froend 2001).

The aim of this study was to develop a mechanistic model of fluvial seed dispersal by: (1) developing a model that describes the dispersal curve; (2) quantifying the dispersal curve of fluvially dispersed seed; (3) calibrating and validating the model against the observed data.

2. MODELLING APPROACH

The modelling approach described here uses a set of core parameters, mainly a function of velocity, to predict the dispersal curve. This approach highlights the key parameters, which helps to demonstrate their importance in shaping the dispersal curve, and results in a simple model that is relatively easy to apply (Nathan and Casagrandi, 2004).

To develop the model we examined a combination of anemochory and hydrological models, as these research topics have been extensively modelled (Levin et al., 2003; Merritt and Wohl, 2002). Aerial and fluvial seed dispersal curves result in similar distributions, both characterised by a leptokurtic single-modal curve with a long right-skewed tail (Andersson et al., 2000; Levin et al., 2003; Riis and Sand-Jensen, 2006). A common approach to model aerial dispersal has been the use of a tilted Gaussian model to describe the seed distribution (Greene and Johnson, 1989; Levin et al., 2003). However, to consider the roughness factor of a river channel, fluvial dynamics needs to be incorporated into the model (Merritt and Wohl, 2002).

Our model was developed as a unidirectional model, predicting the distance downstream that seeds will be transported over a short time period. Seed dispersion is modelled from a point source and assumed to be deposited from the plant to the centre of the river channel prior to transport. The model is limited to predicting transport of floating seed in a single channel when the flow is confined by the bank, because the roughness factor of the river changes significantly in the event of overbank flow. These assumptions were made to keep the model simple and to help understand the key drivers of seed transport and deposition.

3. THE MODEL

In a fluvial environment in the absence of a trapping mechanism floating seed would continue to be transported unidirectionally downstream. Merritt and Wohl (2002) showed that Froude's number (Equ. 1) is negatively correlated to seed deposition; otherwise stated, the lower the subcritical flow value, the more likely seeds are to be deposited

$$Fr^{-1} = \left(g\overline{D} \big/ \overline{V}^{2}\right) \qquad (1)$$

where Fr^{-1} is the inverse of Froude's number, $\overline{V}$ is average velocity, g is the acceleration due to gravity and $\overline{D}$ is average river depth. Greene and Johnson (1989) and others (Levin et al., 2003) describe the distribution of aerially dispersed seed as a tilted Gaussian distribution, where variation in the velocity changes the dispersal kernel (Equ. 2).

$$\frac{dQ}{dx} = \frac{Q}{x\sigma_u\sqrt{2\pi}}\exp\left(-\left[\frac{\ln\left(x\overline{F}/H\overline{u}_g\right)}{\sqrt{2}\sigma_u}\right]^2\right) \qquad (2)$$

In equation 2 the main dispersal mechanism is described by x = Hu/F; where x is the distance from source, H is the release height, $\overline{u}_g$ is the geometric mean of wind velocity and $\overline{F}$ the constant descent velocity. We substituted Froude's number into the above equation with two empirically derived constants C_1 and C_2,

$$\frac{N(x)}{N(0)} = \frac{1}{xC_2\sigma_v\sqrt{2\pi}}\exp\left(-\left[\frac{\ln\left(xC_1\sqrt{\overline{D}g}/\overline{V}_g\right)}{2C_2\sigma_v^2}\right]^2\right) \qquad (3)$$

where σ_v is the standard deviation of ln($\overline{V}$), and $\overline{V}_g$ is the geometric mean of velocity (Equ. 3). The above equation predicts the relative density distribution of seed deposited from source.

4. METHOD

4.1 Study site

The study sites were located on the Wingecarribee River and two of its tributaries, Joadja and Black Bobs Creek, New South Wales, Australia (Fig. 1). The Wingecarribee River site was a 5km reach, passing through pasture land and recently planted species of *Eucalyptus* and *Leptospermum* as riparian plantations, just outside Bowral township. The river is highly regulated as it is used for interbasin transfers for urban consumption. The average discharge is 454MLd^{-1}, fluctuating between 12 – 10,000MLd^{-1}. The study sites on the two tributaries were 0.2km long, on free flowing waterways. The channels vary from 1 to 15m wide with the discharge fluctuating between 0.00001MLd^{-1} and 1,200MLd^{-1}. Joadja Creek has an intact overstorey of *Eucalyptus*, *Casuarina* and *Acer* (an alien species) trees with *Leptospermum* and *Acacia* midstorey trees. Black Bobs Creek passes mainly through agricultural land, which has a fragmented riparian overstorey of *Eucalyptus* and *Casuarina* trees.

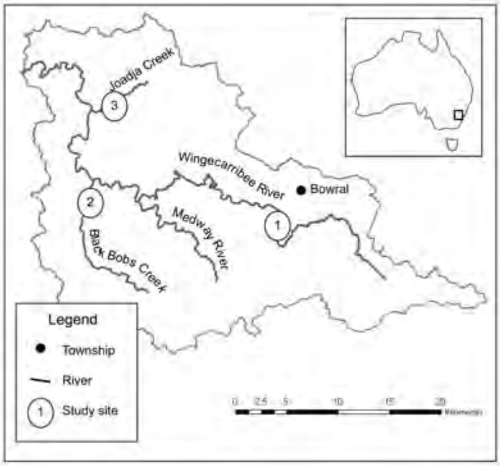

Figure 1 - Location of study sites in the Wingecarribee Catchment, New South Wales Australia.

4.2 Mimic release

To parameterise and test the fit of the model the river banks were surveyed and achenes of *Helianthus annus* (sunflower) were used to quantify the dispersal kernel. Cross-sections along the Wingecarribee R. and its tributaries were surveyed at 100m and 20m sections respectively. Discharge was measured from a gauging station on the main river, and a velocity meter (FLO-MATE 2000) was used for the two tributaries. At three sites 1km apart (Fig. 1), on the Wingecarribee River, 40,000 sterilized, colour coded *Helianthus annus* seeds were released in August 2007. Similarly, on the two tributaries, 3000 colour coded seed were released at 50m, 100m and 200m intervals (Fig. 1) in October 2007 (release 1) and again in November 2007 (release 2). Nets were placed at the end of each study site to catch any seed that might have dispersed outside the survey area. Twenty four hours after releasing the seeds the river banks were surveyed to measure the distance from the release point to the point of deposition.

5. RESULTS

5.1 Comparison of model predictions to the field observations

The model generally predicted a steep decline in seed deposition with a long right-skewed tail (Fig. 2). However, with higher velocity, such as for the second release in Joadja creek, the curve flattened and the tail became more prominent. The summary of the model validation is presented below (Tab. 1), which shows that the model generally overpredicted seed deposition, but the overall model fits are high (R^2 > 0.80).

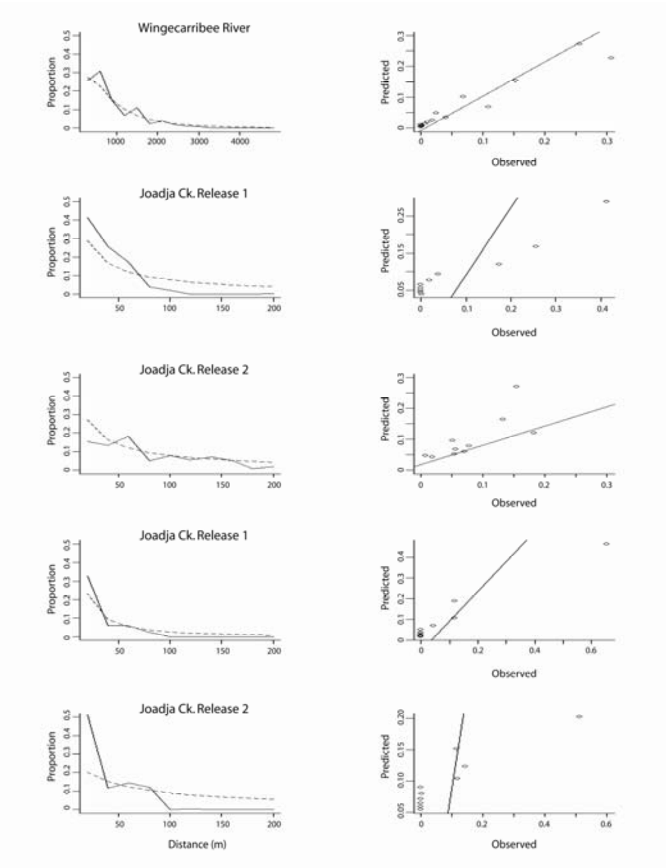

Figure 2 - Observed (—) and predicted (---) dispersal curves with their corresponding scatter diagrams, for seed released in three water courses in southern New South Wales Australia. There was one release in the Wingecarribee River and two in each of Joadja and Black Bobs Creek.

5.2 Wingecarribee River

The average ratio for observed/predicted for the Wingecarribee River was 0.84, ranging from 0.70 to 1.14 between the three release points (Tab. 1). These values show that the model slightly overestimated seed deposition, but it remains within a reasonable range. The correlation for the combined dispersal data was good, ($R^2 = 1.00$), though the R^2 varied between 0.79 and 0.90 for individual releases.

Table 1 - Geometric mean velocity ($\overline{V}_g$), average depth ($\overline{D}$), standard deviation of velocity (σ_v), and the percentage of seed found; also summarised are the ratios of the observed/predicted values, and the results of the correlation.

Water course	$\overline{V}_g$	$\overline{D}$	σ_v	Seed Found (%)	Obs./pred. Mean	Regression b	Regression R^2
Wingecarribee R							
Combined sites	0.94	1.30	0.50	8	0.84	1.11	1.00
5000m	0.94	1.30	0.50		0.70	1.17	0.87
4000m	0.95	1.20	0.40		1.14	1.01	0.90
3000m	0.98	1.20	0.44		0.70	1.47	0.79
Joadja Ck. (R1)							
Combined sites	0.20*	0.55*	0.94*	24	1.03	1.83	0.97
200m					0.85	2.83	0.95
100m					1.25	-0.02	0.43
50m					1.00	1.73	0.96
Joadja Ck. (R2)							
Combined sites	0.39*	0.65*	0.94*	14	1.00	0.79	0.80
200m					1.14	0.35	0.22
100m					1.05	-0.03	0.52
50m					0.80	1.68	0.92
Black Bobs Ck.(R1)							
Combined sites	0.003*	0.20*	0.80*	48.5	0.64	1.54	0.98
200m					0.56	1.04	0.94
100m					0.38	2.44	0.93
50m					0.96	1.63	0.93
Black Bobs Ck.(R2)							
Combined sites	0.32*	0.26*	0.80*	15	0.72	3.09	0.91
200m					0.72	1.59	0.51
100m					0.85	8.03	0.80
50m					0.58	1.37	0.93

*Difference in observed tributary variables between release sites was insignificant

5.3 Joadja Creek

The overall observed/predicted ratios for Joadja Creek were 1.03 and 1.00 for release one and two respectively (Tab. 1). The R^2 for the combined releases were 0.97 and 0.80 for the two respective release dates, with the lowest R^2 being 0.22. The model on the first release underpredicted the first 60m and overpredicted the tail, although the overall observed/predicted ratio was 1.03 (Tab. 1). Both correlations were negative over the 100m reach with the corresponding slopes being -0.02 (R2 = 0.43) and -0.03 (R2 = 0.53), for the two releases. However, the slope and the correlation for the other sites all fitted the model well.

5.4 Black Bobs Creek

Results from Black Bobs Creek are summarised in Tab. 1. The ratios for the observed/predicted were 0.64 and 0.72 for the respective releases, with a range of 0.56 to 0.96, excluding the first release over the 100m site. This site was greatly overestimated by the model (obs./pred. 0.38), mainly because of the high aggregation of seeds in the first 20m. Also the model did not predict the high deposition within the first 40m during the second release. Since velocity was higher, the model predicted a flatter curve with a longer tail. Overall, the correlation with the model for the combined sites fitted well with an R^2 of 0.98 and 0.91 respectively for the two release dates.

6. DISCUSSION

The dispersal curve shows that most of the seeds were deposited near the release site with a long right-skewed distribution, largely corresponding with results from other studies (Andersson et al., 2000; Campbell et al., 2002; Greene and Johnson, 1989; Hampe, 2004; Johansson and Nilsson, 1993; Levine, 2003; Riis and Sand-Jensen, 2006). The model simulated this dispersal curve for both the main river and its tributaries, although there was some microscale variation in the observed data, and the model often overpredicted the tail.

The model fitted the Wingecarribee River data, although the predicted values are slightly high. This is mainly reflected in the tail of the model where the model overpredicted the observed data. The model similarly correlated well for the releases in the tributaries, although the correlation for the releases at 100m on Joadja Creek was negative (Tab. 1). Similarly, the observed/predicted ratio at 100m for the first release on Black Bobs Creek was particularly low. The model did not do well at predicting the first 40m (Black Bobs Creek second release), significantly underestimating the seed deposition. These discrepancies may be caused by the low number of observations (*n* = 10) for these sites, because the models for the combined sites performed well. Alternatively it may be because of microscale variations along the water courses.

Seed transportation and deposition in a fluvial environment are influenced by both macroscale and microscale factors (Merritt and Wohl, 2002). Within the model the main macroscale factors were used to predict the seed dispersal curve. However the microscale factors such as pool and riffle variations, large woody debris and sinuosity, which have been reported to cause seed aggregation, were not taken into account (Johansson and Nilsson, 1993; Merritt and Wohl, 2002; Schneider and Sharitz, 1988). These variables may have caused the variability in the observed data, such as that for the second Joadja release. Likewise, these microscale factors may have been the reason for high seed deposition near the release point on Black Bobs Creek (second release) even with higher velocity (Fig. 2). Microscale variation may also be particularly relevant along the 100m site on Joadja Creek, where the slope was negative, as the mean of the seed distribution curve for this site was further down the river than predicted (unpublished data).

7. CONCLUSION

The model that we present is a simple mechanistic model that predicts the dispersal curve of fluvially dispersed seed from a point source. To develop the model hydrological and aerial dispersal approaches were incorporated using stream velocity as the main driver for seed distribution. The model predicted the dispersal kernel accurately ($R^2 > 0.80$) over these three river reaches in South Eastern Australia. However, at finer scales microscale factors influence seed transport and aggregation. Future studies therefore should look at this finer scale variability that influences seed transport and aggregation, and refine models to take this into account. The ability to accurately predict fluvial seed transport and deposition will help our understanding of riparian plant ecology and consequently catchment management.

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BIODIVERSITY CONSERVATION AND RIVER RESTORATION: FROM PLANNING TO EXECUTION THROUGH A LIFE PROJECT IN ARAGON RIVER, NAVARRA, SPAIN

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ABSTRACT

In application of the Habitat Directive, the Regional Government of Navarra decided in the year 2000 to draw up the management plans for each one of the 42 Sites of Community Importance located in the region. The management plan of the site "Lower reaches of the Aragon and Arga rivers" was the first of the plans elaborated for fluvial sites in Navarra. It proposed numerous measures addressed to the conservation of the habitats and species listed in the Habitat Directive and present in the area through the restoration of the hydromorphological processes from which the habitats and species are dependent. The management plan includes some important passive management measures, such as "*the flow management from the headwater reservoirs should create artificial floods in the dates and flows that would occur in a natural regime*" or "*the Fluvial Territory will be recovered as the basic space for the fluvial ecosystem*" and active measures, such as restoration actions of various types: creation of fish passages to allow fish movements, restoration of riparian vegetation, enlargement of floodplain by elimination of dykes, of ripraps to activate erosion processes, creation of wetlands to increase biodiversity, etc. Some of these restoration works were carried out between 2005 and 2007 through the LIFE project "Ecosystemic Management of Rivers with European Mink", in which the restoration of habitat for this priority species was carried out. The main objective of the project was to achieve continuity, space and sufficient ecological quality to maintain the ecological and hydrogeomorphological processes and interactions in the fluvial system. In this way, both fluvial dynamics and carrying capacity of fauna were improved and the movements along the river were facilitated. The restoration works consisted in the restoration of small tributaries, creation of wetlands, restoration of river forests, and of floodplains through dyke's removal, etc.

Key words: Biodiversity conservation, Aragon River, geomorphological processes, restoration

1. INTRODUCTION

Since its publication in 1992, the Habitat Directive (1992/43) which is dedicated to the conservation of natural habitats and wild flora and fauna, became the cornerstone for biodiversity conservation policies all over Europe. Later, with the publication of the Water Framework Directive (WFD) in 2000 (2000/60), the need to coordinate the application of these two directives to obtain the common goal of the good ecological status through biodiversity conservation in fluvial ecosystems was highlighted. The WFD established the need for river basin management plans, and the Habitat Directive stated the need to define measures to ensure the conservation, and avoid further deterioration, of the habitats and species included in Annexes I and II, and present in the Natura 2000 sites. Although the directive does not require the production of individual management plans for the Natura 2000 sites, these are widely regarded as the best way to coherently give structure to the active conservation measures proposed in a natural area (García et al., 2003). These plans will, furthermore, allow to establish the specific prevention measures required by each case.

The Regional Government of Navarra decided to draw up individual management plans for each of the sites. The management plan of the site “Lower reaches of the Aragon and Arga Rivers” drawn up in 2002 (ES2200035), was the first technical document elaborated for a fluvial site. The Department of Environment, through its public company GAVRN, is in charge of preparing and implementing the plan and the management of the site. However, the Ebro Basin Water Authority (CHE) is also involved in the implementation, because in Spain while nature management is responsibility of the regional administration, management of water-related issues is competence of the water body Authorities. The municipalities and private owners are also involved since they are the current owners of the land.

This paper is a review of the management plan elaboration process in the Site of Community Importance (SCI) and its later application through two different E.U. co-funded projects We focussed especially on the actions carried out to preserve the river biodiversity through the recovery of the river dynamics and hydromorphological processes that habitats and species depend on.

2. SITE DESCRIPTION

The region of Navarra is located in the Northeast of the Iberian Peninsula, in the Western Pyrenees. The SCI “Lower reaches of the Aragon and Arga Rivers” is located on the lower parts of these two rivers and covers 2.420 hectares including a 54 km long stretch of the Aragon River and a 19 km stretch of Arga River. The confluence of the two rivers is only 9.7 km upstream from their confluence with the Ebro River in the South of the region. In both rivers two or three ordinary floods occur as average in each hydrological year. Extraordinary floods occur more often in the Arga River (approximately one per year) than in the Aragon River (less than one every two years). This is mainly due to the regulatory effect of the Yesa reservoir (447 Hm^3) on the fluvial dynamics, which is stronger than the effects of the Eugui (22 Hm^3) and Alloz (66 Hm^3) reservoirs on the Arga River. The effect of Yesa on Aragon River's flow regulation is particularly clear during the spring thaw, having a detrimental effect on biodiversity conservation.

Salix alba and *Populus alba* galleries (code 92A0 of the 92/43 Directive) is the most represented habitat in the SCI. Less-represented, but not less important, habitats present in the area are the *Tamarix* forests (92D0), communities colonising gravel deposits (3250) and muddy river banks (3270) or nitrophilous annual and perennial grass and sedge formations of the alluvial banks of Mediterranean rivers (3280) (García et al., 2004). Fish communities are represented by Cyprinid species of running waters, the most relevant being *Chondrostoma miegii, Cobitis calderoni* and *Barbus graelsii* (Elvira et al., 2005). In the oxbow lakes (backwaters) and small tributaries, *Emys orbicularis* is frequent. Birds breed and/or overwinter in the area. Species such as *Alcedo atthis, Ardea purpurea, Nycticorax nycticorax*, and flocks of *Phalacrocorax carbo, Circus aeruginosus* and *Ardea cinerea* are common (Lekuona, 2001). Two species of carnivorous mammals are important: *Mustela lutreola* and *Lutra lutra*, both included in the 92/43 Directive, being the former also declared a High-Priority Species. It has been estimated that the populations of *Mustela lutreola* for the entire Spain reach a total of less than 500 individuals, 50-75% of which are recorded in Navarra. Given the density of this species in the area (1.8 individuals/Km) it is estimated that at least 10% of the Spanish population lives in this SCI (GAVRN, 2006), representing the highest density area of this species in Europe, which indicated the importance of the area for the conservation of this species.

3. SCI ANALYSIS

Before and during the elaboration of the management plan, the environmental analysis of the SCI was carried out from many sources. Among these, the study of the historical aerial photographs and the hydrograms (Geogune, 2002) turned out to be the most relevant, and highlighted the two main problems of the SCI: the altered flow regime and the use of the fluvial area for human activities. All the other problems are always related to these two.

As stated earlier, the flow regulatory effect of the headwaters reservoirs have reduced the river dynamics of both rivers (Díaz et al., 2002). The effect of the fluvial dynamics is as much spatial, guaranteeing the connectivity, as temporal, assuring the renovation of habitats and a good ecological state (Ollero et al., 2007). However, the dynamics of the rivers Arga and Aragon have been modified during the last decades, through the numerous protection works, especially with the canalization of the final reaches of the river Arga, and the regulation created by the Yesa reservoir on the Aragon River. Since 1956 a decline of the sinuosity of river Aragon has occurred (Geogune, 2002). This is explained by the ripraps that protect the concave banks of many meanders. Also, the smaller number of floods and the retention of silts in the Yesa reservoir have favoured the linear erosion of the river channel, that has abandoned some secondary channels concentrating on the shortest way. Floods are essential for the ecological functioning of riverine communities (Ollero and Elso, 2007). They play a crucial role in the geomorphological dynamics of river systems by transporting and redistributing the sediment, forming sand and gravel banks, changing the channel morphology, developing new channels and wetlands, rejuvenating the riparian vegetation, improving nitrogen removal and recharging the groundwater. The result is a more diverse habitat distribution that increases the ecosystem biodiversity.

Due to the decline of flood frequency and erosion intensity, and to changes in river layout, the SCI suffered a reduction of the river space and hydromorphological processes intensity that produced a decrease in habitat diversity and conservation status. These impacts are shown by the aging of some of the habitats with interest for conservation (92A0 and 92D0) and the decrease of the area of others (3250) that are highly dependent on flood and erosion processes. Similar processes have been described for other river systems after the construction of big reservoirs (Egger et al., 2007).

4. METHODOLOGY: FROM PLANNING TO RESTORATION

Once the environmental analysis was completed, the management plan was elaborated following the methodology that was later published by García et al. (2003). The management plan outlines in detail which actions to undertake and which not, what to promote and to finance in each area, in order to preserve those species and habitats that have promoted the designation of the area as a SCI. The first step was to identify the key elements for conservation (at a community, state or regional level) which were significantly present in the area and need to be managed in order to be maintained, improved and controlled. In Arga-Aragon Rivers SCI, 11 key elements were designated: natural habitats; features and processes of the fluvial system (dynamics, groundwater, islands, oxbows,…); Fluvial Territory (floodplain, longitudinal and lateral barriers, …); endangered tree species (*Populus nigra* and *Ulmus minor*); freshwater bivalves; fish communities (and water quality); European turtle (*Emys orbicularis*);

aquatic birds; raptors (in the cliffs and similar habitats); European mink (*Mustela lutreola*) and management support tools (communication, public use and research).

Once the key elements were selected, two different types of conservation objectives were defined for each of them.: final and operative objectives. Final objectives describe the ideal condition which it is desirable to reach, and therefore they describe the good state of conservation of the key elements. However, in most of the cases this condition can not be reached within the applicability period of the management plan (six years), but in a longer term. Operative objectives are those that should be reached during the plan application period and therefore they are concrete and realistic.

Next step in concrete planning was to establish two different kinds of conservation measures needed to fulfil the defined objectives: passive and active measures. Passive measures are those addressed to preserve the ecological values through administrative tools and include guidelines and regulations. Active measures are those that require an economic investment and generally are addressed to the improvement of the knowledge necessary for the management (censuses, studies, etc) or of the ecological conditions of the SCI (restoration works, public use equipment, etc). All these active measures are defined in the management plan with all the necessary details for their immediate implementation, for instance the geographical location where the action should be carried out, the budget required, and the agency in charge of the execution of the measures.

5. RESTORATION ACTIONS

Once the planning process was completed, the information acquired was enough to start restoring the most appropriate areas. Some co-financing was searched in different European funding programmes to carry out the work. This way, through the INTERREG III A initiative, Navarra and SMEAG (Syndicat Mixte d'Etudes et d'Amenagement de La Garonne) worked together in a cross border cooperation programme: Integral Management of European Rivers (GIRE) (www.interreg-gire.eu). Through this initiative studies, fauna censuses and restoration projects were carried out in the Aragon and La Garonne rivers (Urra and Campión, 2005). The restoration projects were later executed in the Aragon River through a LIFE project.

The "Ecosystem Management of Rivers with European Mink" (GERVE) LIFE project (www.life-gerve.com) was carried out between 2005 and 2008; with a budget of 1.6 M€ had as a main objective to "*Achieve continuity, space and sufficient ecological quality to maintain fluvial systems' ecological and hydrogeomorphological processes or interactions so the fluvial dynamics and river's carrying capacity are improved, in turn that fauna's no natural mortality is reduced and movements along the river corridor are facilitated*". This was achieved through the following specific objectives: restoration of habitats; specific objectives related to European mink's conservation (mortality reduction, etc…), public awareness and dissemination of the project and its results.

Restoration works accounted for most of the budget of the project (1.1 M€) and 14 actions were carried out under the following themes: restoration of ravines and oxbows (376000 €); wetlands creation (67000 €); cleaning of dumps (30000 €); river forests restoration (182000 €); river forests quality improvement (295000 €); vegetation (revetment) of ripraps (71000 €); elimination of ripraps (40000 €), and dyke removals (100000 €).

Here are some examples of the restoration works carried out through the LIFE-GERVE project:

5.1 Ponds creation in Carcastillo

This action, carried out in the winter of 2005-2006, consisted in the creation of a system of small channels and ponds in a favourable area for European mink's reproduction. The creation of these wetlands would compensate for the lack of these kind of habitats necessary for the life cycles of some species of fauna, like the European mink, aquatic birds or the European turtle. The aim was to replicate the areas where maximum mink densities have been observed: small channels with dense vegetation and small ponds. These habitats use to be frequent due to the strong dynamics of the Aragon River, but now they are almost disappeared and the mink does not find appropriate refuge and breeding areas. Several channels and three small ponds were excavated in a clearing of the river forest located on the lower part of a small tributary of the Aragon River. Water depth in the channels was kept low. Channel banks were reverted using different bioengineering techniques which allowed a quick and natural growth of riparian vegetation, which offers refuge to the target species. The vegetal material used for the bioengineering techniques was collected from adjacent areas, guaranteeing the autochthonous origin of the species.

Once works were finished, all the remaining vegetable material (woody debris) was accumulated *in situ* close to the water bodies, creating refuge areas for European minks. The location of the constructed channel favoured the creation of a new sheltered area located between the channels and the ravine and surrounded by water. Such area acted as a quiet and secure island protected from the impacts of men and domestic animals. This fact, together with the rapid development of the vegetation from the bioengineering structures, allowed the whole area to be colonised in a few weeks by fish, crayfish and amphibians, which in turn attracted European minks and otters which colonized the area within the first summer after the installation. The total cost of the action was about 67000 € and it was carried out in common land of the municipality of Carcastillo.

5.2 Elimination of riprap and river forest restoration in Santacara

An area were poplar plantations had been abandoned was restored as river forest in autumn-winter 2006. The land belonged to the municipality of Santacara, Aragon River. A total of 300 meters of ripraps (3 meters high) that were used to defend the poplar plantation from erosion were removed to restore the local erosion processes in the area and recover the naturalness of the river bank. An artificial levee (dyke) 160 meters long and 2 meters high located at the top of the riverbank and that was used to defend the plantation from floods was also removed. Afterwards, the riparian forest was allowed to be restored naturally in the lower part of the river bank were floods are very frequent and groundwater is easily reachable by the roots. In the drier areas, floodplain forest was planted using autochthonous trees and shrubs; the area was fenced to prevent damage from cattle grazing. A walking path was constructed for the local inhabitants. Shade along the path was provided by increasing the plantation density at the borders of the path. The total cost of the action was about 57000 €.

5.3 Floodplain forests quality improvement in Caparroso

This action was carried out in another abandoned poplar plantation, surrounded by a well-preserved floodplain forest along the Aragon River, in autumn and winter 2005, in land belonging to the municipality of Caparroso. Due to the impact of cattle, self-restoration of the floodplain forest had not occurred. Because the plantations were abandoned, it was decided to restorate this area; such action was compatible with floodplain ecological restoration. Grassland for cattle in a fenced area was grown using water from an old irrigation well which was equipped with a water pump fed through a solar panel. Autochthonous species of shrubs we planted in small fenced areas in the grassland to provide shade for the cattle in the future, and at the same time to increase the diversity of habitats.

The lower areas of the floodplain were left to evolve naturally and in the drier areas where no grassland was grown, small forests of autochthonous trees and shrubs were planted. Two ponds were constructed in strategic areas to enhance movements of European minks and other species between two areas of well preserved floodplain forest through the newly created habitat. An island was left in the middle of one of the ponds to act as a quiet reproduction area. Ponds banks were riveted with vegetative reproductive willow and tamarix and drier areas were planted with *Fraxinus angustifolia, Populus alba, P. nigra, S. alba, S. atrocinerea, T. galllica, Crataegus monogyna* and *Rhamnus alaternus*. Woody debris were accumulated near the ponds to provide cover for minks and otters. The total cost of the action was 153000 €

5.4 Dyke removal in Peralta

The lower reaches of the Arga River were canalized in the 80's, cutting the original meanders of the river. The canalization did not take into account any environmental criteria; it was carried out under the conviction that it was the best method to prevent flooding of the urban areas. But time has proven that the construction of floods prevention defences has not provided the foreseen security of the area. Floods still occur, especially in the town of Funes, and they are even more harmful than before. As a result of the canalization works, a large part of the natural heritage of the area was lost in form of riparian forest clear cutting. Lineal erosion has deepened the phreatic level and has affected the remaining river forests and irrigation wells that are drying up.

The restoration action consisted in removing the canalization dyke to recover the natural floodplain at the confluence with Vallacuera Stream, one of the tributaries. This action was carried out on land of the municipality of Peralta. As a result, the natural floodplain surface has increased 3.9 hectares, and the increase in the flood frequency will allow to recover .the buffer strip vegetation of the river banks and to improve the quality of the grasslands located inland.

The 1000 meters long, 5 meters high and 7 meters wide dyke was removed in the 2006-2007 winter. After the dyke was removed, the river banks were reshaped to a smooth transitional river bank to allow self-colonisation of natural vegetation, helped with some vegetative reproductive willows. In the inland areas, allochthonous poplars from the plantation were removed and natural vegetation was planted, although most of the area was left to evolve naturally because the geology of the area (a salty ravine's ejection cone) shows that salty grasslands are the most appropriate vegetation community.

A shallow pond was excavated to increase the biodiversity values of the area. The objective of the pond construction was to create high quality habitat for the European mink and the European turtle in the newly recovered floodplain. Plant-vegetated roll revetments were used to improve colonization of helophytes. This material was grown in nurseries, so it would root rapidly after installation, preventing early damages caused by floods before the roots are developed. Vegetative reproducers of *Tamarix* were also planted in the river banks. As final complement, woody debris were anchored in the surroundings of the pond for mink and otter refuge, and dead wood logs were planted in the area to facilitate woodpecker's nesting. The final cost of the action was 156000 €.

6. DISCUSSION AND FUTURE ACTIONS

Biodiversity in fluvial ecosystems is highly dependent on geomorphological processes and, therefore, habitats and species conservation must be addressed together with the recovery of these same processes. This would be a cheap and effective way to recover the naturalness of fluvial ecosystems. But restoration can not be successful if prevention is not applied. Dredging, ripraps, flow regulation and other man-induced disturbances should be kept to a minimum to allow river restoration and biodiversity conservation.

Planning before restoring is a priority in biodiversity conservation, and a wide and complete diagnosis is necessary for correct planning. Different scales of planning allow different expected results, and the more complete is the planning, the better are the results. The decision of acting on a certain area must be the result of previous planning and good use of the opportunities provided. Opportunities most of the times come from the close relationship between stakeholders and experts. Working together facilitates the expert's work and assures the future of the restoration.

Many actions still have to be carried out in the SCI in the next years to achieve the final objectives proposed by the management plan. The plan was drawn up for a period of six years and at the moment the first revision is being carried out. New problems will be addressed in the near future. The restoration works completed so far were mainly located in common land belonging to the municipalities and areas with no economic value. Therefore, through an agreement with the local authority, it was relatively easy to act. However, in the near future it is foreseen to restore habitats in areas were agricultural interests are important. For this reason an Environmental Contract System is being developed in order to facilitate river restoration in private lands. Another issue for the near future is flow regulation from headwater reservoirs. The plan proposed what the flow regime should be (giving details about flow intensity and variability) but it is competence of the Ebro River Basin Authority to apply it through the management of the headwaters reservoirs. In application of the WFD, the Ebro Basin Management Plan is being reviewed and the first draft (that is exposed to the public at the moment), already proposes a change in this direction (www.chebro.es). Finally, other problems that could affect the biodiversity conservation such as climate change and a recently discovered beaver unofficial reintroduction, will be addressed during the revision of the plan.

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RESTORING STREAM CHANNEL COMPLEXITY WITH LARGE WOOD. EFFECTS ON ECOSYSTEM STRUCTURE AND FUNCTIONING

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ABSTRACT

Aiako Harria is a 7000 ha Natural Park and Natura 2000 site located in the eastern tip of Guipuscoa (Basque Country, Spain), in a very rainy (> 2000 mm/y) and rugged area. The park includes the Añarbe reservoir, the most important drinking water supply in Guipuscoa. Streams draining to the reservoir have excellent water quality and are habitat of threatened species like European mink and Pyrenean desman. Nevertheless, large inputs of leaf litter and sediments into the reservoir create some concern, and show that stream channels, historically devoid of large wood, have reduced retention capacity and perhaps poor habitat quality. Thus, a LIFE-Nature project was designed to increase in-channel retention, reduce litter inputs, and enhance stream habitat complexity. Following a BACI design, large wood has been added to reach natural abundance (40-80 m^3/ha) in 4 stream reaches ranging in width from 3 to 15 m, which are compared to 4 upstream controls. The hypotheses are that large wood will result in: a) higher in-channel retention of dissolved nutrients and particulate organic matter, that will lead to enhanced metabolism, more detritivores, and more efficient use of inputs; and b) higher channel complexity, that will lead to enhanced diversity and resistance of aquatic communities. All reaches, control and experimental, have been monitored for one year prior to wood addition, and are being followed for two years after. Variables measured include channel form, sediment storage, hydraulic retention, retention of dissolved nutrients and particulate organic matter, decomposition of leaf litter, whole-stream metabolism, periphyton, invertebrate abundance and diversity, fish abundance and size structure, and presence of the Pyrenean desman. Results so far obtained point to a key role of large wood on stream ecosystem structure and functioning. Therefore, actions should be taken to restore the natural abundance of large wood in stream channels, at least where this will not increase flood hazard or damage properties.

Key words: Channel complexity, large wood, restoration, biodiversity, sediment retention

1. INTRODUCTION

Stream and river ecosystems across the world are subject to many impacts, like pollution, regulation, water abstraction and changes in channel form (Allan, 1995). Human activities in stream channels include snagging, canalization, gravel mining, and bank reinforcement, which can all have profound impacts on channel form. As a result, many streams have been transformed from dynamically active and spatially complex ecosystems to more static and homogenous systems. Heavy channel modifications, like conversion to concrete canals, have obviously detrimental effects on stream ecosystem biodiversity and functioning (FISRWG, 1998). Less is known on the effects of more subtle activities, like snagging. Nevertheless, as these practices have been widespread for centuries, at least in Europe, their cumulated impact could be relevant, and the environmental benefits of restoration efforts significant (Gregory *et al*., 2003). Here we report the preliminary results of a restoration project where logs were reintroduced into mountain streams to increase instream retention of sediments and nutrients, and to enhance habitat diversity.

2. STUDY AREA

Aiako Harria is a 7000 ha Natural Park and Natura 2000 site located in the eastern tip of Guipuscoa (Basque Country, Spain), in a very rainy (precipitation > 2000 mm/y) and rugged area over granites and schists. Extensive oak and beech deciduous forests and conifer plantations cover most of the catchment, where management goals are switching from timber production to conservation. The park includes the Añarbe reservoir, the most important drinking water supply in Guipuscoa, with a capacity to store up to 44 hm^3 of water. Streams draining to the reservoir have excellent water quality and are the habitat of threatened species like the European mink and the Pyrenean desman. Nevertheless, there is some concern, due to the large inputs of leaf litter and sediments into the reservoir, their total volume being estimated at 123,000 m^3/y, and to the decline of the populations of endangered species. Such large inputs suggest that stream channels, historically devoid of large wood, have today a reduced retention capacity, and this could be associated to a decrease in habitat quality. Thus, a project was designed to increase in-channel retention, reduce litter and sediment inputs, and enhance stream habitat complexity.

3. PROJECT DESIGN

The Life-Nature project NAT/E/000067 included many actions to improve the conservation status of species and habitats in the Aiako Harria Natural Park. One of the main work packages focused on increasing the amount of dead wood in stream channels to enhance habitat diversity and in-channel retention, thus reducing sediment and nutrient inputs into the reservoir. It was a pilot project of limited extent, not designed to solve the reservoir problem by itself, but rather to test whether restoring channel complexity might benefit both the reservoir and the streams.

Therefore, it was decided to restore the load of dead wood in 4 streams of contrasting size (Tab. 1). As it is usual in Europe, there were no clear ideas of the natural amount of wood to be found in "reference" conditions, and consequently, of the amount of wood that should be introduced to each stream. The highest amount of large wood (LW) found in the catchment, about 330 m^3/ha streambed, occurred in the first-order Olin stream, and thus it was not directly applicable to larger stream orders. Therefore, a relationship between channel width and wood loading for New Zealand mountain streams under beech forest (Bailey *et al.*, 2008) was used as a rough guideline for the amount of wood to be expected in larger streams, and thus, to the amount to be restored (Tab. 1). Because it was thought that passive restoration methods should be used whenever possible, it was decided to introduce large wood mimicking the kinds of structure usually found in nearby streams, instead of specifically designing each structure to optimize sediment retention, stability or whatever (Fig. 1). Similarly, the added logs were not cabled or fixed in any way, as there was not risk of damaging any structure or property located downstream.

Table 1 - Characteristics of studied streams and amount of wood added to experimental reaches.

	Atseginsoro	Malbazar	Latxe	Añarbe
Channel width (m)	3	4	5	15
Reach length (m)	100	100	100	400
# logs added	81	74	53	72
LWD added (m^3/ha)	216	239	144	33

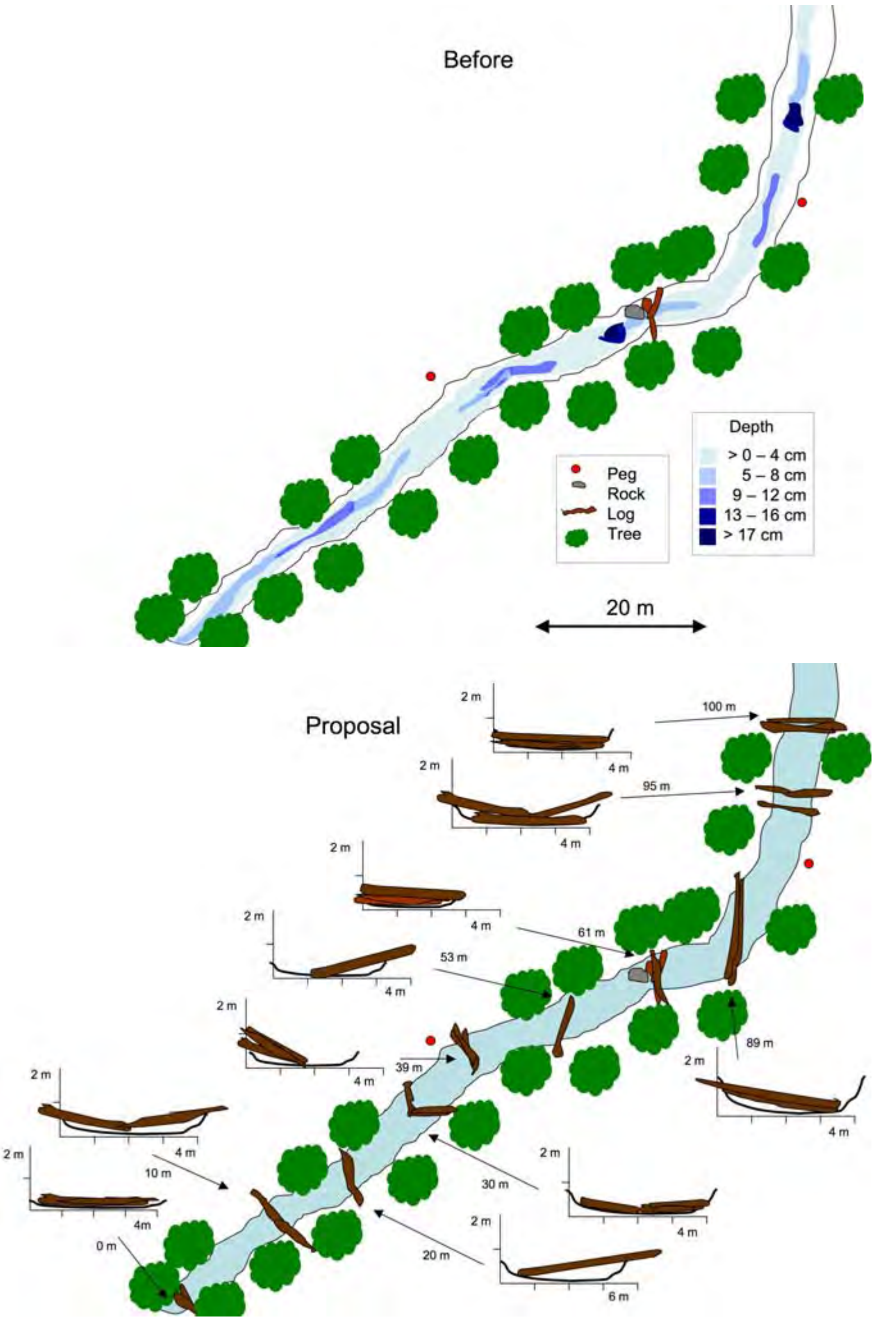

Figure 1 – An example of the project design. Characteristics of Latxe stream prior to restoration (top) and proposed structures (bottom).

The hypotheses are that addition of large wood will result in: a) higher in-channel retention of dissolved nutrients and particulate organic matter, that will in turn lead to more detritivore organims, more fish, and more efficient use of inputs; and b) higher channel complexity, that will lead to enhanced diversity and resistance of the aquatic communities.

4. METHODS

The experiment followed a BACI design, with 4 reaches ranging in width from 3 to 15 m to be restored, and one control reach upstream from each restoration reach. Reaches were 100 m long at the three smallest streams, 400 m long at the largest one. All reaches, control and experimental, were monitored for one year prior to wood addition, and are presently being monitored; monitoring will continue for a total of two years after wood addition.

Channel complexity was restored on January 2008 by adding large wood. Because the area is protected and streams are remote, local wood, collected from the forest floor, or cut from trees far away from the channels, was added by means of hand-held motor winches. The restoration works took three weeks to complete by a crew of 5 people, at a cost of about 96000 €.

The effects of wood addition on stream ecosystem structure and functioning are being assessed with the following methods. Channel form, type and storage of sediment is measured each summer from fixed transects with the help of topographic material (Díez *et al.*, 2001). Storage of organic matter is measured each summer and late autumn by gravimetry from Surber samples taken at random at all reaches. Hydraulic retention, and retention of ammonia and phosphate are measured periodically from constant rate or slug (in the large stream) additions of a solution containing common salt, ammonium chloride and potassium phosphate (Stream Solute Workshop, 1990). Retention of leaf litter is measured periodically by releasing *Ginkgo biloba* leaves and measuring the distance travelled in one hour and the retaining structure (Elosegi, 2005). Breakdown of alder (*Alnus glutinosa*) leaf litter is measured in autumn by the mesh bag technique (Bärlocher, 2005). Periphyton is sampled periodically taking 10 cobbles at random per reach, abundance is measured gravimetrically, and chlorophyll *a* content spectrophotometrically (Izagirre and Elosegi, 2005). Surber samples are taken at random in the dominant habitats in summer and late autumn to sample macroinvertebrate communities. Fish communities are also sampled in summer and late autumn by electrofishing, and presence of Pyrenean desman is being checked in late summer with net traps.

5. PRELIMINARY RESULTS AND DISCUSSION

Less than a year has passed after the restoration works took place, therefore our results are still preliminary. Nevertheless, they point to an important role of large wood on stream ecosystem structure and functioning, and to a very fast recovery of key ecosystem characteristics after wood addition.

The spring of 2008 was extremely rainy in the Basque Country, with continuous spates from March to May. Nevertheless, most wood structures remained in place in the small streams, whereas in Añarbe, logs were rearranged in more spaced, larger structures. In any case, no logs were lost from the experimental reaches. This suggests that restoring large amounts of dead wood in small stream channels is relatively safe. For larger streams, as is the case of Añarbe, it is essential to identify safe places where the risk of damaging properties or lives is minimal.

As regards the physical habitat, streams responded to wood addition by agrading the channel and storing fine sediments. In this sense, the trajectory followed by experimental reaches is almost the contrary to that described by Díez *et al*. (2000) in an experimental wood removal. Stream response was extremely fast. For example, the uppermost dam of Latxe stream collected over 15 m^3 of leaf litter in the first week, and extensive sand bars (a substrate that was almost absent prior to restoration) formed at all reaches by late spring (Tab. 2). Also, leaf litter became much more abundant after wood addition. Litter packs were fairly abundant in stream channels in autumn-winter, but tended to decay or be scoured downstream, and thus, in summertime their presence was tightly associated to large wood. Similarly, salt addition experiments showed a significant decrease in mean water velocity (Fig. 2), and a faster retention of leaves at the restored reaches (Fig. 3).

Table 2 - Percent of streambed covered by substrate categories at experimental reaches before wood addition and six months after wood addition. Both surveys were carried out in summer.

	Atseginsoro		Malbazar		Latxe		Añarbe	
	Before	After	Before	After	Before	After	Before	After
Silt	0.4	6.5	0.0	1.4	2.1	1.2	0.4	0.0
Sand	0.4	2.5	1.9	4.3	0.4	0.8	3.9	5.0
Gravel	52.7	60.0	49.6	39.7	16.6	37.6	22.9	40.4
Cobbles	37.5	18.9	28.7	11.7	59.2	26.0	44.5	30.1
Boulders	3.0	1.2	5.6	3.9	13.6	14.0	10.9	4.0
Rocks	0.0	0.0	7.8	0.4	0.0	0.4	2.7	2.2
Bedrock	6.1	4.1	6.3	5.3	8.1	5.4	14.7	15.5
Roots	0.8	1.2	0.0	0.7	3.0	1.2	0.0	0.4
Wood	0.0	3.3	0.0	13.5	0.4	3.5	0.6	0.8
Litter	0.0	2.5	0.0	19.2	0.0	10.1	0.0	1.4

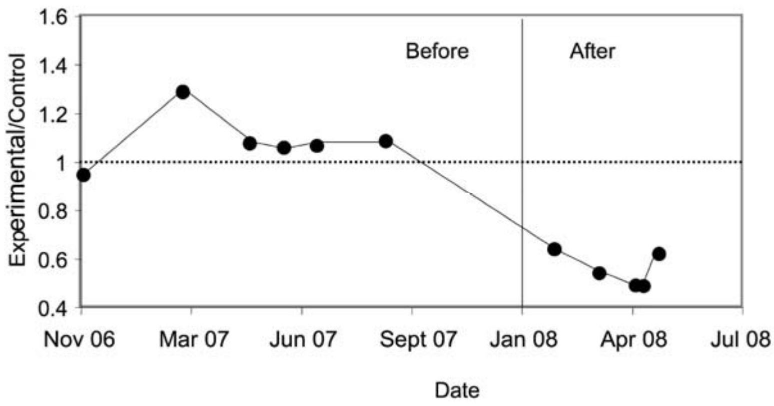

Figure 2 –Effects of restoration on mean water velocity as measured from salt additions. The ratio of water velocity between the experimental and control reaches is shown. Points above the dotted line show water which is faster at the experimental than at the control reach.

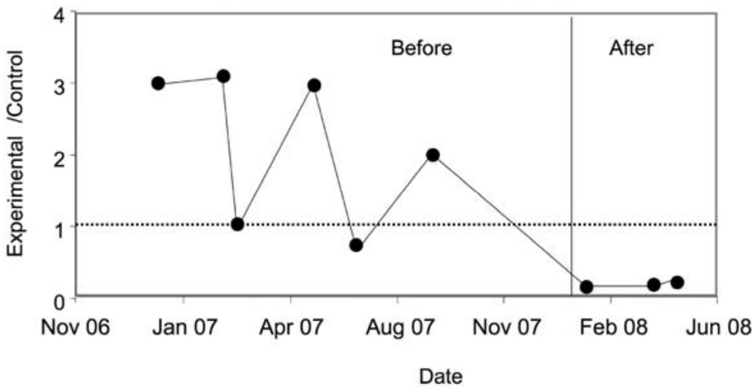

Figure 3 – Effects of restoration into average distance travelled by *Ginkgo biloba* leaves before being retained in the channel. The ratio of distance between the experimental and control reaches is shown. Points above the dotted line show that leaves are less-readily retained at the experimental than at the control reach.

The time spent after restoration is still too short to expect great changes in communities (Darby and Sear, 2008), and indeed, most of the samples are still being processed. In the case of fish, restoration works were carried out after trout spawning, and thus, could have been detrimental to egg survival. Only two fish species occurred in the study area: brown trout (*Salmo trutta*) and common minnow (*Phoxinus phoxinus*). All reaches were dominated by smolt, thus suggesting a poor habitat for adults, probably due to lack of refugia. A general increase in fish densities was detected from summer 2007 (before restoration) to summer 2008 (after, Tab. 3), but it occurred similarly in control and experimental reaches, and thus, showed no clear effect of wood addition. Nevertheless, it is expected that the effect of wood will be more evident after the first post-project spawning season.

Table 3 - Fish captured (#/m^2) in the study reaches in summer 2007 (before) and summer 2008 (after).

		Atseginsoro		Malbazar		Latxe		Añarbe	
Reach	Species	Before	After	Before	After	Before	After	Before	After
Control	Trout	0.30	0.39	0.15	0.18	0.31	0.56	0.009	0.027
	Minnow	0	0	0	0	0.02	0	0.005	0.006
Experimental	Trout	0.68	0.69	0.42	0.59	0.45	0.74	0.007	0.030
	Minnow	0	0	0.04	0.07	0.05	0.18	0.030	0.030

One of the most dramatic effects produced so far by the project, is a generalised change in attitude towards large wood in stream channels. Initially, most managers in the area, from local authorities to people in the water agencies, saw large wood as a nuisance, as is often the case in most of Europe (Piégay *et al.*, 2005). It took a long time to convince some of them that introducing wood in a safe setting could be an interesting scientific experiment. Nowadays most of them think the project was a good idea, and like the "wild" look of the restored areas.

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ECOLOGICAL EFFECTS OF RE-MEANDERING LOWLAND STREAMS AND USE OF RESTORATION IN RIVER BASIN MANAGEMENT PLANS: EXPERIENCES FROM DANISH CASE STUDIES

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ABSTRACT

River restoration was authorized in Denmark with the Watercourse Act from 1982. Since then, more than 60 large re-meandering projects have been carried out but only a few have included monitoring the ecological effects. In this paper we have analysed the ecological benefits of three types of re-meandering projects covering small headwater streams (1st and 2nd order), medium-sized streams (3rd and 4th order) and large streams (5th and 6th order). All three re-meandering projects included pre-monitoring and post-monitoring of macrophytes and macroinvertebrates; the longest monitoring period lasted for 19 years after re-meandering. We found large differences in the recovery of macoinvertebrate and macrophyte diversity in the three different stream types. The 1st order Gudenå stream had a poorer ecological quality two years after re-meandering work had finished, the 3rd order river Gelså had recovered after two years, and the 6th order river Skjern had already regained or even improved the ecological quality after one year. The results suggest that the start of post-monitoring programmes should be planned with due attention to the stream order and upstream colonization potential. The nineteen years of post-monitoring in the Gelså case study show that passive restoration by ceasing stream maintenance (weed cutting) can be a restoration measure as effective as active re-meandering of the stream channel. Finally, we have analysed how river restoration can be used as a mitigation measure to improve the hydromorphological and ecological conditions in a Danish river basin when implementing the EU Water Framework Directive. Our case study is the Pilot River Odense catchment where we suggest four new restoration measures to be

implemented for a total of 227 km open stream channels and 236 km culverted streams not supposed to reach good ecological status by 2015.

Key words: river restoration, re-meandering, ecological effects, monitoring, maintenance, Water Framework Directive.

1. INTRODUCTION

European rivers and their riparian areas are used for many purposes and are among those habitats most severely affected by human activities (EEA, 2005 and 2007). In many countries, modification of rivers and their riparian areas has been undertaken for centuries (e.g. EEA, 1995; Phillips, 1995; Sparks, 1995; Kronvang et al., 1998; Bernhardt et al., 2005). Physical degradation has been particularly great over the last two centuries as a result of land drainage, flood plain urbanisation, flood defence and navigation (EEA, 1995). In Denmark, less than 10% of the watercourses and riparian areas are still in a natural physical state (Hansen, 1998). Poor physical conditions often have a negative impact on water quality, e.g. because oxygenation and self-purification are less effective. At the same time, habitats for the flora and fauna will be limited in number and quality if the watercourse lacks physical variability. The consequence has been extensive damage to the river ecosystems with an extensive loss of habitats for wild fauna and flora. As a consequence, the biodiversity of European rivers and floodplains is today significantly reduced compared to that which existed under reference conditions, i.e. with only slight anthropogenic pressures (EEA, 2007).

Since 1982, a large number of stream restoration projects have been undertaken in Denmark with the purpose of: (1) increasing habitat diversity; (2) restoring free passage between stream reaches to ensure the migration of fish and macroinvertebrates; (3) restoring the natural physico-chemical and biological contact between streams and floodplains through e.g. remeandering of formerly straightened stream channels (Hansen, 1996). Active re-meandering of stream channels has been a widely used restoration tool with the aim of immediately bringing back the river morphology to a near natural hydromorphological conditions.

Although re-meandering of straightened reaches is expensive, very few studies have so far documented its hydromorphological and ecological effects (e.g., Friberg et al., 1994; Friberg et al., 1998; Kronvang et al., 1998; Biggs et al., 1998). The purpose of this paper is to describe the short and long term effects of re-meandering projects conducted in different Danish stream types. The hydromorphological and ecological conditions were measured by monitoring different biological indicators (macroinvertebrates, macrophytes and fish). Based on a pilot study in river Odense we also analysed watercourses at risk of not fulfilling the Water Framework

Directive objectives of a good ecological quality, and we suggest solutions such as which restoration methods would be the best choice in the river basin management plan.

2. CASE STUDY SITES

In this study, the focus is on three remeandering projects conducted in each of the three Danish stream types (Type 1 1st and 2nd orders; Type 2 3rd and 4th orders; Type 3 5th and 6th orders), and the Odense Pilot River Basin as a demonstration of how river restoration methods can be used when implementing the EU WFD. The four case study sites are situated in different parts of Denmark (Fig.1). The River Gudenå project was carried out near the source of the river system and is therefore characterised as a Type 1 stream, the river Gelså project is a Type 2 and the River Skjern å re-meandering project was conducted at the lowermost 20 km of the river system, therefore being Type 3. The three re-meandered streams and the streams in the Odense Pilot River Basin are all lowland rivers running in alluvial or moraine sediments. The natural planform of Danish rivers are single channel meandering rivers. Agriculture is the dominant land use in the four studied catchments as in most Danish catchments.

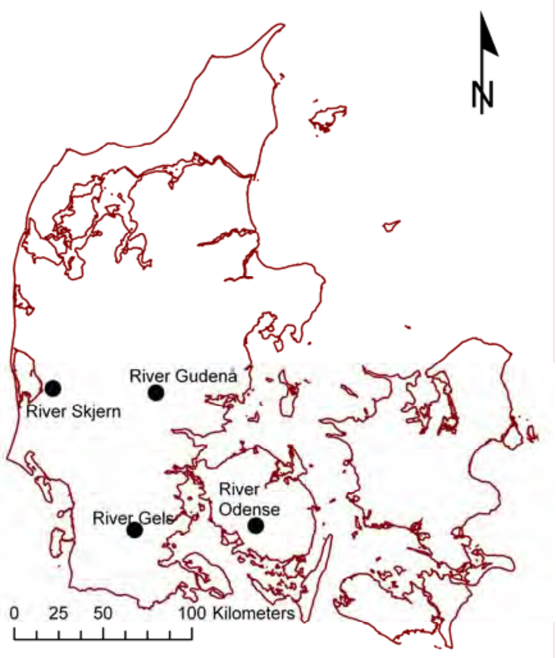

Figure 1 - Location of the four case study sites being the three remeandering projects (Gudenå, Gelså and Skjern å) and the Pilot River Odense.

3. RESULTS

3.1 Ecological effects of re-meandering Type 1 streams: upper River Gudenå

The hydro-morphological conditions changed considerably following remeandering of the upper river Gudenå (Tab. 1). The width of the channel was designed and created narrower than the channelized reach and the number of meanders increased from 2 to more than 50. Consequently, the length and sinuosity of the river channel were increased.

Macro-invertebrate diversity had not recovered to pre-restoration level after 2 years (Tab. 2). Furthermore, re-meandering did not increase total species richness of plants, compared to data collected before re-meandering, and total plant cover had not recovered to pre-restoration levels 2 years after re-meandering (Tab. 2).

Table 1 - River channel characteristics before and after re-meandering of the upper river Gudenå.

River Gudenå	Channel width (m)	Slope (‰)	Length (m)	Number of meanders	Sinuosity	River bed Width (m)	Gravel/ stone coverage (%)
Before	2-5	1.8	2700	2	1.06	1-2.3	0
After	1-41	1.41	32001	>50	1.25	0.30	0

[1]Hansen, 1997

Table 2 - Number of macroinvertebrate taxa, Average Score per Taxon (ASPT) index, number of plant species and total plant cover before and after re-meandering in river Gudenå.

River Gudenå	Before restoration	1 year after	2 years after
Total number of invertebrate taxa	38		25
ASPT	5.4		4.7
Total number of plants species	192	121	167
Total plant cover (%)	38	6	8

3.2 Ecological effects of re-meandering Type 2 streams: River Gelså

The hydromorphological conditions changed considerably following remeandering of the river Gelså (Tab. 3). The width of the channel was designed and created narrower than the channelized reach and the number of meanders increased from 0 to 16. Consequently, the length was increased by 38% and the sinuosity of the river channel increased from 1.15 to 1.60. The increase in slope following remeandering of river Gelså was due to the demolition of a weir just upstream the project area occurred at the same time as the restoration (Kronvang et al., 1994).

Table 3 - River channel characteristics before and after re-meandering of river Gelså.

River Gelså	Channel width (m)	Slope (‰)	Length (m)	Number of meanders	Sinuosity	River bed Width (m)	Gravel/ stone coverage (%)
Before	9-12	0.81	1300	0	1.15	5-6	47/2
After	4-8	0.861	18001	16	1.60	1.7-5.51	25/16

[1]Kronvang et al., 1994

In River Gelså abundances of brown trout recovered to pre-restoration levels 1-2 years after re-meandering (Tab. 4); however, the restoration did not result in increased abundance of brown trout in the re-meandered section compared to pre-restoration levels. Furthermore, habitat suitability modelling in river Gelså showed that re-meandering of this stream did not result in increased habitat suitability for brown trout compared to control sites (Fjorback et al., 2002). Similar to abundance of brown trout, macroinvertebrate and plant communities in river Gelså were found to recover relatively fast to pre-restoration levels after re-meandering with the number of invertebrate taxa, ASPT value and plant diversity reaching pre-restoration levels after 2 years and showing tendencies to improve further in the following years (Tab. 4).

Table 4 - Brown trout abundance, macroinvertebrate taxa, ASPT index, number of plant species, total plant cover before and after re-meandering river Gelså.

	Before[1]	1 year after	2 years after	7 years after	8 years after	13 years after	19 years after
Brown trout density in spring (ind. per 100 m^2)	17.01	3.55	8.99	7.48	9.21	-	8.92
Total number of invertebrate taxa	35	30	45	-	42	-	39
ASPT	5.4	5.3	5.5	-	5.2	-	5.7
Total number of plants species	19	23	30	-	-	28	-
Total plant cover (%)	41	14	47	-	10	-	21

[1]estimate made in June 1989

The total richness and coverage of plant species increased during the first two years following the restoration (Tab. 4). Species that are not confined to grow within the stream channel i.e. emergent terrestrial species increased more, probably reflecting the increased migration of bank species into the stream during summer. This enhanced contribution of emergent species to the total richness probably relates to the more shallow banks created in the restoration works that facilitate the migration of these species. The abundance of species also changed following restoration. Of particular interest is the appearance of *Potamogeton alpinus*, a species previously widely distributed in Danish streams but that has undergone a marked decline due to a more intensified land use. The appearance of this species highly sensitive to disturbance is probably due to changes in the stream maintenance practice (Pedersen, Baattrup-Pedersen and Madsen 2006). Thus, prior to restoration, the vegetation within the stream channel was cut regularly (more than once per year), whereas after restoration the vegetation was left undisturbed.

Combined habitat and ecological effect monitoring in the River Gelså was not only carried out at the remeandered reach but also at an upstream control site (Friberg et al., 1999). River maintenance work (weed cutting and excavation) ceased at both control and restored reaches following re-meandering in 1989. The hydromorphological conditions developed in an almost similar way at the control and remeandered reaches 19 years after completion of the restoration work. Main differences in substrate conditions between the upstream control and downstream restored reaches showed that less gravel and more stones were present at the latter and that no major differences occurred between the two years of mapping (Fig. 2). The density of brown trout was on average higher at the two upstream control reaches (11.3 trout per 100 m^2) than at the five restored reaches (8.9 trout per 100 m^2). On the other hand, the ASPT index for macroinvertebrates was on average higher at the active restored reach (5.7) than at the control reach (5.1). The reason for the difference was only due to stone-dwelling species linked to the much higher coverage of stones in the active restored channel (Fig. 2). The diversity of macrophytes was almost the same at both the remeandered and the control reaches.

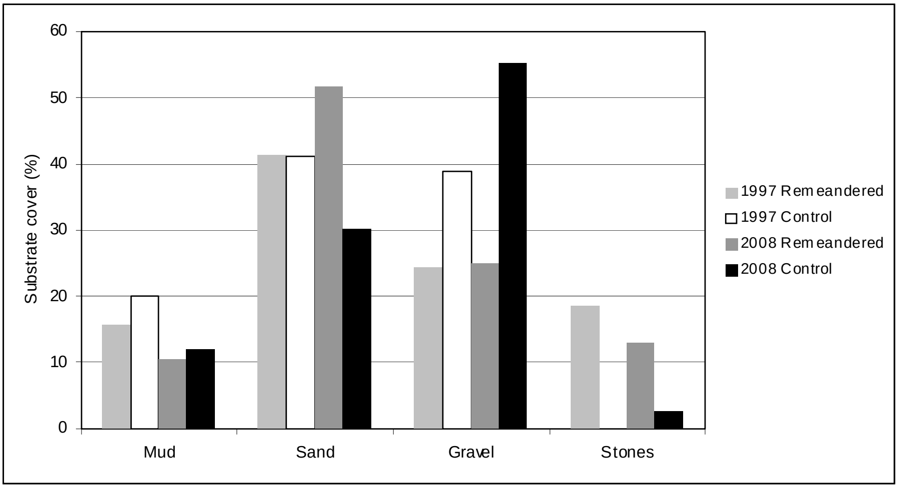

Figure 2 - Substratum conditions on two upstream control reaches and five re-meandered reaches in 1997 and 2008 in river Gelså.

3.3 Ecological effects of re-meandering Type 3 rivers: the River Skjern

The hydro-morphological conditions changed considerably following remeandering of the River Skjern Å (Tab. 5). The width of the channel was narrowed considerably (31%) and the number of meanders was increased from 8 to more than 45. Consequently, the length was increased by 37% and the sinuosity of the river channel increased from 1.04 to 1.23. No changes in channel slope occurred along the re-meandered River Skjern as a weir at the upstream part of the restored reach was demolished (Pedersen et al., 2007b).

In River Skjern macroinvertebrates rapidly colonized the three studied sections of the 26 km new meandered reach. The remeandering of the old 19 km river channel lasted 3 years starting downstream with section 3 the first year, section 2 the second year and ending the last year with section 1. Post-restoration monitoring was conducted in the new meandering channel after 3 years. The results of e macroinvertebrates monitoring therefore reflect different colonization times for the three sections surveyed (Tab. 6). However, macroinvertebrate diversity had exceeded pre-restoration levels at section 1 after one year and at section 2 and 3, respectively, 2 and 3 years after restoration (Tab. 6). ASPT values were nearly the same following restoration at section 1 after one year and section 3 after three years, whereas it was lower at section 2 two years after restoration work was completed (Tab. 6). Two rare macroinvertebrate species (the caddisfly *Glossosoma boltoni* and the stonefly *Isopetena serricornis*) never recorded in the channelized reach of the River Skjern were found during post-monitoring of the re-meandered channel. *Glossosoma boltoni* is known from stony riffles on unregulated upstream parts of the River Skjern, whereas I*sopetena serricornis* requires stable sandy substrate as preferred habitat. The diversity of plant communities also developed fast following re-meandering in all reaches, however, total plant cover was found to be slightly lower three years after restoration (Tab. 6).

Table 5 - River channel characteristics before and after re-meandering of the river Skjern.

River Skjern	Width (m)	Slope (‰)	Length (m)	Number of meanders	Sinuosity	River bed Width (m)	Gravel/stone coverage (%)
Before	49	0.23	19000	8	1.04	35-45	8
After	341	Not affected[1]	260001	>45	1.23	25-35	12

[1]Pedersen et al., 2007

Table 6 - Number of macroinvertebrate taxa, the ASPT index, number of plant species and total plant cover before and after re-meandering in river Skjern.

	Before	1 year after	2 years after	3 years after
Total number of invertebrate taxa				
Section 1	40	44		
Section 2	44		50	
Section 3	41			55
ASPT				
Section 1	6.0	6.1		
Section 2	6.5		6.0	
Section 3	6.1			6.1
Number of plants species per m^2	0.7	-	-	0.6
Total plant cover (%)	34	-	-	24

3.4 Case study Odense Pilot River Basin: use of restoration measures when implementing EU WFD

Odense Pilot River Basin covers an area of approx. 1,050 km^2, corresponding to approx. 2.5% of the Danish land area. There are just over 1,000 km of watercourse in the river basin, including the largest river on Funen, the River Odense, which is about 60 km long and drains a catchment of 625 km^2. Clayey sand (46%) and sandy clay (46%) are the dominant soil types in the catchment and land use is dominated by agriculture (Tab. 1). Madsen et al. (2007) give a characterization of the different stream types and the length of streams being at risk of not fulfilling the objective of a good ecological quality by 2015 under the EU WFD (Tab. 7). 53% of the open natural stream channels are at risk of not fulfilling the objective of a good ecological quality by 2015 and this is of course also the case for the entire length of the culverted stream channels (Tab. 7). The major reasons for this rather poor ecological status of the streams are the different pressures caused mainly by a poor hydromorphological state (Tab. 8). Thus, approx. 80% of the stream channels are at risk due to direct pressures on biota from obstructions, and another 86% are at risk due to morphological pressures such as channelization and poor physical habitat conditions.

Table 7 - River Odense Catchment divided into natural streams of different types (sizes. Length of natural stream channels where improvements in hydromorphological conditions are needed is estimated (from Madsen et al., 2007).

Stream channels	Type 1 streams (1-2 order)	Type 2 streams (3-4 order)	Type 3 streams (> 4th order)	Artificial watercourses	Total
Total stream length (km)	662	216	53	84	1015
Length of open stream channels (km)	426	216	53	67	762
Open stream channels at risk in 2015 (km)	339	156	39	-	534
Need for improvement of hydromorphological conditions (km)	155	54	18	-	227
Length of culverted stream channels (km)	236	0	0	17	253
Need for improvement of hydromorphological conditions (km)	236	0	0	-	236

Table 8 - Assessment of the pressures on the streams in the Odense Pilot River Basin being at risk of not fulfilling the EU Water Framework Directive of a good ecological status in 2015 (adopted from County of Funen, 2006).

Direct pressures on biota from obstructions, etc.	Morphological pressures.	Hydrological pressures from water abstraction	Hazardous substances	Organic and nutrient pollution
80 %	86 %	1.1 %	4.3 %	41 %

To obtain a good ecological quality in all natural streams in the Odense Pilot River Basin by 2015 the river basin managers will need to adopt mitigation measures that can improve the hydromorphological state of the stream channels at risk. Introduction of a suite of restoration methods will be an obvious choice for the river basin manager. Madsen et al. (2007) present a suite of measures; however, based on our experience from previous Danish restoration projects, we suggest the following four main restoration methods to be applied in the river basin:

R-I: Securing free passage by removal of all obstacles such as weirs, or introduction of bypasses.

R-II: Hard active restoration through re-opening and re-meandering of culverted stream reaches.

R-III: Soft active restoration through ceased stream maintenance in Type 1 streams and allowing for a 2x10 m uncultivated ‘green’ corridor with excavation of a wide double profile if the channel is too deeply incised with steep unstable banks as compared to reference morphological dimensions in Danish streams (Mernild, 2001).

R-IV: Passive restoration through ceased stream maintenance in Type 2 and 3 streams together with improvements in the physical habitat conditions by reinstating gravel, stones and wood in the regulated channel.

Our suggestions on how to implement the four different mitigation measures in the in the Odense Pilot River Basin are shown in Table 9.

Table 9 - Suggestions on how to improve the hydromorphological conditions in the River Odense Catchment, in order to achieve a good ecological status by 2015 through the implementation of four different restoration methods.

	Type 1 (1st -2nd order)	Type 2 (3rd -4th order)	Type 3 (> 4th order)
R-I: Securing free passage (estimated number of barriers)	175	45	0
R-II: Hard active restoration through re-opening and re-meandering of culverted streams (km).	236	0	0
R-III: Soft active restoration (km)	155	0	0
R-IV: Passive restoration – ceased river maintenance (km)	0	54	18

4. DISCUSSION

The three cases of remeandering presented in this study represent some of the most intensively monitored restoration projects in Denmark. Based on the results from this monitoring and evaluations from additional project, it is possible to draw some general conclusions concerning the ecological effects of remeandering lowland streams.

Two years after re-meandering the headwaters of river Gudenå (Type 1: 1st order stream) had not recovered to the ecological state present priori to the restoration (Tab. 2), probably reflecting the poor recolonization possibilities due to the limited extent of upstream areas and therefore recolonization sources. Aquatic plant dispersion is mainly dependent on downstream transport of either whole plants, shoot fragments or other vegetative organs (Barrat-Segretain and Amoros, 1996). Similarly, recolonization of macroinvertebrates is also partly dependent on potential upstream sources, e.g. through downstream drift of individuals (Matthaei et al., 1997). Furthermore, the recolonization of macroinvertebrates in river Gudenå might have been further delayed because of the low plant cover. Being of paramount importance for the structure and function of lowland stream ecosystems, macrophytes affect the recolonization rate of other stream organisms, including macroinvertebrates (e.g. Sand-Jensen, 1995). Following future restorations in headwater streams, active interventions to assist recolonization should therefore be considered. The river Gudenå is the only case where monitoring data have been published for a Danish type 1 stream and general conclusions should therefore not be drawn. However, evaluations of headwater disturbances (including restorations) in other parts of the world have also highlighted the limited recolonization potential for plants and macroinvertebrates in headwater streams (Whiles and Wallace, 1995; Milner, 1996; Laasonen et al., 1998) and the recommendations may therefore still apply.

In contrast to the restoration of the headwaters in river Gudenå, the biota in river Gelså (Type 2: 3-4th order stream) was only affected on a short-term by the disturbance caused by the re-meandering works (Tab. 4). Two years following re-meandering of this medium sized stream, the biota had almost completely recovered or even improved, reflecting the generally high recovery potential of stream ecosystems with recolonization sources located upstream (Matthaei et al., 1997). Post-restoration monitoring in the three sections of the river Skjern (Type 3: 5-6th order stream) corroborates these findings as already one year after restoration work was finished, the macroinvertebrate community had recovered at section 1, i.e. the upstream-most (Tab. 6). These results agree with results from other evaluations of remeandering of relatively large streams in Denmark (Biggs et al., 1998; Kristensen, 2004; Sode, 2005). Recolonization of the remeandered river Skjern by the rare caddisfly *Glossosoma boltoni* and the rare stonefly *Isopetena serricornis*, two macroinvertebrate species never found in the channelized reach of the river Skjern, is also an indicator of the rapid recovery of a re-meandered reach to a more natural state.

Long-term monitoring results from the river Gelså showed that still after 19 years, the diversity of macrophytes and macroinvertebrates is developing towards a more diverse and natural species composition. Moreover, a comparison of the biota on upstream control reaches and the re-meandered reaches revealed that ceasing river maintenance (weed cutting) also had a positive effect on the ecological conditions measured such as brown trout density, number of macrophyte species and number of macroinvertebrates. However, the latter could be ascribed to the higher abundance of introduced larger stones on the restored as opposed to the control reaches, thereby indicating that passive restoration through ceased river maintenance together with the addition of gravel, stones and wood would in many cases be a cost-effective restoration measure. The occurrence of long-term changes in community structure may take place after restoration measures is confirmed by a ten year study in another Danish Type 2 stream (Sode, 2005).

Comparison of macroinvertebrate communities among seven re-meandered and seven naturally meandering streams showed that the re-meandered streams had communities similar to the naturally meandering ones (Kristensen, 2004). This suggests that re-meandering in relatively large streams has the potential to restore macroinvertebrate communities to a more natural state in conjunction with rapid recolonization. The results from Kristensen (2004) were, however, not a clean effect of re-meandering as maintenance in the streams (weed cutting, dredging) was reduced or ceased at the same time and therefore further improved the communities.

In fact, an earlier study of river Gelså showed that passive restoration of channelized rivers simply by ceasing river maintenance work (dredging and weed cutting) can improve the diversity of macroinvertebrates to a higher level than active restoration through remeandering (Friberg et al., 1998). Another study of 10 re-meandered Danish streams showed that f change in maintenance practises and reduction of the maintenance frequency were important factors in the development of natural macrophyte communities (Pedersen et al., 2006). This study also highlighted that shallow and wide banks improved the connection between the river and the surrounding valley promoting the development of diverse plant communities (Pedersen et al., 2006). When combined, these results therefore suggest that macroinvertebrate and plant communities can recover and improve after re-meandering, provided that stream maintenance is minimised and that the stream banks are reprofiled with a lower bank angle to improve the lateral connectivity between the stream and its valley.

Our results from the three remeandering case studies show that post-restoration monitoring of restoration projects should wait for recolonization of macroinvertebrates and macrophytes to have a reasonable chance to take place (Fig. 3). Post-restoration monitoring should therefore not take place before 2-3 years after restoring 1-2nd order streams (like the headwaters of river Gudenå), and should also be avoided during the first year following remeandering of 3-4th order streams (like the river Gelså) in order to avoid false results and save resources for longer term monitoring. Only in 5-6th order streams with a high upstream colonization potential post-restoration monitoring may be conducted with reasonable results one year after completion of the restoration work. However, it should still be kept in mind that significant changes may occur over several years (e.g. Sode, 2005).

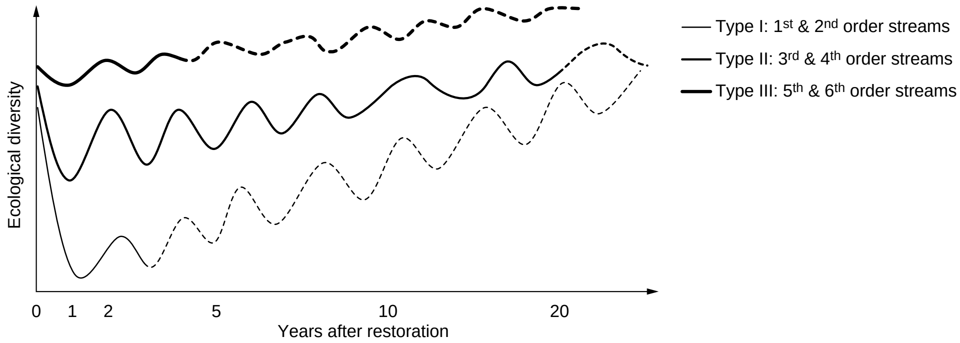

Figure 3 - Possible development in the ecological diversity following remeandering in different types of streams (stream orders).

5. CONCLUSIONS AND RECOMMENDATIONS

The ecological monitoring results from some of the best surveyed Danish case studies covering three existing stream types according to the EU Water Framework Directive (WFD) have enabled us to propose a concept for the recovery in biota following active re-meandering in different stream orders. The following concept should be taken into consideration when planning post-monitoring strategies of river restoration projects:

Recolonization of biota in re-meandered river channels can be very fast in > 4th order streams having an upstream colonization potential as it was the case of river Skjern where the macroinvertebrate community recovered within one year.

Recolonization of biota in small 1st and 2nd order headwater streams can take several years as it was the case of the upper river Gudenå case study, where macrophyte and macroinvertebrate diversity were lower than prior to remeandering two years after restoration work had been accomplished.

Recolonization in the medium-sized 3rd order River Gelså took place during the first two years but the ecology seems to steadily improve during the 19 years of post-monitoring, coupled mainly to a development in the plant community towards more disturbance-sensitive submersed species following ceased stream maintenance.

When planning post-restoration monitoring, the results from the three Danish case studies show that river managers should avoid post-monitoring during the first 2-3 years in 1st and 2nd order streams or in streams with a low upstream recolonization potential. In larger streams post-monitoring should be avoided during the first year to avoid false ecological signals.

Our post-monitoring results from the River Gelså shows that ceased river maintenance (stopping weed cutting and dredging) is more cost-effective as a passive restoration measure than active re-meandering especially when combined with the addition of gravel, stones and wood in the river channel.

We suggest a new restoration measure to be adopted along existing channelized and deeply incised 1st and 2nd order stream channels, which include establishment of a 'green corridor' allowing excavation of the nutrient-rich topsoil in a 10 m buffer zone (establishing a double profile) and at the same time ceasing stream maintenance on the channelized reach.

However, our findings clearly show that there is a need for more studies that can assist us in making assessments of the ecological effects of river restoration projects. We believe that hydromorphological and ecological surveys of larger number of existing re-meandering projects covering gradients in stream orders and restoration ages would be a successful way for describing the recovery process in detail, and at the same time mapping the upstream and downstream colonization potential for individual sites.

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PROJECT FOR ECOLOGICAL IMPROVEMENT OF RIVER NEGRO AND TRIBUTARIES (ZAMORA-SPAIN)

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ABSTRACT

The river Negro rises in the Cabrera Alta range in the mountains of Leon and is a left-bank tributary of Zamora's river Tera, which in turn runs into the Esla, in the Spanish part of the Douro basin. It is a siliceous mountain river without regulation on its headwaters or mid-course and is home to a threatened population of freshwater pearl mussel (*Margaritifera margaritifera*), which biological cycle requires a specific host, the common trout, whose gills are parasitized by the larval phase of glochidia. The interest of this species and the river section that it colonises is recognised in a European Union LIFE programme, promoted by the Regional Government of Castile and Leon with the collaboration of the Ministry of the Environment (LIFE 03NAT/E/000051).

The project contemplates several actions which aim at improving the trout habitat to reduce the loss of river connectivity which is an obstacle for the trout migration. The basic idea is that the parasite colony will benefit from the improvement of the trout habitat. In addition, the project describes other actions on fluvial habitat related to water quality, spawning grounds and riparian habitats, bearing in mind the actions to enrich the users` information and its responses. Finally, in order to verify whether the measures adopted are effective, a monitoring program will be implemented.

1. INTRODUCTION

River naiads and mussels are freshwater bivalve species belonging to the *Margaritiferidae* and *Unionidae* families which are of great interest for their biological cycle. To complete their biological cycle, each species requires a specific host, i.e. the larval phase of glochidia is a parasite of the gills of fishes. In the case of *Margaritifera margaritifera*, the host species is the common trout (*Salmo trutta*), which acts as the vector for the propagation of the species. Thus, the improvement of the trout habitat would increase the reproduction of naiads, whose populations of the river Negro are very old (most of the studied specimens are between 60-80 years of age) and present serious replacement problems (only one parisitised young trout has been observed).

Figure 1 – Naiad specimen from the river Negro

The disappearance of freshwater bivalves is a worldwide problem. According to a UICN report, 41% of the 306 evaluated species are seriously threatened. This poorly known fauna group has aroused the interest of scientists and conservationists, and is now the object of a number of studies.

In the Douro basin, recent studies have determined the presence of several freshwater bivalve species, such as the naiad *Margaritifera margaritifera*, the object of the planned ecological improvement actions within the national river restoration strategy.

The interest of this species and the degree to which it is threatened have led to the development of a LIFE programme for the conservation of *Margaritifera margaritifera* in the Zamora SCI (LIFE03-NAT/E/000051) promoted by the Regional Environment Department of the Regional Government of Castile and Leon, and supported and cofinanced by the Ministry of the Environment of the Government of Spain. Work has been carried out between the years 2003-2007 by specialised personnel who assessed naiad populations (densities, composition and abundance) and implemented actions for the conservation of this species.

The Douro Basin Authority has developed a project complementary to this work to improve the ecological state of the river Negro and its tributaries, whose objectives and main actions are presented in this paper.

In order to expand the information about this subject, the existing freshwater bivalve species within the Duero river basin are listed below. The list distinguishes between native and exotic bivalve.

1. Native bivalve taxa present or whose presence is recorded in the Douro basin:

1.1. River naiads and mussels (*Margaritiferidae* and *Unionidae*)

- *Margaritifera margaritifera*: rare, located in the rivers Tera, Castro, Águeda and Negro
- *Margaritifera auriculata*: fossil remains of specimens in Soto de Medinilla Iron Age archaeological site close to the river Pisuerga (Valladolid)
- *Potomida littoralis*: common species, widely distributed throughout the basin, although considered to be vulnerable
- *Unio spp*:
- *Anodonta spp*

1.2. River clams and other bivalves (*Sphaeridae*)

- *Pisidium spp*
- *Muscullium spp*
- *Sphaerium spp*

2. Exotic bivalve taxa present in the Douro basin (*)

2.1. *Corbicula flumminea*: quite widespread

The presence of zebra mussel (*Dreissena polymorpha*) larvae/adults in the Douro basin is periodically checked, but so far their presence has not been detected.

Figure 2 – Field surveying for colonies and individual specimens

2. STUDY AREA DESCRIPTION

As a consequence of the field work carried out within the LIFE programme, a series of sites of singular importance for the species were identified, the river Negro sub-basin stands out for its abundance of them.

The river Negro rises in the Cabrera Alta range in the mountains of Leon, situated in the province of Zamora in the autonomous region of Castile and Leon. In hydrographic terms it belongs to the Douro basin, being a left-bank tributary of the river Tera, which in turn is a right-bank tributary of the Esla, subsequently flowing into the Douro via its right bank.

This is a river of the “siliceous Mediterranean mountain” ecotype, within the Iberian-Macaronesian ecological region, according to the nomenclature of the Water Framework Directive. The basic characteristics of its basin and bed are as follows:

- Area: 415.45 km2
- Altitude range (difference in height in metres between highest point of basin and meeting point with the Tera in Nuestra Señora de Agavanzal reservoir): 2,122 m a.s.l. – 786 m a.s.l. = 1,336 m
- Basin vegetation:

1. Climatophilous: comprised by four series that mark an altitude gradient of decreasing precipitation. From high to low, an oromediterranean series of creeping juniper in the area above 2,000 m a.s.l.; two series, one humid-hyperhumid and another subhumid, whose potential vegetation is *Quercus pyrenaica* oak wood, and finally in the lower areas of the left bank, a dry series of *Quercus rotundifolia* oak woods. State of conservation: highly deforested basin, long subjected to very intensive livestock farming with heavy use of fire. Reforestations of *Pinus sylvestris*, *Pinus nigra* and *Pinus pinaster* in the areas of the two oak series. Highly washed-out soils.
2. Edaphohygrophilous: the middle and lower sections are dominated by a siliciphilous riparian geomegaseries of *Alnus glutinosa*, while the upper sections dominated by *Salix salvifolia* and other willows which, together with the alders, jointly dominate some middle and lower sections. Important riparian formation of *Populus tremula* on the lower section. State of conservation: in the middle and lower areas these riparian strips coincide with farmed alluvial plains, conserving narrow galleries which in some places are highly degraded and in others have even disappeared.

- Predominant valley type (according to Rosgen): II
- Predominant course type (according to Rosgen): B; straight with sinuosity of less than 1.5
- Bed forms: alternation of rapids and pools with lateral and central bars, some forming islands
- Predominant substrate: pebbles and gravels of siliceous origin (quartzites, sandstones and slates)
- General hydrological characteristics: basin subjected to heavy floods, with rapid response due to the siliceous substrate, deforestation, high rainfall at headwaters and strong slopes in a basin without regulation. Marked intra- and interannual irregularity.
- Hydrological parameters of interest: mode between 5 and 6 m^3/s, average in month of lowest flow (August) less than 0.4 m^3/s. Maximum instant flow of more than 380 m/s.
- Mean inflow: around 200 Hm^3
- Regime: pluvial

Figure 3 – Map of Douro hydrographic basin and river Negro sub-basin

3. ACTIONS

As it has already been noted, the project forms part of the national river restoration strategy promoted by the Ministry of the Environment. The Douro Basin Authority, a subsidiary body of this ministry, is developing a number of projects and actions aimed at improving the ecological state of rivers in the Spanish part of the Douro basin.

This project includes several fluvial habitat improvement actions with the important objective of achieving the recovery of naiad populations. The basic aim of the restoration project is to improve longitudinal connectivity on the river by restoring the corridor permeability for fish through a series of weirs that constitute crosswise obstacles to the migration of common trout (*Salmo trutta*), along with a number of actions to improve riparian vegetation and water quality. According to the experts, in order to revitalise pearl mussel populations, which are very old and fragmented, it is necessary to improve the reproduction of their host, the common trout, whose gills are parasitised by the larval phase of glochidia in a very interesting and complex biological cycle. If trout habitat conditions are improved, it is predicted that trout can better fulfil their purpose as vector of freshwater pearl mussels, raising the frequency of parasitisation and improving the species reproduction. The project also incorporates a monitoring program to check that the different actions reach their objectives In addition to these measures, the project also considers other measures of cultural nature, such as the restoration of several interesting mills associated to the weirs, of great ethnographic and heritage value, that will help to improve public use of the river for recreational and educational purposes.

These actions can be summarised as follows:

1. Improvement of longitudinal connectivity by increased permeability of weirs that block the migratory passage of trout. A total of 11 actions are considered, consisting of the construction of ramp-type fish ladders. Rionegro del Puente weir, situated close to the village of the same name, just above the point where the Negro flows into Nuestra Señora de Agavanzal reservoir, is maintained as a barrier to prevent the entry of invasive exotic species from the reservoir with potentially serious consequences for the river Negro's fluvial ecosystem, such as *Lepomis gibbosus*.

Figure 4 – Weir constituting an obstacle to the migratory passage of trout, but with a notable cultural value

2. Improvement of spawning habitat by the recovery of spawning grounds currently lost due to clogging with fines from runoff of hillsides affected by fires, earth movements from forestry work carried out in the basin, or cuttings due to infrastructure works. The restoration of lateral mill streams, which represent highly appropriate areas for spawning of common trout, is also considered.

3. Improvement of water quality, via two approaches: the first being the improvement of urban wastewater discharge treatments, constructing small treatment facilities like septic tanks or Imhoff tanks were these are lacking, or relocating others that are situated in the public hydraulic domain and are thus subject to frequent flooding, which greatly limits their operativity. The second approach comprises a series of hydrological and forestry actions that seek to prevent the runoff of fine materials from hillsides from entering the

river, clogging spawning grounds in natural and artificial pools created by weirs and notably reducing water quality.
4. Improvement of riparian habitat, basically by revegetation of the most degraded areas with native vegetation. Improvement of water oxygenation conditions, consolidation of banks and shade provided by riparian vegetation, will in turn increase the river's biogenic capacity.

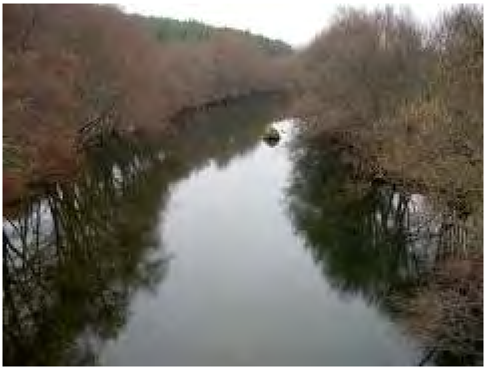

Figure 5 – View of alder woods along the river Negro

5. Improvement of hydraulic heritage and public use. There are several old mills of ethnographic interest as hydraulic cultural heritage elements. A series of actions are proposed for their restoration and public use.
6. Monitoring and follow-up of actions. In order to verify whether the measures are effective and whether other measures need to be adopted or those initially planned need to be changed, the actions will be monitored for a time period longer than the duration of the works. Technical assistance for management and monitoring is planned to be carried out for 38 months. In this type of eminently empirical actions, it is strictly necessary to implement a good monitoring programme that makes it possible to fix deficiencies which can only be detected after the actions have been carried out.

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COMPREHENSIVE APPROACH TO THE RESTORATION OF SMALL WATERCOURSES IN SUBURBAN AREAS CASE STUDY FROM THE CZECH REPUBLIC

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ABSTRACT

A thorough analysis of the current state of watercourses for restoration purposes is presented (hydrology and river engineering, hydromorphology, water and sediment quality incl. toxicity, water macroinvertebrates and phytobenthos). Two small watercourses, Leskava Brook and Troubský Brook (catchment areas 20.6 and 29.8 km^2, respectively), affected by diffuse (farming) and point pollution (sewage) sources were studied in the Brno city suburban area (South Moravia, Czech Republic). The oxygen regime and nutrient conditions in the water column have been evaluated in order to detect organic pollution and the nutrient load. Trace organic compounds and heavy metals in sediments have been analysed in order to assess the total pollution load of the watercourses. Water macroinvertebrates have been used for the indication of organic pollution, phytobenthos for eutrophication and toxicity tests for the evaluation of impacts on water quality, biota and local inhabitants. The most devastating elements in this agricultural landscape are morphological degradation and organic load originating from human settlements.

The comparison of results used to assess ecological state in different seasons (spring compared with autumn after a dry summer) shows a distinctive decrease in ecological quality during dry seasons. This fact can play an important role in association with a smaller dilution of pollutants in dry periods and can be related to the consequences of the global climate change.

Based on the evaluation of the monitored environmental factors, the most suitable reaches for restoration were proposed using criterion combination.

Key words: R.R., small watercourses, water quality, sediment quality, toxicity

1. INTRODUCTION

Small watercourses represent about 80% of the total length of rivers in the Czech Republic. The streams in agricultural landscape have lost their natural character and their conditions are strongly affected. Most of them were straightened, canalized and disturbed by point and diffuse pollution sources. Agriculture contributes mostly with fertilizers, manure, and pesticide runoff and leakage. The point pollution sources are mainly sewage outlets from settlements and insufficiently operating waste water treatment plants.

Two small watercourses, Leskava Brook and Troubský Brook (catchment areas 20.6 and 29.8 km^2, respectively), affected by diffuse (farming) and point pollution (sewage) sources were studied in the Brno city suburban area (South Moravia, Czech Republic). A comprehensive approach brings a detailed view of each type of the main factors affecting the brook catchments and enables the evaluation of the most important stressors.

The precondition of a successful river restoration is a thorough knowledge of the conditions of the watercourse: hydrological characteristics, hydrotechnical measures, point and diffuse pollution sources, water quality, sediment pollution load, and hydrobiological and ecotoxicological state. Therefore, the cooperation of experts from various branches is necessary.

2. SAMPLING

After preliminary analyses of the basin situation and pollution sources, the sampling sites were selected. The sampling frequency for hydrobiology, ecotoxicology and sediments analyses was twice per year (due to limited seasonal variability of biodiversity in strongly affected ecosystems: spring and summer/autumn in the period of minimum flow). Samples of water for hydrochemical analyses were taken seven times a year: from April till October. The method used for the sediment sample collection complies with ISO 5667-12.

3. MORPHOLOGY

The morphology of both brooks (Leskava and Troubský Brooks) has been heavily modified by river engineering. The brooks have a mostly similar trimmed character. Natural fluvial processes, such as accumulation and erosion connected with sediment transport, can be found in headwater reaches with forest cover. After leaving the forest, both brooks flow through agricultural landscape. They have straightened and deepened channels, a trapezoid cross section and concrete bank lining. The brooks' reaches in the municipality areas have a rectangular cross section with concrete banks.

From the fluvial geomorphological point of view, the most valuable is a 1-km-long reach of Troubský Brook meandering in the narrow floodplain just above the confluence with the Bobrava River.

4. HYDROCHEMISTRY

Temperature, pH, conductivity and dissolved oxygen were measured *in situ* using a multi-parameter water quality monitor. The concentrations of nutrients – nitrogen and phosphorus compounds – were monitored. The organic load of the brooks was evaluated as COD and its biodegradable part, which directly affects the oxygen regime, as BOD.

The samples of sediments at selected profiles were taken twice a year – in May and in September. The following pollutants were analysed: mercury, arsenic, cadmium, lead, non-polar hydrocarbons, polychlorinated biphenyls, organochlorine pesticides and polyaromatic hydrocarbons.

The analyses were performed according to Czech Standard Operational Procedures.

The results of the analyses of water (Tabs. 2 and 3) were compared with the general requirements of the Decree 61/2003 Coll. in the wording of the Decree 229/2007 Coll., which indicate values of the permissible pollution of surface waters in the Czech Republic (Tab. 1).

Table 1 – Selected values of the permissible pollution of surface waters in the Czech Republic according to the Decree 61/2003 Coll. and Decree 229/2007.

Parameter	Unit	Value		Parameter	Unit	Value
pH	-	6 to 8		**Temperature**	°C	25
Dissolved O_2	mg/l	> 6		**N-NO_3**	mg/l	7
COD_{Cr}	mg/l	35		**N-NH_4**	mg/l	0.5
BOD_5	mg/l	6		**P_{total}**	mg/l	0.20

Table 2 – Troubský Brook – chemical analyses of water: average value/number of measurements exceeding the limits indicated in Tab. 1.

Profile	Units	1	3	4	6	7
pH	-	7.40/2	7.46/1	7.51/2	7.75/0	7.88/3
Dissolved O_2	mg/l	12.48/1	4.60/4	4.00/5	3.20/5	7.85/1
COD_{Cr}	mg/l	178.1/6	144.7/6	139.0/7	214.9/7	115.4/6
BOD_5	mg/l	7.47/3	14.08/3	9.21/3	90.44/7	11.00/3
Temperature	°C	12.30/0	13.10/0	13.90/0	15.20/0	13.10/0
N-NO_3	mg/l	2.27/0	2.22/0	2.08/0	4.87/2	4.18/1
N-NH_4	mg/l	0.36/2	1.4/6	10.97/6	49.81/7	0.48/4
P_{total}	mg/l	0.66/6	0.83/7	1.35/7	7.08/7	1.24/7

Table 3 – Leskava Brook – chemical analyses of water: average value/number of measurements exceeding the limits indicated in Tab. 1.

Profile	**Units**	**8**	**9**	**10**	**11**	**12**
pH	-	7.49/3	7.51/3	7.77/3	8.04/3	8.21/3
Dissolved O_2	mg/l	6.68/3	3.58/5	4.08/5	5.22/5	11.48/0
COD_{Cr}	mg/l	111.6/5	135.4/5	120.0/6	125.0/6	124.5/5
BOD_5	mg/l	15.91/2	17.24/5	15.05/4	13.62/5	12.11/4
Temperature	°C	12.30/0	14.80/0	14.70/0	16.10/0	15.50/0
$N\text{-}NO_3$	mg/l	7.32/4	2.56/0	2.52/0	2.50/0	4.26/2
$N\text{-}NH_4$	mg/l	0.42/3	14.90/7	11.27/7	10.49/7	5.09/6
P_{total}	mg/l	0.51/4	2.50/7	2.14/7	1.36/7	2.52/6

Troubský Brook is characterized by a slightly disturbed oxygen regime and a high phosphorus load. Organic pollution was found even at reference profile No. 1. The concentrations of nitrogen compounds, particularly nitrates, were low. The very poor quality of water at profile No. 6 is caused by the release of non-treated sewage into the brook.

The quality of water in Leskava Brook is worse than that in Troubský Brook and corresponds with the fact that non-treated sewage is released into the upper part of the brook. The disturbed oxygen regime and high nutrient load are of the major importance. Elevated concentrations of phosphorus and ammonium-nitrogen were found at all the profiles.

The results of the analyses of sediments are summarized in Tab. 4.

Table 4 – Chemical analyses of sediments.

	Units *	**Troubský Brook**			**Leskava Brook**		
		1	4	6	8	10	12
Non-polar HC**	mg/kg	71.5	502	1926	69	694	700
PCB	mg/kg	< 0.05	< 0.05	< 0.05	0.07	0.98	0.125
PAU	mg/kg	< 0.51	3.455	4.77	0.71	5.23	3.79
OCP	mg/kg	< 0.05	< 0.05	< 0.05	0.15	0.34	< 0.05
Cd	mg/kg	0.40	0.61	0.55	0.58	0.76	5.03
Pb	mg/kg	6.15	31.2	28.8	17.3	25.0	30.4
Hg	mg/kg	0.02	0.16	0.06	0.07	0.21	0.15
As	mg/kg	< 10	< 10	< 10	< 10	< 10	< 10

* mg/kg of dry material; ** HC = hydrocarbons

The pollution of sediments of both the brooks was similar and was generally low. It often corresponded with concentrations typical of sediments non-affected by human activities. Of the heavy metals, only concentrations of cadmium were slightly elevated at some profiles. Non-polar hydrocarbons were found in high concentrations at many profiles, especially those affected by non-treated sewage.

5. HYDROBIOLOGY

The two best-suited groups of organisms for the biological monitoring of the selected stream type are benthic macroinvertebrates (macrozoobentos) and algae (phytobentos). Although the Water Framework Directive refers to five usable approaches to ecological status evaluation (hydromorphology, macrophytes, fish, phytobentos and macroinvertebrates), considering the environmental conditions in these strongly polluted streams, only the last two groups mentioned are from the biological point of view appropriate indicators of ecosystem changes (macroinvertebrates for lack of oxygen and changes in stream morphology; phytobentos for nutrient load).

Macroinvertebrate sampling was carried out by the PERLA method (Kokeš et al., 2006; http://www.vuv.cz/perla). Samples were taken by 3-minute multihabitat kick sampling with a pond net (mesh size 500 µm), live material was pre-picked in the field, then preserved material (4% formaldehyde) was subsampled and sorted in a laboratory. Identification was made predominantly to species level using AQEM project species lists and a total of 186 water macroinvertebrate taxa were found.

The evaluation of ecological state by macroinvertebrate community was made by software Asterics 3.01 (http//www.eu-star.at/). The results of this assessment enable the classification of the studied sites into five degrees of ecological state in terms of Water Framework Directive or the division into quality classes by Czech standards (CSN 75 7716, 1998). From the data analyses, the extent of anthropogenic disturbances on macroinvertebrate assemblages was evaluated.

The ecological status according to WFD calculated for macroinvertebrates by Asterics software was relatively stable through the seasons for all the sites and decreased in autumn samples only in two sites. The values of the Czech Saprobic Index increase in autumn samples in comparison with spring results in most of the sites. This phenomenon can be connected to a smaller dilution of organic pollution in the time of low discharge after a long dry period in summer 2007.

The phytobentos samples were collected only at the end of May 2007. It was scraped off five stones using a toothbrush directly at the site and filamentous algae were taken off by tweezers. If there were no stones at the site, the phytobentos was spooned out from the surface of the sediments. Samples were identified to be alive in a laboratory and, after live material pre-screening, the permanent slides for identifying the diatoms were prepared. The results of the taxonomy analyses were used for the calculation of the Trophic Index (Rott et al., 1999) and the Czech Saprobic Index according to the Czech standard (CSN 75 7716, 1998). The total trophic load at each site was evaluated based on this index.

A total of 67 cyanophytes and algal taxa were found in the samples from the sites. The green filamentous algae *Cladophora glomerata*, *Spirogyra sp.* and *Stigeoclonium sp.* were extensively developed at some sites. Diatoms were found in the largest number of species there. The dominant species were *Gomphonema parvulum*, *Navicula avenacea*, *Navicula gregaria*, *Navicula veneta* and *Nitzchia capitellata.* Cyanoprokaryota and Euglenophyta were the other taxonomic group found there. The largest number of species (25) was found at site number 2. The smallest number of species was found at site number 6, where only 8 species were found.

The total load of nutrients at each site was evaluated according to the Trophic Index created by Rott (Rott et al., 1999). The majority of the sites were assessed for the level of polytrophy. Site numbers 3, 4 and 6 achieved the highest level of trophic load and they were assessed at the level of poly-hypertrophy.

The values of the Czech Saprobic Index, calculated for spring samples using different communities, macroinvertebrates and phytobentos, respectively (Tab. 5), differ remarkably in the all sites (from 0.3 to 1.4). The larger differences between the results calculated for these two communities occurred particularly in strongly polluted sites evaluated as having a bad and poor ecological status.

Table 5 – Indexes based on macroinvertebrates and phytobentos.

TROUBSKÝ BROOK		**MACROINVERTEBRATES**				**PHYTOBENTOS**		
Site number	Season	Czech Saprobic Index	Average score per taxon	Rhithron Feeding Type Index	Ecological status WFD (macroinvertebrates)	Czech Saprobic Index	Trophic Diatom Index (Kelly et al., 2001)	Trophic Index (Rott et al., 1999)
1	spring	1.0	6.3	0.7	high	1.7	90	3.2
	autumn	1.1	5.7	0.8	good			
3	spring	3.2	2.7	0.1	bad	2.0	92	3.5
4	spring	3.1	2.8	0.1	bad	3.7	86	3.5
	autumn	3.3	2.3	0.0	bad			
5	spring	2.8	3.0	0.2	poor	1.7	61	3.2
	autumn	2.7	3.7	0.1	poor			
13	spring	3.3	1.5	0.2	poor	1.8	86	3.4

6	spring	2.9	3.8	0.2	poor	3.5	77	3.6
7	spring	1.8	4.4	0.3	moderate	2.2	89	3.2
	autumn	2.0	5.0	0.2	moderate			
LESKAVA BROOK		**MACROINVERTEBRATES**				**PHYTOBENTOS**		
9	spring	3.5	2.0	0.0	bad	2.2	77	3.4
8	spring	1.4	5.1	0.7	good	1.9	80	3.2
	autumn	1.4	4.5	0.7	good			
11	spring	2.8	2.0	0.1	poor	3.1	91	3.2
	autumn	3.5	2.8	0.0	bad			
12	spring	2.3	3.6	0.2	poor	2.9	84	3.4
	autumn	2.5	3.5	0.3	poor			

6. ECOTOXICOLOGICAL ASSESSMENT OF SEDIMENT LEACHATES

Using a standard procedure, extracts of the sediments were prepared for diagnostic tests. These extracts were tested for acute toxicity to fresh-water organisms. The ecotoxicological tests were performed on the fresh-water alga *Pseudokirchneriella subcapitata*, the vascular water plant *Lemna minor*, on a representative of invertebrates – the water flea *Daphnia magna* and on the frog embryo *Xenopus laevis* and luminiscent bacteria *Vibrio fischeri*. Possible toxic effects were evaluated using a test determining the inhibition of the growth of white mustard root *Sinapis alba*. Except for the test on *Lemna minor*, *Vibrio fischeri* and *Xenopus laevis*, all the tests were performed according to a procedure used to determine ecotoxicity in wastes. The test on *Lemna minor* was performed according to CSN EN ISO 20079, luminiscent bacteria test (CSN EN ISO 11348) and the test on *Xenopus laevis* (FETAX test) was conducted as described in ASTM E-1439-98.

The results of the ecotoxicological tests are summarized in Tab. 6.

Table 6 – Results of ecotoxicological tests using undiluted leachate.

TROUBSKÝ BROOK		**Sampling site profile**					
		1		4		6	
Test organism	Parameter	Spring	Autumn	Spring	Autumn	Spring	Autumn
Pseudokirchneriella subcapitata	I_μ%		↓↓↓		↓		
	I_A%	↑↑↑	↓↓↓	↑↑	↓↓↓	↓↓↓	
Daphnia magna	Immobility %						
Vibrio fischeri	*EC20(15,15)*%			↓			
	EC50(15,15)%					↓↓	
Lemna minor	I_A %			↓↓			
Sinapis alba	I %	↓↓↓	↓↓↓	↓			
Xenopus laevis	Mortality %(96h)						
	Malformed%(96h)			↓↓	↓↓↓	↓	↓
LESKAVA BROOK		**Sampling site profile**					
		8		10		12	
Test organism	Parameter	Spring	Autumn	Spring	Autumn	Spring	Autumn
Pseudokirchneriella subcapitata	I_μ%		↓↓↓		↓↓↓		↓↓↓
	I_A%	↓↓↓	↓↓↓	↓↓↓	↓↓↓		↓↓↓
Daphnia magna	Immobility %			↓↓↓			
Vibrio fischeri	*EC20(15,15)*%	↓					
	EC50(15,15)%			↓			
Lemna minor	I_A %			↓↓↓			
Sinapis alba	I %	↓↓				↑	↓
Xenopus laevis	Mortality %(96h)			↓↓↓			
	Malformed%(96h)	↓	↓↓↓				

Stimulation ↑ 30–40% ↑↑ 40–50% ↑↑↑ > 50%
Inhibition ↓ 30–40% ↓↓ 40–50% ↓↓↓ > 50%

Iμ% – algal culture growth rate inhibition over a 72±2-hour period compared with a control

I_A% – freshwater algae growth rate inhibition over a 72±2-hour period compared with a control, as determined by a comparison of areas under growth curves

Immobility % – immobilization (mortality), macroscopically observable inability of independent movement or death of *Daphnia magna* over a 48±2-hour period

I_A% – duckweed growth rate inhibition – reduction of growth rate of duckweed in the sample tested compared with a control calculated from the number of leaves after a 168-hour cultivation

I% – root growth inhibition – difference in average length of roots of white mustard *Sinapis alba* in the sample tested compared with a control (72±2 hours)

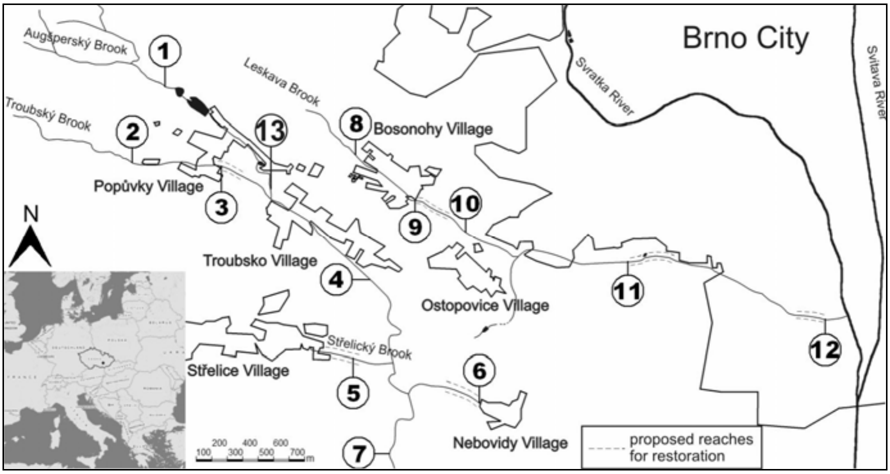

Figure 1 – Scheme of the monitored brooks.

7. CONCLUSIONS

The localities with the highest degree of pollution and morphological degradation were selected for every group of monitored parameters (chemistry, macroinvertebrates, algae, toxicology and hydromorphology). The following reaches were evaluated as the most affected ones: Troubský Brook downstream of Popuvky Village (sample site 3), downstream of Troubsko (sample site 4), Nebovidsky Brook downstream of Nebovidy (sample site 6), Leskava Brook downstream of Bosonohy Village (sample site 9) and Auspersky Brook downstream of Popuvky Village (sample site 13).

In the next step, the restoration feasibility for the selected impaired reaches was assessed based on the floodplain configuration along the watercourse (i.e. there are very limited possibilities of any significant river engineering attempts in an urban area compared with the possible remeandering of the watercourse in a rural zone, after land purchase).

The next criterion of the selection of suitable reaches was a short distance from settlement. Therefore, the reaches close to the villages were selected so that the local community would be interested and would support the restoration as a future recreation area for local inhabitants. According to these three mentioned criteria (ecological state, floodplain suitability and closeness to urban areas), the brook stretches were divided into three categories: (i) natural or slightly impaired, (ii) impaired, but with a small chance of restoration and (iii) impaired, but suitable for restoration (the last category is marked by a dashed line in the map in Fig. 1).

The essential problems in water quality are associated with sewage water from settlements in both catchment areas. Therefore, the first project outcome will include the recommendation of priorities for the building of sewage water treatment plants for the most polluted reaches. Subsequently, the restoration can be carried out with the aims of watercourse morphology and its biological and social functions.

These recommendations help local authorities to determine the priority of steps of river restoration processes for each catchment area.

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THE PECHORA RIVER AS SCIENTIFIC REFERENCE FOR RIVER RESTORATION OF NORTH- AND EAST-EUROPEAN RIVERS

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ABSTRACT

The absence of industry in the greater part of the basin, low population density, undeveloped infrastructure and intact hydrology and ecology allow to view the Pechora river system as a suitable reference model to research natural eco-hydrological relationships and processes in terrestrial and aquatic ecosystems, as well as to study flora and fauna evolution patterns in north- and east-European river basins.

The Pechora river in north-east European Russia is one of the larger European rivers, with a length of 1,809 km and a basin size of 322,000 km^2, including 34,570 channels and 62,140 lakes. The average discharge is 4,380 m^3/s, amounting to an average total annual discharge of 138 km^3. The population in the basin is 500,000. Vegetation is dominated by coniferous taiga forests, decreasing from 90 to 60% from south to north. In the forest tundra and tundra zones, forests become sparse and stunted, covering less than 30%. Peat bogs cover between 5-15% of the area.

Before the 1930s, economic activities in the basin were limited to subsistence farming, logging, hunting and fishing. During the Soviet era, forestry expanded in the central basin, as did coal, oil and gas and mineral mining in the east and north. In post Soviet times, poaching affected Salmonidae populations, while logging largely came to a halt. Today, important oil and gas pipelines cross the basin en route to Europe.

Despite economic developments, land and water conditions mainly were impacted at the point scale, only locally causing physical and chemical disturbances and pollution, while the hydrological regime of the Pechora river remains unaltered. As a result, Pechora basin ecosystems remained largely undisturbed. The non-to slightly disturbed terrestrial and aquatic tundra and taiga ecosystems still sustain an almost intact flora and fauna richness typical for these zones and their characteristic climate, including all 12 species of European Salmonidae.

Key words: The Pechora river, North-East Europe, undisturbed ecosystems, natural biodiversity, monitoring and research.

1. INTRODUCTION

The Pechora river is the largest river among the North-European rivers draining to the Arctic Basin. Its basin covers the largest part of the Pechora plain, which on the east is bordered by the Ural mountains and on the west and south-west by the Timan Ridge, separating the Pechora drainage basin from the Northern Dvina, Mezen and Volga river basins. The total surface area of Pechora river basin measures 322,000 km^2, having a length of 1,809 km. Administratively, 80% of the Pechora river basin is part of the Komi Republic, with 20% being part of the Nenets Autonomous District (Fig 1.).

During the Soviet era, forestry expanded mainly in the central Pechora basin, as did coal, oil and gas and mineral exploitation in the east and north. Despite these economic developments, present-day ecosystems of the Pechora river basin still remain largely in an undisturbed natural state. Human activities have impacted the terrestrial and aquatic environment only at the point scale, causing mainly local physical and chemical disturbances and pollution. Meanwhile, the hydrological regime of the Pechora river remains unaltered, with only 1 dam situated in the upper reaches of the Usa tributary. The basin remains one of the least inhabited regions in Europe: its resident population slightly exceeding 500,000

Figure 1 – The Pechora river basin.

2. REFERENCE FOR RIVER RESTORATION

The absence of human interferences in the greater part of the basin makes that over extended areas terrestrial and aquatic tundra and taiga ecosystems still sustain an almost intact flora and fauna richness and dynamics typical for these zones and their characteristic climate. This widespread occurrence of non-to slightly disturbed ecosystems, almost unique in the present European economic zone, provides for excellent opportunities to research the true natural dynamic eco-hydrological relationships and processes in and between terrestrial and aquatic ecosystems at the landscape scale of a complete river basin.

The Pechora basin is not as much suitable as reference area for "classic" river restoration - focusing on small scale hydro-morphological processes inside a limited stretch of the riverbed - but especially for ecological river restoration, as hydrology, flora and fauna are intact over large areas, subjected to characteristically dynamic environmental conditions. It allows for comparative regional studies on flora and fauna evolution, interaction and migration patterns in north- and east-European river basins, as well as studies on adaptations of regional environmental conditions to assessed climate change in boreal and arctic regions. In this, the completeness of its ecosystems allows for studying the complex dynamic inter- and intra species-environment interactions on a large spatial scale. Results of such studies are urgently needed to move away from today's common practice in river restoration commonly focusing on selected species to assess impacts of restoration interferences, towards establishing true integrated ecological objectives for river restoration. It also allows to define approaches for handling dynamism typical in natural ecosystems and for ecosystem processes.

The Pechora river basin also offers excellent opportunities to establish comparative integrated regional studies of the complex processes of carbon storage and release from boreal forests and peat bogs, as well as their impact on global warming. Results of such studies are of significance for both the scientific community as well as to correctly assess river restoration needs and impacts and to predict restoration outcomes in other regions under conditions of changing environmental conditions at the European and global scale.

As such the Pechora river basin can serve as a unique dynamic landscape ecosystem model to gain reference scientific information as input to river restoration planning in other European river basins, especially in north-west Europe.

3. ENVIRONMENTAL CONDITIONS

The Ural Mountains in the east of the Pechora basin are mainly composed of massive-crystalline and metamorphic rocks, mainly of Paleozoic ageing - Devon, Carbon and Perm (Varsanofyeva, 1953). The absolute heights of the Ural watershed vary between 700-1,000 m, with maximum elevations exceeding 1,800 m above sea level. The average height of the Timan Ridge is 250-300 m. The internal Pechora plain is rather flat to slightly undulating, absolute heights do not exceed 220 m. The downstream Pechora river as well as the Usa tributary transverse the Bolshezemelskaya Tundra, a gently undulating plain bordering the Pechora plain to the north, characterized by extensive permafrost and the large amount of lakes (Ponomarev et al., 2004).

In the upstream Pechora basin and its right tributaries gley-podzol, mountain podzols and mountain-forest non-podzolized soils prevail. In the plain gley-podzols, illuvial-humus podzols (northern and extreme northern taiga) and typical podzols (middle taiga) dominate (Ponomarev et al., 2004).

Climate conditions are typically north continental. Winter begins early October and lasts about 7 months. The average air temperature in January varies from –15°C in the south of the basin to –20°C in the north. Absolute minimum temperatures reach –55°C. The average temperature in the warmest month (July) varies from 16.5°C in the south to 13.5°C in the north of the basin. Absolute maximum temperature reach 35°C, while minimum values may be as low as -4°C. Precipitation varies from 300-350 mm in the north and north-east to 400-420 mm in the south of the basin. Precipitation mainly occurs mainly during the warm season (65-70%).

Rivers in the Pechora basin are predominantly fed by melt water (60-80%). The surface water chemistry depends on location and season, conditioned by soil type and parent material. Hydro-chemical features are: low mineralization (30-50 mg/l) during spring flooding, increasing during summer and winter (to 100-200 mg/l); HCO- and Ca^{2+} (28-36%) prevalence; low water hardness; high Fe^{2+} concentration (to 2.2 mg/l); relative high organic matter and phenols; low iodine and fluorine; pH varying between 6.0-8.0 (Vlasova, 1988).

Vegetation in the Pechora river basin is dominated by coniferous taiga forests, their coverage decreasing from 90 to 60% from south to north. In the forest tundra and tundra zones, forests become sparse and stunted, covering less than 30%. Peat bogs cover between 5-15% of the area.

4. HUMAN ACTIVITIES

Today the Komi Republic part of the Pechora basin has about 550,000 inhabitants, with 30,000 inhabitants in the Nenets Autonomous District. Population density varies from 9.6 person/km^2 in Ukhta to 0.4 in Troitsko-Pechorsk and Ust-Tsilma, to 0.23 in the Nenets Autonomous District.

Until the 1930s, activities in the Pechora basin were limited to subsistence extensive agriculture, reindeer breeding, logging, hunting and fishery. In the 1930s large coal deposits were discovered in the Usa tributary, and coal-mining developed. The cities of Vorkuta and Inta with complex infrastructure and support industry (processing, electricity, food) were established. Also the industrial exploitation of the first oil field (1932) and gas field (1935) started along the Izhma tributary, while accompanying oil and gas processing factories appeared. Peak developments in oil and gas extraction and refinery occurred in the 1970s, large oil and gas fields were discovered, in the taiga zone as well as in the Bolshezemelskaya tundra. The cities of Ukhta, Sosnogorsk and Naryan-Mar got new development impulses, while in the central Pechora basin Vuktyl and Usinsk were established.

Today, industrial activities mainly focus on mining – coal, oil, gas - and logging. About 85% of the work force is employed in industrial activities, predominantly oil and gas production (50%), concentrated in the cities of Usinsk, Ukhta, Sosnogorsk, Pechora, Vuktyl and the Nenets Autonomous District. The extraction of ores, ferrous, non-ferrous, rare and precious metals is insignificant, being important only in Inta (manganese) and Vorkuta (barite). In Pechora, Vorkuta and Inta large thermo-electric power stations are working fed by domestic fuel. During the 1940s a railway was constructed, connecting cities in the Komi Republic with Central Russia. Nowadays important oil and gas pipelines cross the basin on route from west Siberia to central Russia and Europe. Only 25% of oil and 49% of gas is processed within the Pechora basin. Re-orienting the energy complexes to natural gas caused a strong reduction in coal volumes needed, with mines being closed, unemployment and resettlement (Kuhry et al., 2005).

Logging in Pechora basin decreased in recent years to half of the amounts common during the Soviet era, from 1,505,000 to 818,000 m^3. Logging volumes are far below state-assessed allowable cut volumes, from 14% in the Ukhta forestry to 0.5% in the Pechora-Ilych forestry. In addition to wood quality the limited transport infrastructure is considered the main limitation. Meanwhile traditional economic activities – agriculture, fishing, reindeer breeding and navigation continue to play their role in the regional economy. In post Soviet times, especially poaching expanded rapidly, affecting valuable Salmonidae populations.

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CHAPTER 3

Session 2

Basin Scale Restoration for fisheries rehabilitation: planning and monitoring

Chairpersons

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Introduction
BASIN SCALE RESTORATION FOR FISHERIES REHABILTATION: PLANNING AND MONITORING

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Restoration of streams and rivers is often undertaken at a site or project level with an incomplete understanding of how to restore an entire basin. This has lead to small rehabilitation projects scattered across the landscape – many of which do not lead to the desired physical, biological or ecological goals. In this session speakers from throughout the world presented successful techniques, examples, and case studies of fisheries and habitat rehabilitation at a basin scale. The session included a total of 12 presentations from a broad range of countries including: Austria, Belgium, Canada, Denmark, England, Ireland, Italy, Mexico, Scotland, and the United States. The first session, consisted of six presentations focusing on assessment techniques from different countries used to identify and prioritize potential restoration actions (Schmutz et al., Poppe et al., Giannico et al., Hansen and Jensen, Parish et al., Ovidio et al.). This including discussions of assessment techniques and prioritization methods from different countries as well as two talks focusing on methods for identifying barriers and restoring connectivity of rivers. The second session focused on the use of basin scale monitoring techniques to assist with both planning restoration and determining the success of restoration actions (Pini Prato, Campbell et al., Maltby and Dugdale, Martinez Rivera et al., O'Grady, Roni) The session closed with a discussion of factors to consider when monitoring basin scale restoration.

In addition to the two sessions, we were fortunate enough to have six posters that covered a similar range of topics including: basin-scale assessment techniques, regional restoration and recovery efforts for threatened fishes, evaluation of specific restoration actions, and examination of reference basins to assist with restoration of modified basins (Naura et al., Jensen, Santos and Ferreira, Wolter et al., Simoens et al, Ponomarev and Leummens, Lagutov). Finally, the two sessions were followed by a brief workshop where many of the speakers and other interested conference participants discussed planning, prioritizing and monitoring at a basin scale (see workshop summary).

The main results of the workshop were the discussion of novel or low cost methods of conducting basin wide inventories of fish indices, geomorphology, riparian and habitat conditions, and inventory of barriers to connectivity. Collectively, these methods should be used to identify areas in need of restoration across a basin or region. Assessments such as these are also important for identifying areas within a basin critical for recover of fishes that are endangered or of interest to management. In terms of prioritizing restoration actions, the involvement of all stakeholders is critical not only to help develop multi-metric methods for prioritizing restoration but achieve buy from diverse interests on restoration of an entire basin. Finally, both restoration and monitoring and evaluation of restoration need to be designed and planned at a basin rather than project scale.

4th ECRR Conference on River Restoration
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THE PRIORITISATION OF RESTORATION MEASURES IN MULTIPLE-AFFECTED RIVERS. AN AUSTRIAN APPROACH

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ABSTRACT

This paper introduces a decision support tool for river restoration based on the relationship between human pressures and the responses of fish. Up to 80% of the large rivers in Austria (n=53) are moderate to heavily impacted. The main pressure types are channelisation, continuum disruption, impoundment, water abstraction, hydro peaking and land use. Data of near natural as well as anthropogenically altered catchments in Austria were compiled. The main pressures were identified through pressure-specific indices. This enables us to implement restoration measures that focus on crucial problems in Austrian rivers affected by multiple pressures. The results show that (1) restoration measures should be targeted at (sub-)basin scales, (2) focus should be given to less impacted catchments as fastest and largest restoration effects are expected to occur there and (3) measures with large scale effects should be favoured. According to these results decision trees for the selection of restoration measures are developed for key pressure types (channelisation incl. land use and continuum disruption). Adequate restoration measures are documented in a catalogue of measures which is divided in four system components (morphology of the river-floodplain system, hydrology, longitudinal continuum and catchment).

Key words: restoration measures, prioritisation, decision support tool, channelisation, land use, Austria

1. INTRODUCTION

According to the EU Water Framework Directive (WFD) restoration measures should lead to the "good ecological status" or "good ecological potential" of running waters by 2015 (WFD, 2000), instruments are needed to optimize restoration measures. Fish fauna is one of the four organism groups (fish, macrozoobenthos, algae, macrophytes) that can be used as an indicator to describe the ecological status of riverine systems.

Up to 80% of the large rivers in Austria are moderately to heavily impacted (Muhar et al., 2000). As water pollution is not the main problem anymore, the main impacts on Austrian running waters concern hydromorphological alterations. The aim of the MIRR-project (**M**odel-based **I**nstrument for **R**iver **R**estoration) is to develop a strategic instrument for integrated assessment of restoration measures based on fish ecological criteria.

In this paper the methods and the main results concerning the prioritisation of restoration measures are summarised.

2. METHODS

Within the MIRR Project restoration is treated as a reversed process of impact (Fig. 1). We assume that the ecological status of running waters is improving after restoration in a similar way, as it was deteriorated by pressures.

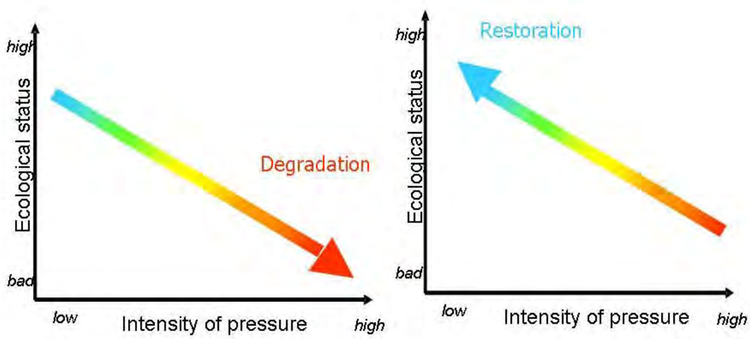

Figure 1 – Degradation is seen as reversed restoration

This assumption has limitations, because the restoration process can evolve differently than the degradation process for several reasons (Lake et al., 2007). Because there are not enough restoration data in Austria available for statistical analyses, we used this analogy approach.

Data from the main pressure types (channelisation, continuum disruption, land use, impoundment and water abstraction) were assembled for about 400 fish sample sites in Lower Austria.

For the assessment of the ecological status of the sites, we used fish indices composed of several fish ecological criteria (metrics). A regression model was developed for each metric using environmental characteristics (altitude, slope, distance to source, etc.) considering less impacted sites in order to incorporate the natural variability of fish assemblages. These models were used to predict a baseline for situations with stronger pressure and to calculate the deviation from this theoretical value (residuals). Reactive metrics were selected by comparing less and more impacted sites. The five most reactive and non-redundant metrics were combined to create pressure-specific indices for each pressure type and fish zone (rhithral and potamal) separately, resulting in ten indices. In addition, general indices without differentiating pressure types were developed for comparison. To predict the type of pressure at a given site, we used a discriminant function analysis with the ten pressure-specific indices as predictors. For further analyses, we developed a “combined index” by taking the most reactive pressure-specific index (separately for rhithral and potamal). We used regression trees to analyse combined pressure effects (Schmutz et al., 2007).

3. RESULTS

Fish showed strongest reaction to single pressures in case of intensive land use and continuum disruption (Schmutz et al., 2007). For these key pressure types we developed decision trees for the selection of adequate restoration measures deduced from the modelling results and completed by expert knowledge (concerning channelisation and land use; see Fig. 2, concerning continuum disruption; see Zitek et al., 2008 this volume). The aim is an enhancement of the fish-ecological status.

The detailed analyses of single pressures showed clear relationships between the morphological river type index and fish. This index describes the extent of channelisation at reach scale (Poppe et al., 2007). Class 1 indicates a river section with no or only few local stabilisation measures, whereas class 5 describes a completely channelised river bed with no lateral dynamic.

The models show a spatial hierarchy of pressure intensities. Pressures of smaller scales were only important when pressures at larger scales were below certain limits. Vice versa, in case of straightened and channelised river courses large-scale restoration measures comprising river and floodplain area are needed. Restoration measures at local or reach scale are recommended if the ecomorphological river habitat condition (NLR, 2001) shows a habitat deficit (class >2). The next decision parameter describes the habitat quality of the potential river floodplain area. If there is a loss of dynamic processes in this area, there are different implications according to the fish zones (e. g., change of land use within the river floodplain area, initiation of floodplain habitats).

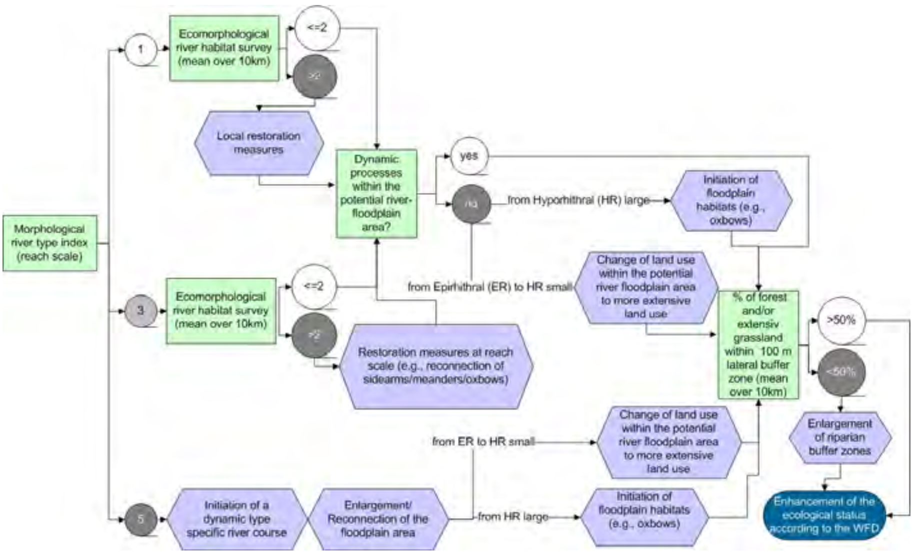

Figure 2 – Decision tree to identify the main restoration measures concerning key pressure types channelisation and land use. Green rectangles show decision parameter, the circles indicate benchmarks, blue hexagons include restoration recommendations.

Analysing the combined effects revealed that land use intensity was strongly correlated with fish. Sites with less than 50% forest within a 100 m lateral buffer zone had lower indices than others. Therefore, the last decision parameter assists in identifying the land use intensity in the adjacent area of the river sections. In case of less than 50% forest within a 100 m lateral zone, the enlargement of wooded riparian buffer zones is recommended.

All restoration implications specified above are described in detail in a comprehensive catalogue of restoration measures.

This general decision tree was applied using GIS technology in a case study for the catchment of the river Traisen in Lower Austria (Hohensinner et al., 2008). The detailed results are summarised in Fig. 3 to give an overview of the recommended restoration measure types for the whole catchment.

In the upper reaches of the catchment, mainly local restoration measures concerning river bed and riparian structures (blue line) are recommended. Land use of several sub-catchments (yellow signature) should be changed to more extensive land use. The green crosshatching indicates whole floodplain restoration (e.g., the enlargement or initiation of floodplain forest and typical floodplain habitats). This green zone is combined mostly with restoration implications at reach scale (violet line - e.g., the initiation of a dynamic type specific river course) as the morphology of these river sections has completely altered due to channelisation.

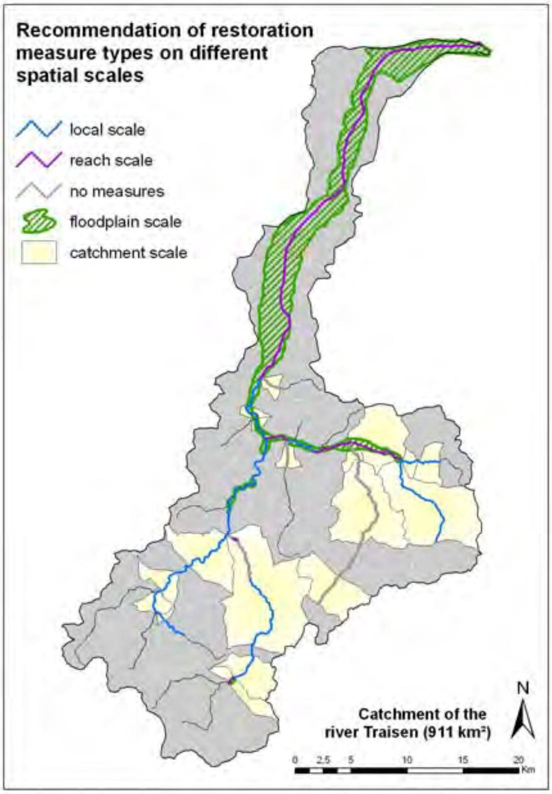

Figure 3 – Spatial prioritisation of the main restoration measure types for the catchment of the river Traisen in Lower Austria

4. DISCUSSION

Based on statistical analyses of a vast dataset, the main pressure types of Austrians large rivers were identified. Analysing combined effects revealed that land use is strongly correlated with fish. Correlation analyses of all pressure types show a high redundancy between land use and channelisation parameters. This partly explains the overwhelming importance of land use for fish, as land use subsumes many other impacts such as alteration of bank vegetation characteristics (e.g., shade, cover, woody debris) and also indirect effects via the buffer function of riparian vegetation (reduction of harmful substances input). Consequently, we developed a decision tree combining both pressure types, channelisation and land use.

The aim of the decision tree tool is enhancement of fish ecological status. Monitoring programmes should prove if restoration measures will lead to “good ecological status”.

The results lead us to general recommendations for the prioritisation of restoration measures:

- ❖ Development of programmes of measures from “the large to the small”, i.e. from catchment (sub-catchment) to the local scale.
- ❖ Focus should be given to less impacted catchments as fastest and largest restoration effects are expected to occur there.
- ❖ Measures with large scale effects should be favoured (e.g., re-opening of the continuum at the mouth of the river – see Zitek et al., 2008 this volume)

The GIS application of the decision tree using the pressure types channelisation and land use is the first step in spatial prioritisation of restoration measures at a catchment scale and could be a helpful tool to compile the programmes of measures in the River Basin Management Plans according to the WFD.

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RIVER REHABILITATION FOR FISH: FISH PASS MANAGEMENT IN THE ARNO RIVER WATERSHED

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ABSTRACT

A river rehabilitation project for fish was developed for the management of fish passes along watercourses of the Arno River Basin. The project was planned with cooperation between the Department of Forest and Agricultural Engineering of the University of Florence and the Arno Watershed Authority during 2007. The aim of the project is the study of longitudinal river connectivity along the Arno watershed, which has been fragmented by the high number of artificial weirs constructed for river bed erosion, hydropower plants, water catchments and urbanization. The ecological consequence of these obstacles is the extinction of migratory fish from the Arno watershed, generally caused by blocked access to breeding areas. Around 300 km of river was analysed to check the points of interruption and to compare the fish population of fragmented reaches. Consequently, the project suggests a new methodology for establishing priorities for constructing fish passes at weirs based on cost benefits/cost ratio of the works: the economic resources could be directed mainly toward areas of high ecological value. The discrepancy between the necessity of fishpasses and the economic potentiality of the administrations must be underlined. Moreover, the Administration prefers to use fund for management of fisheries for other goals, and the realization of fishpasses has been much neglected in Italy. Furthermore, the project furnishes guidelines for fish pass design criteria and monitoring. The results of the works are available and usable by the administration involved in watercourses management, specially wildlife and fisheries offices, for example using special resources assigned for environmental projects and biodiversity conservation.

Key words: River continuum, river rehabilitation, fishpasses, Arno river

1. INTRODUCTION

The total restoration of river connectivity isn't actually possible in all Italian rivers because of the very high number of weirs, dams and other obstacles. The high level of watercourse fragmentation implies the impossibility of the migratory movements of fish, with irreversible consequences for biodiversity (Autorità di Bacino del Fiume Arno, 2007). The planning of *river continuum* restoration is based mostly on the necessity to realize fishpasses on existing obstructions and the best allocation of economic resources for these works. Thanks to a special analysis to determine critical situations and maximising the benefits/cost relationship, the Arno River project became a complete example of river continuity recovery.

2. MATERIALS AND METHODS

2.1 Area of study

The study area is the Arno River watershed, which is the largest watershed in Tuscany (around 8.000 km^2). Five rivers have been studied: the choice was made on geomorphological and ecological criteria, which generally corresponds to a different fish fauna composition. The watercourses analyzed were the Arno River and its main tributaries: Elsa, Greve, Sieve and Corsalone rivers. The Arno River is the longest and contains many different fish communities: salt water and diadromous species in the low and middle course, rehophilic Cyprinids and Salmonids in the upper course. The Arno River has been analyzed and divided in four different reaches (low course= Arno Planiziale, middle course= Arno Pedocollinare, reservoirs reach= Sistema degli Invasi , upper course= Arno Casentinese). The analyzed length is 224.8 km, approximately 92% of its total length. Elsa River was analyzed from the confluence with the Arno to Certaldo locality. A control station for fish and hydraulic simulation exists in the analyzed reach and it was used for the recent project using microhabitats method called “Biodemiv”(Biological minimum flow) (Nocita 2005). The choice of this reach is therefore due also to the availability of important data useful for the present study. Moreover, Elsa River is an important watercourse crossing the low plain of the Arno watershed. The reach analyzed was 30.9 km long, approximately 39% of its total length. The Greve River has been analyzed from the confluence with the Arno to the first obstruction, approximately 19.2 km upstream, including another control station for the Biodemiv research. Also, the availability of a number of data was useful to the present study. Approximately 18% of its length was analyzed. The Sieve River was analyzed from the confluence with the Arno to the big dam of the Bilancino Basin, approximately 48.1 km upstream. Along this reach there are four control stations used for the pilot project called “Determination of the Minimum Flow on Biological Basis”. Moreover, the Sieve is the main watercourse of an important area called Mugello and it is the main tributary of the Arno River. The Corsalone Torrent is typical of Appenine Mountain waterscourses and was analyzed from the confluence with the Arno to the weir immediately upstream of a hydroelectric power station. A distance of approximately 8.1 km or approximately 41% of the total length.This stream is of interest for the protection of the fish and it has been the object of a specific management in the recent years.

2.2 The instruments used: Priority Indexes

The *relationship of continuity* (RC) was defined as the relation between the length of a river reach (Lt) and the number of obstructions (N) separating it, which can be written as $RC = Lt/N$ *(1)*

The author, using this formula, have recently been produced technical instruments to describe the state of fragmentation of a water course and to compare it with others, with the aim to choose and to plan interventions for the restoration of the continuity. These descriptors are called Priority Indexes, and have been planned as instruments of easy and applicative use; able to evaluate the priority of constructing fishpasses at existing obstructions (Pini Prato 2007). They can be used to estimate the feasibility between two or more alternative interventions on single obstruction at the level of entire fluvial lengths or parts of them. The result of the indexes is a dimensionless number.

The two indexes are called IPs (Priority Index for Single weir intervention) and IPt (Priority Index for a total reach).The first one is used in order to evaluate the scale of fishpasses construction in case of the presence of two or more obstructions. The analysis could be made on the same or different watercourses. The second index is used on an entire water course, on a part of its or in order to compare different water courses. The indexes have been prepared in order to support the planning of fishpasses in the following situations:

- low level of longitudinal watercourse fragmentation (high RC value), therefore, where it is easier to restore the continuum
- watercourse fragments in which the upstream reach (respect to an obstruction) is significantly longer than the downstream reach
- low height obstructions, in which the fishpass building could be simpler and less expensive than a higher weir
- highly migratory or protection requirements compared to those that are sedentary, allochthonous, or undesired and unprotected

Priority Index for Single weir intervention is calculated: *IPs = Ms * I (2)*
- Ms (morphologic factor) = (Lv+Lm) * Lm/Lv * 1/H
- I (fish factor) = ∑ki

Lv = length of the continuous reach downstream of the obstruction (Km)
Lm = length of the continuous reach upstream the obstruction (Km)
H = height of the obstruction (m)
∑ki = sum of the coefficients of priorities (ki) of all the species present downstream of the obstruction

The morphologic factor (Ms) contains the physical parameters characterizing the area: the total length joining the downstream and upstream reaches and the height of the obstruction. Moreover, this factor considers the dimensional relationship of the two reach lengths, that is the weight of the upstream reach in comparison with the downstream one. The fish factor (I) considers all the species living downstream the obstruction. Its value depends on the characteristics of the fish communities, calculated using to the priority coefficient ki.

Priority Index for a Total reach is calculated: *IPt = Mt * I (3)*
- Mt (morphologic factor) = (Lt) * $1/N\sum h_i$
- I (fish factor) = $\sum k_i$

Lt = total length of the reach as connected (Km)
N = number of obstructions
$\sum h_i = (h_1 + h_2 + \dots h_n)$ = sum of the heights of all the obstructions (m)
∑ ki = sum of the coefficients of priority (ki) of all the present species

The morphologic factor (Mt) contains the physical parameters characterizing the analyzed area: the total fluvial length joining all the reaches downstream and upstream of every obstructions are the number of the obstructions to equip with fishpasses and the sum of their heights. This factor contains the relationship of continuity since Lt/N = RC. The fish factor (I) is calculated summing the priority coefficient ki of the living species.

The coefficient of priority (ki) expresses the importance of each species based on its habitat and environment; therefore, it is flexible and adaptable to any geographic context. The evaluation of the ki is mainly focused on the migratory behaviour of the species and their ecological value. It is based on two parameters: Mobility (Mob) and naturalistic Value (Vn) to which a score has been attributed. The sum of the two parameters squared, constitutes the coefficient of priority for fish: $ki = (Mob + Vn)^2$ *(4)*

The parameter Mob depends from the ability of fish to make more or less long migratory movements. Such value is maximum for large diadromous migratory species, and minimum for non migratory species. The scale is shared in 6 classes with score from 0 to 5.

The parameter Vn depends on the classification of a species under IUCN (International Union for Conservation of Nature) or other appropriate legislation on biodiversity conservation. The scale can assume values comprised between 0 and 1. Vn= 1 was assigned to species inserted in lists both at the national and regional level; Vn= 0.5 for the species found only one list (or national or regional level); Vn= 0 was for unprotected species. Undesired species don't contribute in the summary and they are given a value of 0. Once the composition of fish community has been determined, the fish factor can be calculated by summing the ki of every specie (Tab. 1). To make the total indexes calculation easier, a special software called Priority Index 1.1. was developed. The software was planned for use by administrators, specially for wildlife, management and water protection public agencies (Barneschi & Pini Prato, 2007).

Table 1 – Example of ki determination

Category	Specie	Mob	Vn	*ki*
Diadromous	Anguilla (Anguilla anguilla)	5	1	*36*
	Cheppia (Alosa fallax)		1	*36*
high migratory requirements	Barbo padano o comune (Barbus plebejus)	4	1	*25*
	Trota fario (Salmo trutta trutta)		0.5	*20.25*
moderate migratory requirements	Carpa (Cyprinus carpio)	3	0	*9*
	Tinca (Tinca tinca)		0,5	*12.25*
low migratory requirements species	Cobite (Cobitis taenia)	2	0.5	*6.25*
	Ghiozzo di ruscello (Gobius nigricans)		1	*9*
eurialine	Chelon, Liza, Mugil	1	0.5	*2.25*
	Spigola (Dicentrarchus labrax)		0.5	*2.25*
alien in Tuscany rivers	Siluro (silurus glanis)	0	0	*0*
	Pesce gatto (Iactalurus melas)		0	*0*

2.3 Methodology

The level of river fragmentation was analyzed by studying cartographies and aerial photos to identify weirs and hydraulic obstacles. Subsequently, we conducted field surveys to verify remote sensing data" and for the integration of lacking data. For every obstruction, the height, distances downstream and upstream was recorded and every obstruction is identified with an acronym containing the progressive number from downstream to upstream (example: AR02 is the second obstruction of the Arno going upstream). Another form was completed for obstructions equipped with fishpasses. Finally, each obstruction was given a qualitative score on the possibility of fish overcoming each obstruction. The data collected were use to calculate the morphologic factor Mt and Ms.

To establish the fish factor I of every reach and watercourses, the characteristics of the fish communities were determined through consultation of official documents from provincial fishery offices. Moreover, these data were integrated with interviews of fishermen, unpublished data of fish samplings, and personal observations. We also conducted field sampling in reaches with little available data.

3. RESULTS

The river fragmentation of the study area is showed in the following table (Tab.2):

Table 2 – Fragmentation in the study area.

	Arno	Elsa	Greve	Corsalone	Sieve
Analyzed lenght (km)	224.8	30.9	19.2	8.1	48.1
N°of weirs	37	12	13	7	6
N° of fishpasses	4	2	0	1	0
N° efficient fishpasses	0	0	-	0	-

The high morphologic factor reaches were the Arno Planiziale, the Arno Casentinese and the Sieve rivers. The Greve River and the Corsalone Torrent had a very low Mt factor.

Concerning fish factor, watercourses of greater dimensions had a greater wealth of species, many of them allochthonous; on the contrary, small torrents like the Corsalone, were characterized by the presence of low number of protected species and often had a lower I factor (Tab. 3).

Table 3 - Classification of Mt (Morphologic factor) and I (Fish factor) for Arno River and tributaries

Arno River			Tributaries		
reach	Mt	I	watercourse	Mt	I
Arno Planiziale	0.54	270.75	Sieve	0.50	242.5
Arno Casentinese	0.48	230.25	Elsa	0.10	161.25
Sistema Invasi	0.14	153.50	Greve	0.07	152.25
Arno pedocollinare	0.10	241	Corsalone	0.06	119.75

The IPt index has been calculated in order to define the level of priority of single reaches of the Arno River and its tributaries (Tab.4). Also the priority map of IPt has been arranged (fig.1).

Table 4 – Priority level calculated by IPt (Priority Index for Total reach)

priority levels	Arno River		Tributaries	
	reach	IPt	watercourse	IPt
1° - max	Arno Planiziale	146.20	Sieve	121.25
2° - high	Arno Casentinese	109.39	Elsa	16.82
3° - moderate	Arno Pedocollinare	24.00	Greve	10.18
4° - low	Sistema Invasi	20.85	Corsalone	7.57

Figure 1 – Map of IPt priority (Priority Index for Total reach); the points represent the obstructions

The IPs index was also calculated for each obstruction of the Arno River in order to verify the priority of obstructions in each reach. The following scheme (Tab. 5) shows the results and the order of the possible interventions.

Table 5 - Priority level of reaches (level) and obstructions within reaches calculated by IPs (define) for Arno River

order of priority	Reach			
	1st level Arno Planiziale	2nd level Arno Casentinese	3rd level Arno pedocollinare	4th level Sistema Invasi
1	AR05 La Bassa	AR36 Subbiano	AR22 Gualchiere	AR31 La Penna
2	AR06 Avane	AR35 Ponte Caliano	AR19 Anchetta 2	AR29 Levane
3	AR07 Stadio	AR32 Giovi	AR28 Acquedotto	AR La Penna 2
4	AR08 La Torre	AR33 La Lama	AR13 S. Niccolò	
5	AR09 Camaioni	AR34 La Nussa	AR23 Rignano	
6	AR01 Caprona		AR21 Ellera	
7	AR02 La Botte 1		AR12 S.Rosa	
8	AR03 La Botte 2		AR20 Oleificio	
9	AR04 Scolmatore		AR11 Cascine	
10	AR10 Porto di Mezzo		AR24 Bruscheto	
11			AR15 Nave a Rov	
12			AR18 Anchetta 1	
13			AR27 Incisa 3	
14			AR26 Incisa 2	
			AR25 Incisa 1	

4. DISCUSSION

The recommended order of the restoration of connectivity of the Arno River is as the follows: The maximum priority (1st IPt level) is assigned to the Arno Planiziale reach, due to the elevated value of the morphologic and fish factors. The score is also very high because of the presence of highly migratory diadromous species. The Arno Planiziale is a very important ecological corridor for the upstream migration of protected species such as shad (*Alosa fallax*), sea lamprey (*Petromyzon marinus*) and *Mugillidae* that could recolonize currently inaccessible breeding areas. The high priority level (2nd level IPt) is assigned to Arno Casentinese reach because of the morphologic factor. The fish factors is also elevated in this reach because of the presence of mixed communities of Salmonids and Cyprinids – communities typical found in reophilic fluvial areas. The 3rd level priority (IPt moderate) is assigned to Arno Pedocollinare reach: it has a higher fish factor than the Arno Casentinese reach because of the existence of fluvial habitats for reophilic and limnic Cyprinids; however, it possesses an elevated degree of fragmentation, which results in a low morphologic factor Mt value.

The plan of reconnection of fluvial continuity could be particularly difficult from an economic point of view. Moreover, the greatest threat seems to be the presence of alien species. The 4th level priority (low IPt) is assigned to the reservoirs reach. Because of the presence of two large high dams, the river reach is now two lakes. Building fishpasses on two 30 m high dams would also be costly. A restoration project appears very difficult and there probably isn't an ecological justification because of the absence of fish with high migratory requirements.

Regarding Arno's tributaries, the maximum priority level is the Sieve River. This is because of both the elevated level of continuity, which corresponds to the maximum value of morphologic factor Mt, and for the reophilic Cyprinid fish community, which corresponds to the maximum score of I. The 2nd level priority is assigned to the Elsa River because of the low degree of fragmentation and because it would be optimal habitat for eel (*Anguilla anguilla*). The recovery of the continuity of the Arno Planiziale would be a very favourable action and probably be most effective for conservation of the diadromous species. The 3rd level or moderate priority is assigned to the Greve River. The impacts on fish population depend not only on the high level of longitudinal fragmentation, but also on anthropogenic disturbance and because of high number of allochthonous species. Moreover, urbanization has altered the territory and drastically diminished the fluvial functionality. The programming of works on the Corsalone Torrent has the lowest and fourth level priority. The restoration of the continuity in the Corsalone, can, however, be important if it is focused on the critical points of discontinuities. The Corsalone, like the greater part of the torrents and upper course of rivers, represents a watercourse typology where the complete recovery of the fluvial continuity is often very difficult, and also not entirely useful because of the presence of natural discontinuities. The lower courses of these torrents are often important habitat for small species characterized by reduced migratory requirements and, generally, the confluence with the main river areas represent the only suitable reaches for migratory species.

5. CONCLUSIONS

The planning of the restoration of river continuity for fish was based on the calculation of priority indexes. The integration between the numerical results and qualitative considerations such as the personal knowledge of the studied areas, the methodology of the interviews of fishermen and local populations, and the historical memories of the presence of migratory species are necessary. The fishpass program can, however, be modified: every situation of restoration of existing hydraulic structures, or adaptation of them for hydroelectric use, could be opportunities for fish pass construction, even if the obstruction is not high priority.

The next step of the proposed methodology is "how" to design the fish pass. Thus, there is also a chapter called Guide Lines for Fishpass Design which provides the technical support for the improvement of the works. In fact, it is essential that administrations involved in watercourses management be equipped with technical instruments for fish pass design, evaluation and appraisal. Because of the absence of specific management of fish passes in Italy, there are many erroneous fish passes and all those observed in this study were ineffective and poorly designed. Therefore, as final phase of this study, an operating committee for the Arno River Watershed was proposed. They would have the authority to develop a number of actions for fishpasses and river reconnection. The proposal committee, called the Technical Commission of Fishpasses Evaluation, would have as main objective the appraisal of validity of fishpass planning.

The Commission must be composed of a multidisciplinary group of specialist with expertise in river hydraulics, freshwater ichthyology, and applied ecology. Furthermore, the Commission should have as auxiliary tasks: establishing fishpass monitoring, river reach prioritization on its watershed, characterization of critical zones, and the allocation of resources for river restoration. The last aim of the Commission should be educational: preparing technical staff in the competent administrations, how to apply to the Guide Lines Guide for fish pass planning and the use of the software Priority Index 1.1.

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STURGEON SPECIES AS AN INCENTIVE AND INDICATOR IN RIVER RESTORATION AND INTEGRATED TRANS-BOUNDARY WATER MANAGEMENT IN THE URAL RIVER BASIN

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ABSTRACT

Sustainable watershed development should consider three main components, i.e. economic, social and environmental aspects. However, to address all three components in a balanced way might be difficult in real-life watershed management. It is suggested to use sturgeon species as a natural indicator in the Ural River basin. Preserving sustainable sturgeon populations can be seen as an incentive for successful transboundary IWRM cooperation. The Ural River, the only free-flowing river in the Caspian basin, is a unique ecosystem with a preserved natural hydrological regime and it hosts the last sturgeon spawning habitats. It contains the only self-sustaining, viable sturgeon population capable of natural reproduction. However, five of the six Ural sturgeon species are listed in the IUCN Red Book as endangered or critically endangered. The presence and well-being of this worldwide flag species in a river network indicates the “good quality” of the river ecosystem health. Activities towards successful integrated water management will secure preservation and even restoration of sturgeon population.

Community-based management of sturgeon stocks also resolves social and economic problems through restoration of the traditional life style of local communities, exclusively focused on sustainable utilization of aquatic resources, e.g. through fishing.

The high economic and social values of sturgeon allow the combination of both ecological and socio-economic aspects of sustainable development. The Ural River Basin Project (http://uralbas.ru) aims at the establishment of an international Ural Sturgeon Park, sustainable basin development, IWRM and sturgeon restoration.

Key words: watershed management, river basin, integrated water resource management, indicator species, sturgeon, integrated environmental assessment, community-based environmental protection, Ural river, Cossacks, integrated modelling

1. INTRODUCTION

Water resources mismanagement may not only result in a breakdown of economic activities, but also in biodiversity loss, habitat degradation, as well as social and political tensions.

The need for a holistic cross-sectoral approach to water resources management is increasingly recognized and has resulted in a drastic increase in the number of watershed management programs worldwide.

Though the issues of sustainable watershed management and development are widely discussed, there is no uniform terminology accepted by all stakeholders nor consensus on the best way to achieve sustainability in water resource use. Nevertheless, some fundamental principles underlying best management practices are common for most approaches.

Despite the international consensus on the need for an integrated approach to sustainable river basin management, practical implementation of these appropriate principles is difficult.

2. IRWM PROBLEMS AND OBSTACLES FOR SUCCESS

The concept of IWRM is closely linked to the idea of sustainable development (SD). Both concepts, SD and IWRM, have difficulties in definitions and practical implementation (Anthony et al. 2003; Jewitt 2002; Jonker 2002). Apart from the conceptual problems there are a number of obstacles in practical IWRM implementation.

The first commonly accepted principle recognizes a river basin as the most appropriate unit for considering the management of water resources. Nowadays this principle is mentioned in almost every water management-related directive or policy recommendation, though rarely duly realized even in national environmental management practices.

Another undisputable point in the theory of IWRM is that sustainable development of watersheds should consider three main components: economic, social and environmental. However, as a rule the first priority in water use is given to economic development at the cost of environmental needs.

The very definition of "sustainable" applied to water use is a vague concept (Hedelin 2007; Lagutov 1995). Not only different stakeholders and water users, but also different scientists define this concept in often contradictory ways. This creates problems for a participatory approach, one of the pillars of sustainable watershed management. Apart from that, particular and essential ecological water services such as biodiversity needs are often not considered by stakeholders. Hence, these needs are often neglected even in case of participatory decision-making.

Another basic yet controversial IWRM principle is the introduction of the economic analysis of water use (EU 2000). Assessment of a certain species extinction in monetary terms or, even more, economic comparison of such a loss to, for example, electricity generation, is hardly possible. In addition the integrated watershed management is often complicated by the transboundary nature of the river basins.

New approaches should be sought and applied to integrated water resources management to make it an effective tool in practical environmental management. These approaches should be based on an ecosystem sustainability, e.g. water cycles, and non-disruptive character of human activities with regards to ecosystem functions.

3. IWRM INDICATORS

Careful selection of appropriate indicators in altered watersheds is an essential part of sound policy and decision-making in IWRM. On the one hand, these indicators should integrate the long-term temporal and spatial basin-wide environmental characteristics of a watershed. On the other, it should ideally be possible to assess the socio-economic activities in a watershed using this indicator. However, indicators in general and integrated indicators in particular are still not a well elaborated aspect of IWRM (Chaves and Alipaz 2007; He et al. 2000).

There are many indicators and indices suggested to evaluate the progress in a particular aspect of the IWRM process. For example, the number of published articles or sent messages to stakeholders are suggested as indicators of public participation or awareness raising in IWRM (Hedelin 2007).

Another case study for indicators use in IWRM can be drawn from the WFD. A long list of different indicators of “good ecological status” is suggested. These indicators are isolated and treated separately, which by itself cannot result in sound policy. Most of these indicators concentrate on water quality. At the same time, other river-floodplain system characteristics (i.e. habitats fragmentation), economic or social aspects are either not taken into account or inadequately considered.

In comparison to isolated indicators of the physical environment, economic or social aspects of the IWRM process, the ecological and biodiversity indicators are usually either not taken into account or little attention is paid to them in water management practices.

Given the holistic, “integrated” nature of IWRM it is essential to introduce some basin-wide indicator of sustainable watershed development which can bring together different sectors and stakeholders concerned with IWRM. This indicator should also encourage involvement of different disciplines related to water management as well as incorporate concerns of ecological, socio-economic and policy aspects of sustainable development.

4. URAL RIVER BASIN

The Ural River, the third longest river in Europe, forms the traditional boundary between Europe and Asia. It has its spring on the South-eastern slopes of the Ural Mountains and flows into the Caspian Sea. The Ural river is the only river in the Caspian basin that is free-flowing and non-regulated in the lower and middle reaches.

Thanks to the natural hydrological regime of the Ural, riverine biodiversity has not deteriorated as much as that of other large rivers. The Ural River contains the only available spawning and wintering habitats of worldwide famous sturgeon species which are protected under numerous international conventions. This feature is unique as most of the rivers of the Northern hemisphere have undergone severe anthropogenic alterations (i.e. damming, channelization, etc).

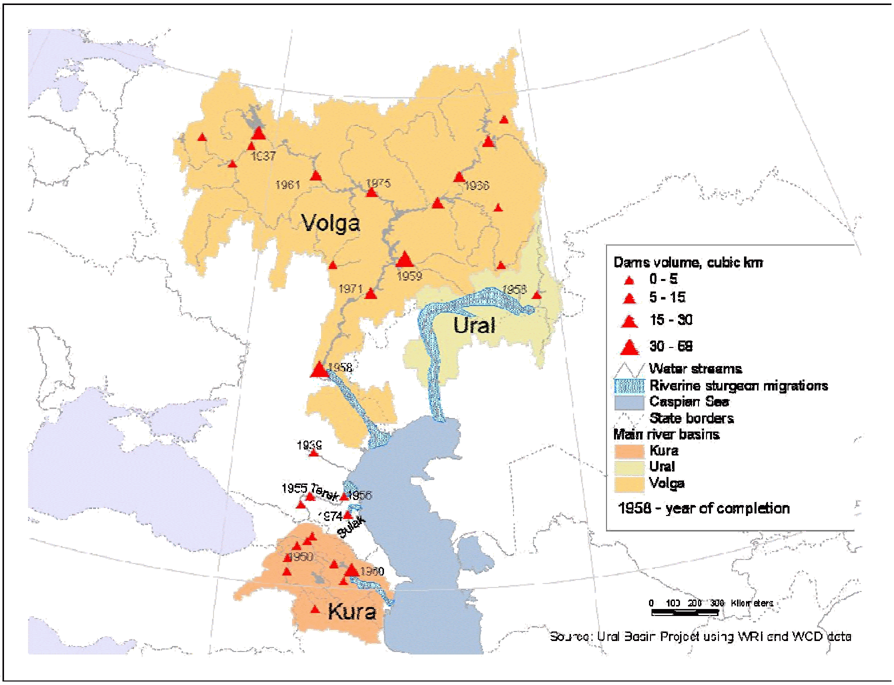

Figure 1 – The dams and sturgeon habitats in the Caspian river basins (Source: Ural Basin Project)

The Ural river basin is shared by only two countries, Russia and Kazakhstan. 72% of its total runoff is formed in the Russian part of the basin.

Although Russia and Kazakhstan are both remnants of the Soviet Union and at that time had a single indivisible water management system, at present official transboundary cooperation on water management and regional environmental issues is almost negligible.

5. SUSTAINABLE STURGEON POPULATION AS AN INCENTIVE FOR TRANSBOUNDARY INTEGRATED WATER MANAGEMENT

Being a unique ecosystem, the Ural river basin provides an encouraging incentive for transboundary IWRM, i.e. the preservation of the sturgeon species.

There is no need to describe the importance of sturgeon conservation and worldwide concern over the sturgeons' fate. Besides this species high ecological value sturgeon, caviar is synonymous with luxury and wealth worldwide. The importance of this flag species preservation is acknowledged by many international Conventions and Agreements (FAO 2007; WWF 2002a).

Sturgeon is an anadromous species, whose reproduction takes place in freshwater with the growing phase in the sea. Spawning habitats are located in the upper branches of rivers. After maturation in salted water sturgeons migrate back to freshwater for the purpose of breeding. Their size varies from 0.5 to 6 meters and from 0.5 kg to 1.5 tons. Sturgeon is a long-lived fish standing at the top of food web.

Out of six different sturgeon species inhabiting the Ural river basin, five are listed in the IUCN Red Book as endangered or critically endangered (IUCN 2007).

Extinction of sturgeon, probably, is one of the most tragic and representative examples of the destructive influence of humankind on Nature. Sturgeon, sometimes called the "living fossil" or living "dinosaur" of the fish world, is known to have existed since the time of the dinosaurs, for at least 250 million years, and is currently on the verge of extinction solely due to anthropogenic impacts.

The drastic decrease in the sturgeon populations of the Caspian Basin is believed to be caused by various reasons (i.e. overfishing, pollution, etc), but the main ones are habitat degradation and blockage of the spawning places and migration routes by dams on the main basin rivers (Uralbas 2007). From this perspective the Ural River is unique since it contains the only sturgeon population capable of natural reproduction. The future of the whole Caspian sturgeon stock and worldwide restoration programs depends on the Ural River spawning and nursing habitats.

The sturgeon spawning grounds in the Ural River are located on the territory of Russia, while the migration routes, nursing and feeding habitats are in Kazakhstan. Thus, the sturgeon can be preserved only by joint efforts and transboundary cooperation in river basin management. Taking into account the high economic value and worldwide demand for sturgeon, maintaining its natural reproduction and sustainable extraction is a genuine interest of the basin countries. In order to secure this possibility integrated sustainable management of water resources in the basin should be assured.

Figure 2 – The Ural Basin with water reservoirs indicated

Though the importance of the Ural River basin sturgeon habitats for the conservation of the whole Caspian Sturgeon population is well understood, practical measures which have been undertaken so far in this area are not satisfactory. Sturgeons are high on the international political agenda nowadays and this region increasingly attracts attention from international and national institutions.

6. STURGEON POPULATION AS AN INDICATOR OF THE SUSTAINABILITY OF WATERSHED MANAGEMENT

Apart from its high economic value, sturgeon is a perfect indicator (an umbrella) species for the river basin it inhabits (Lagutov 1995; Lagutov 1996, 1997; Uralbas 2007). The presence and well-being of the sturgeon population in a river network indicates the "good quality" of a river's ecosystem health.

Sturgeon meets the requirements for integrated IRWM indicator discussed above.

Sturgeons utilize a variety of habitat types throughout their life cycles: rivers for spawning; rivers, lakes, estuaries, or the sea for feeding and wintering. Depending on life stages sturgeon habitats are spread through the whole river network, estuaries and adjacent marine areas. Living in the Caspian Sea and regularly migrating for spawning to the upper river branches in Russia through the territory of Kazakhstan, the Ural sturgeon population links up the marine and riverine ecosystems.

The most critical factors for the Ural sturgeon populations are over-fishing, flow regime and habitat degradation, which depend on both environmental and anthropogenic factors.

Second, there is no natural predator of mature sturgeons, so apart from fishing mortality the sturgeon population is a function of river environmental conditions, which can to a great extent be controlled by IWRM.

Next, the sturgeon life cycle lasts up to 100 years which is almost the double of the expected life duration of a human being. Taking into account its top position in the food chain (like human beings) and the fact that sturgeon is a subject for bioaccumulation, sturgeon is a good integral indicator of water quality over a long period of time.

The presence of a sustainable sturgeon in the river indicates the natural character of the hydrological regime, including regular floods and river self-purification.

Sturgeon is sensitive to physical characteristics of a river, e.g. blockage of migratory routes, excessive water abstractions, habitat degradation and fragmentation, siltation, pollution, water quality, etc. and can hence be seen as an indicator of the ecological health of the aquatic system. Some of the aforementioned factors directly depend on the land use patterns in the river basin due to water runoff from the catchment area.

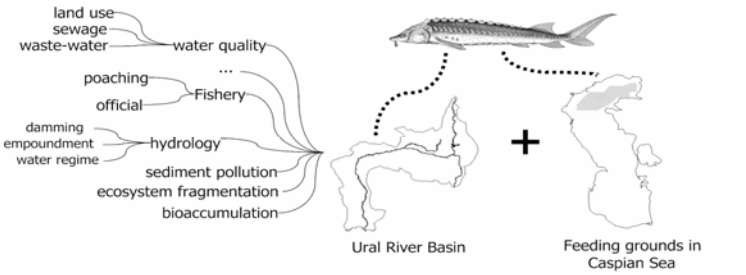

Figure 3 – Sturgeon as an indicator of river ecosystem health

Sturgeons are also representative for regional economic development and social structure, as poaching and illegal fishing which reduce sturgeon populations development in areas with a poor unemployed population. For example, the WWF's European Freshwater Programme considers Sturgeons as Flagship species, Species of special concern and Indicator species (WWF 2002a, 2002b).

It is obvious that securing natural sturgeon reproduction, protection and sustainable management of sturgeon stock is directly linked to integrated water resources management in the river basin and sustainable watershed development. These activities influence each other and should be considered only in an integrated manner.

The measures aimed at preservation and sustainable management of the Ural sturgeon population can combine environmental and socio-economic aspects of sustainable development and underpin the strategies for sustainable watershed development.

7. PUBLIC PARTICIPATION

Public participation is one of the essential principles of IWRM and sustainable watershed development. Any nature protection activities are ineffective if they are not supported by local communities.

High level of public participation can be easily achieved in the Ural watershed. Active cooperation of local communities with regional authorities might be possible thanks to the peculiarities of regional identity. This area is historically populated by Ural Cossack communities, a self-governing paramilitary ethnic group. Cossack troops were traditionally involved in various State services in Russian Empire. In exchange for military service they enjoyed exclusive rights to control natural resources on their territory (e.g. fish and water) and paid no taxes (Semple 1907).

The Ural Cossacks' historical settlements are stretched in a line along the banks of the Ural river for more then 450 km. The Ural Cossacks' Land closely matches the shape of the Ural basin, covering all sturgeon habitats.

The traditional life style of the Ural Cossacks directly relates to the issue of sustainable water management in a river basin. Living in harsh environmental conditions characterized by low soil fertility they had to fully rely only on the river ecosystem to support their communities. Consequently, all the aspects of water usage and fishery were very carefully described, regulated and enforced. There were fishery and water laws. Out of two elected commanders (atamans) one was a military commander, while the other one was solely responsible for river-related issues (e.g. fishery). Special troops used to guard the rivers during spawning migrations.

Sturgeon and river worshipping by Ural Cossacks was reflected on their coat of arms: sturgeon and water were the only items depicted on it in addition to their weapons.

Unfortunately, this interesting experience of sustainable river-related management was not adequately reported in the Soviet, and correspondingly, foreign literature, due to the persecution of Cossacks by the Soviet regime during the 20th century.

Revival of the Cossack movement is a widespread phenomenon through the whole territory of Russia nowadays. Recovering from repressions they are actively looking for their place in modern society and possibilities of State Service, demanding changes in legislation and society structure.

The involvement of local communities in nature protection activities (e.g. establishment of ethno-natural protected territories) in the Ural river basin may not only protect the sturgeons and ecosystem of worldwide concern, but also stabilize the social and economic situation in the region by providing employment. In this case, Cossack groups can be effectively used for guarding the protected areas to prevent poaching and serving as rangers.

8. URAL BASIN PROJECT

The Ural River Basin Project was launched to facilitate the sturgeon restoration and sustainable watershed management in the Ural River Basin in 2007. The Project is a joint initiative by the Central European University and the Research Center “DonEco”.

The underlying idea of the Project is the concept of sustainable basin development by securing natural reproduction of autochthonous migratory sturgeon species. In order to assure the implementation of this idea, an international Ural Sturgeon Park should be established which should extend along the sturgeon migration routes and habitats from the spawning grounds in the upper branches of the Ural to the river mouth. Such a Park should also become a Biosphere Reserve and Ethno-Natural Protected Area. Integrated water management and community-based management of sturgeon stocks can be the basis for sustainable basin development. In this way the Project aims not only to preserve this flag species, but also to solve social and economic problems by restoration of the traditional life style of local communities.

The scope of the Project covers different environmental disciplines and anthropogenic activities related to the well-being of the sturgeon population, taking into account the triple function of the sturgeon in the river ecosystem (as indicator species, flag species and species of special concern). By adopting this holistic, integrated approach the Project will be a focal point for specialists on water quality, fishery, international and national environmental law, as well as sturgeon experts.

While the establishment of a Ural Park seems to be long-term distant goal, other activities have been carried out in the framework of the Project. Public awareness rising has been approached through a number of regular publications in regional and local mass-media. The website of the Ural Basin Project was launched at the beginning of 2007. A number of research projects on river management and biodiversity have being also undertaken in cooperation with regional organizations (i.e. GIS databases creation, river ecosystem and sturgeon population modelling).

The First Ural River Basin International Workshop “Rescue of Sturgeon Species by means of Transboundary Integrated Water Management in the Ural River Basin” was held in Orenburg (Russia) on June 13-16, 2007 within the framework of the Ural Basin Project. More information on this and other Project activities can be found on the Project’s website at http://uralbas.ru.

9. CONCLUSION

Sturgeon species can be considered an excellent natural bioindicator of a river basin’s health – in this case the Ural river basin. Their conservation will also serve the Region’s sustainable economic and social development.

Appropriate experiences and practices from the UralBas project can be applied to worldwide sturgeon restoration and watershed development programs.

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CHAPTER 4

Session 3

River Restoration and EU Directives

Chairpersons

T. M. IVERSEN, G. NEVEU

Introduction
RIVER RESTORATION AND EU DIRECTIVES

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No doubt environmental issues were not a top priority of the political agenda in 1957 when the Rome Treaty were signed by six countries and what is now known as the European Community was formally established. Today 27 countries are members of EU.

In the mid 1970ies environmental issues came on the EU agenda. One of the first pieces of EU-legislation related to rivers was the Surface Water Directive (1975) but more important was the Freshwater Fish Directive (1978) setting quality objectives for designated fresh waters to support fish life. In 1992 the Habitats Directive was agreed aiming at securing good conservational status for species and habitats of Community importance. However, in the mid 1990ies it was recognized that the EU legislation on water consisted of many fragmented pieces, which were far from coherent, and the process started towards the decision on the EU Water Framework Directive adopted in 2000.

The session on River restoration and EU Directives started with a presentation of the Spanish strategy of river restoration, which is unique on European scale in recognizing river restoration as one of the key measures to achieve compliance with the WFD. The session also included presentations on specific experiences with river restoration in a number of countries as well as presentations on methods and approaches to the tool box.

In these days water authorities all over Europe are preparing water plans, which will be sent in public hearing 2008/2009. The plans shall be implemented no later than 2012 in order that good ecological quality can be achieved by 2015. Judged from the presentations only in Spain the river restoration community is formally involved in the national WFD process.

In Denmark a preliminary study showed a need for restoring 3,000-5,000 km rivers in order to achieve good ecological state. Although it is impossible to extrapolate to a European scale a good guess of the need for river restoration might be in the magnitude of 100,000 km rivers to be restored by 2015. This will be a golden opportunity for the river restoration community to bring all their experiences into this process wherever possible. Similarly it is a golden opportunity for ECRR to secure a continuous exchange of knowledge and ideas and not least to provide the updated overview of “best practises”. Hopefully there will be a significant improvement of the European rivers in the coming years and hopefully the experiences and knowledge presented at this session and at this conference have contributed to this success.

4th ECRR Conference on River Restoration
Italy, Venice S. Servolo Island
16-21 June 2008

THE SPANISH NATIONAL STRATEGY FOR RIVER RESTORATION

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ABSTRACT

The Spanish Ministry of Environment has recently defined the National Strategy for River Restoration. This is an ambitious strategy that promotes restoration and rehabilitation works in river and streams, in order to fulfill the Water Framework Directive requirements in time.

The Strategy is conceived as a *compendium* of multiple principles and activities arranged in successive and cyclic stages, in order to formulate objectives, support assistance, diagnosis, priorities, programmes and projects, and to carry out implementation, monitoring and evaluation measures. Principles, objectives and guidelines are formulated for the hierarchical levels represented by plans, programmes and projects, in all cases taking into account the catchment scale, considering effects in the medium and long term, and promoting public participation and stakeholder involvement.

The main objectives of this Strategy are (1) improve the river ecological status, (2) integrate water resources management into river management plans should and include them in sustainable land planning, (3) improve the technical training on ecological restoration works, (4) exchange and disseminate practical restoration experiences and (5) improve public participation and social learning.

Priorities and work actions are outlined in six main programmes on Education and Training, Conservation, Restoration and Rehabilitation, Volunteer activities, Administrative coordination and Research, with an estimated budget of 1.500 millions euros for the period 2008-2015.

Key words: River restoration, Spain, Water Framework Directive, National Strategy

1. INTRODUCTION

It is obvious that rivers in Spain do not often have an adequate environmental status. This is due to the intensive use and exploitation of their resources without regard to their function as ecosystems and to the fact that management and use require a new focus that is more in agreement with the principles of sustainable development and conservation of biodiversity as stated in the objectives of the Water Framework Directive.

Moreover, following the rationale of the Water Framework Directive, it is necessary to diversify and broaden the training of the technicians entrusted with the planning and management of water bodies in Spain, and to create multidisciplinary teams and forums, which can promote a debate that encourages public and stakeholders participation to the management of river systems and their natural resources.

All these circumstances have prompted the Spanish Ministry of the Environment, Agriculture and Marine Resources to propose a new conception of management of rivers while developing new lines of action (González del Tánago & García de Jalón, 2007). In this way, focuses and objectives may be updated and a policy of conservation and restoration of the rivers as ecosystems designed while making more sustainable use of the water resources. It is also foreseen that debate and public participation will be the main source of inspiration for this plan.

2. BASIC PRINCIPLES

Figure 1 outlines the main principles on which the Spanish National Strategy of River Restoration is based. Scientific concepts and principles from Hydrology, Fluvial Geomorphology, River Ecology, Floodplain analysis, Landscape Ecology, etc. are necessary to evaluate the existing ecological status of rivers, to understand the processes that cause the deterioration of the river conditions from their more natural previous ones and to cope with uncertainities related to them (see Darby & Sear, 2008). The Water Framework Directive offers valuable indicators and criteria for evaluating the ecological status of rivers, and promotes the use of reference conditions to quantify degradation and design restoration or rehabilitation measures.

2.1. An strategic environmental tool for river restoration planning

The proposed National Strategy should become a strategic environmental tool for integrated watershed management and river restoration planning (Heathcote, 1998; FISRWG, 1998). Therefore, it must integrate all the social, economic and cultural variables that affect rivers, and incorporate all the existing protection status and legislations (Habitat Directive, Ramsar Convention, Spanish ZEPA´s (Zones of special protection for birds), LIC`s (Sites of Community interest), etc.). This Strategy is also intended to be used for promoting the concentration of effort and investments for the conservation of the rivers in the best ecological status, or for the protection of those river reaches which are in good conditions but threatened by human pressures or impacts.

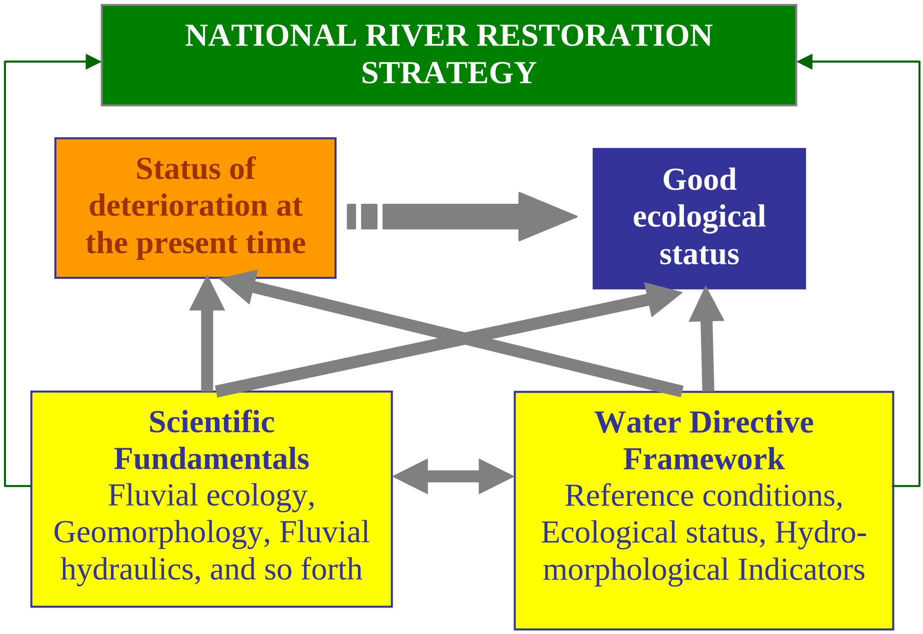

Figure 1 – Fundamentals of the National River Restoration Strategy aimed at achieving a good ecological status of the river courses through scientific-based actions promoted by the Water Framework Directive.

2.2. A strategic environmental tool for sustainable development

The principles and guidelines proposed within the National Strategy of River Restoration reinforce the concepts of sustainability, aiming to (1) relate river natural resources with river environmental services; (2) to establish a balance between economic, social and ecological benefits, at different time-scales; and (3) to transmit the concepts of environmental justice to future generations, in agreement with the Spanish Strategy for Sustainable Development approved by the Spanish Government in November 2007.

2.3. A strategic environmental tool for discussion, agreement and public participation

Finally, this National Strategy intends to integrate different river management approaches that have been implemented in a traditional way in Spain, with new and more environmentally-based approaches that have been formulated from scientific groups and NGOs, with different environmental management strategies that exist in regional administrations, and with the points of view and interests of stakeholders (van Ast & Boon, 2003). Several working groups, document reviews, web-pages, workshops, seminars, etc. have been organized during the formulation of the Strategy, in order to promote discussion and public participation, and many outcomes and projects have derived from them, which contribute to increase social learning and agreement on objectives and procedures for river restoration.

3. STAGES OF THE NATIONAL STRATEGY OF RIVER RESTORATION

In Fig. 2 the main consecutive stages of the National Strategy for restoring Spanish rivers are represented. The river image in Fig. 2 depicts the Segura river, a Mediterranean river with intensive pressures and impacts from agriculture and urbanization, in a river reach where compatibility of many water uses (irrigation, hydropower, recreation, etc.) and preservation of ecological values (water quality, biological communities, riparian vegetation, etc.) is possible, during a severe drought period (July 2006).

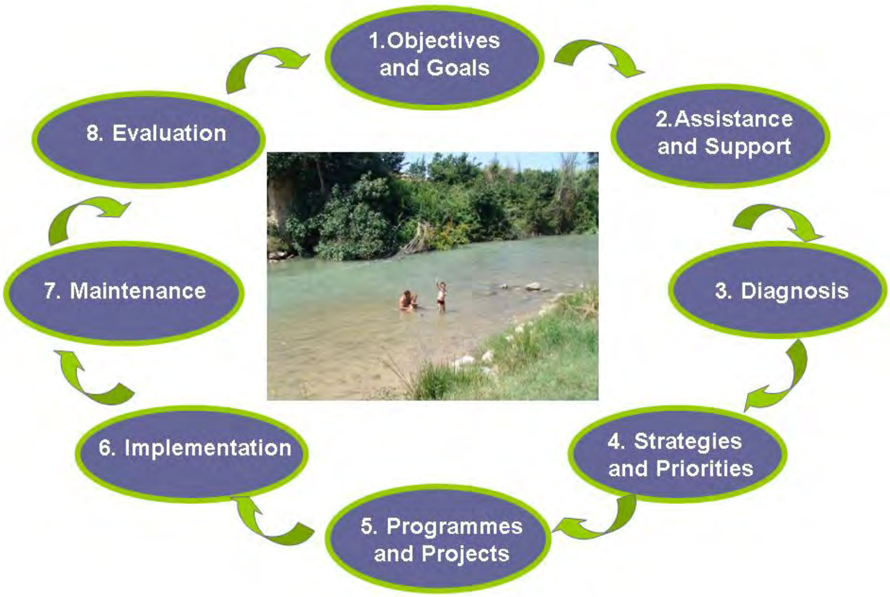

Figure 2 – Stages of the Spanish National Strategy for River Restoration

The objectives proposed within the National Strategy must have both public and scientific support. All the actions have to be based on analysis and diagnosis of main problems, according to public interests and scientific reference conditions, which will facilitate the definition of priorities and contents of programmes and projects. Implementation of activities should be conducted according to ecological restoration principles and be followed by monitoring and evaluation activities at different working scales (planning, programmes, projects). Finally, the success of the National Strategy will be evaluated according to the increase of "social capacity for river restoration", taking into account criteria based not only on invested budget and technical knowledge but also on public participation in project promotion, public confidence in river managers and social knowledge on river environmental values and river restoration benefits (Thomson & Pepperdine, 2003)

4. SUPPORT FOR THE NATIONAL STRATEGY

The creation of a national strategy has to be backed by technical and scientific support to help set out objectives and lines of action as well as social support. Such support will be the evidence of the agreement on and acceptance of the objectives and projects proposed to the riverside residents and affected groups.

Fig. 3 shows the methodology proposed for obtaining this support for the national strategy, which should be put into practice through information programmes, consulting programmes and requests for technical and scientific reports as well as public participation programmes. The most appropriate teams of specialists should be selected for each of these steps.

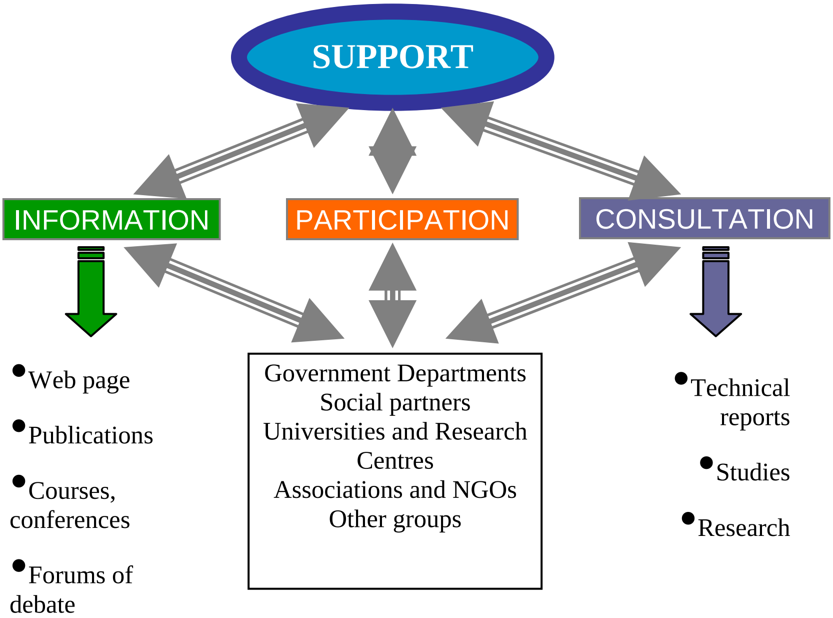

Figure 3 – Organization to obtain assistance and support based on information and implication.

5. DIAGNOSTICS OF THE PROBLEMS AFFECTING THE RIVERS IN SPAIN

All proposals for actions to enhance the environmental status of the rivers should arise from a sound knowledge of the deficiencies of their structure and functioning, referring not only to the symptoms of deterioration but also to the causes generating the problem (Nilsson *et al.*, 1991; Wissmar *et al.*, 2003). Therefore, to determine the actions required for the national river restoration strategy, we have considered the major pressures and impact on the Spanish rivers that were detected by working committees. The effects and incidence of such impacts and pressures were studied together with the possible courses of action.

The resulting documents, which are available on the Internet, highlight the following problems:

- The need to improve the training of technicians entrusted with river management, who will have to deal with new demands and regulations.
- The need to improve coordination between government departments, creating agreement on integrating river restoration in the policies of town and country planning,
- The importance of agriculture and urban development as principal pressures on the Spanish rivers, giving rise to flow regulations, dredging work and channelling, and of pollution of waters as the main impact, with a very pronounced effect on the proliferation of exotic invading species that are a serious threat to the conservation of the indigenous species.
- The need to increase surveillance of the rivers and their water flow to detect and sanction possible encroachment of the public water supply and hydraulic resources (PWSHR) and to improve public participation in the maintenance and protection of the rivers and their riversides.
- The need for studies that delimit the fluvial space, draw plans of the flood-prone areas, and analyse the status of the rivers with respect to invading species and the role of the protected areas in the conservation of the functions and services of river systems.

6. ACTION PRIORITIES

In light of the problems raised, and bearing in mind the objectives of the Water Framework Directive, we propose that the national strategy embrace the following actions, listed in order of priority and importance: (a) to avoid all further deterioration of the rivers with respect to the physical, biological and ecological status of the river courses and their floodplains (b) to conserve those river stretches in better ecological conditions through direct measures of conservation and protection or indirect measures of elimination of threats and pressures; (c) to reduce pressures and impact on the rivers; (d) to restore and rehabilitate fluvial stretches with structural and functional deficiencies.

7. DEFINITION OF LINES OF WORK

For the purpose of better coordinating the actions that can be implemented with the national river restoration strategy, we propose the following lines of work constituting different Programmes, each of which will include different execution projects (see fig. 4).

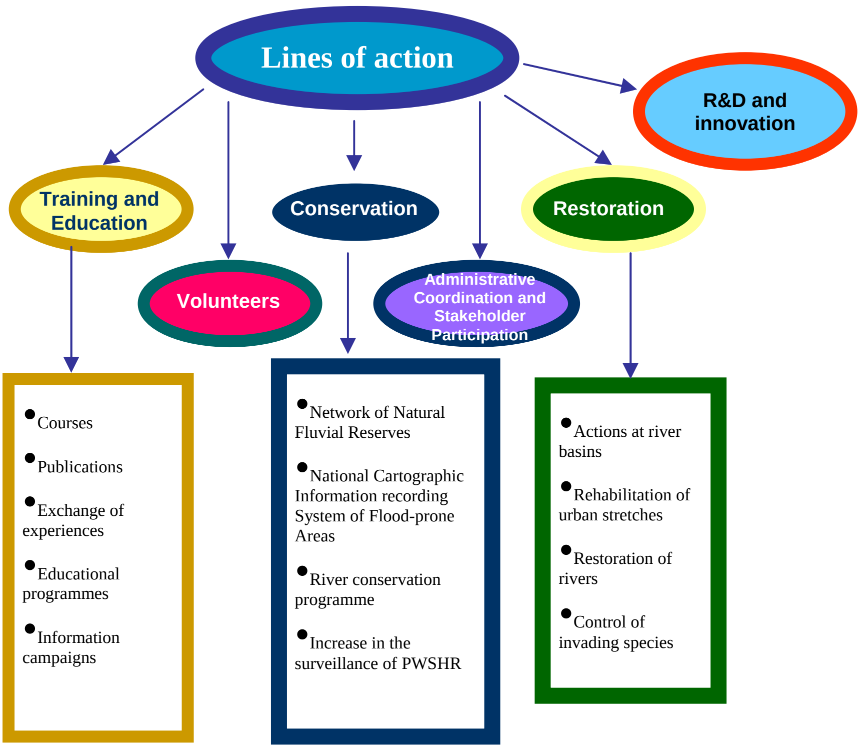

Figure 4 – Lines of action proposed for the development of the national river restoration strategy in Spain

8. CONCLUSIONS

In synthesis, we can say that in 2007 the foundations for initiating the full development of the national river restoration strategy have been laid. The Strategy will embrace a set of actions aimed ultimately at achieving an improvement of the ecological status of the rivers, implementing the conservation of scenic rivers and stretches of reference, the restoration of part of the Spanish fluvial network as well as the rehabilitation and adaptation of the stretches considered to be highly deteriorated.

At the present time, the following foundations have been laid: the methodology manual for the creation of river restoration projects has been published as well as the Volunteer's Guide to Rivers; a legal manual is about to be published while the national cartographic information recording system of flood-prone areas is underway as is the proposal of Fluvial Natural Reserves; a marked impetus has been given to the Flow Conservation Programme, and we have contracted out the compilation of 80 river rehabilitation and/or restoration projects, which are being conducted at the present time.

Figure 5 – Stretches of river initially selected for their rehabilitation or restoration in Spain

This set of actions, promoted by the Spanish Ministry of the Environment, Agriculture and Marine Resources has to be integrated with the water planning established by the respective river basin authorities in compliance with the Water Framework Directive.

In order to achieve these objectives, there will have to be an improvement in training, in the mechanisms of participation and involvement of social groups, in the setting up of multidisciplinary teams and in the capacity to implement the respective projects while establishing collaboration and sharing responsibilities.

We will also need to set up mechanisms of assessment and follow-up of the single actions and to encourage research aimed to review the decision which will be taken. We will need to design new alternatives as problems and environmental challenges evolve, and to enhance the collective capacity of Spanish society to deal with these problems and challenges.

All the information on the National River Restoration Strategy is available on the web pages of the Ministry of the Environment, Agriculture and Marine Resources at www.mma.es.

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DEMONSTRATING STRATEGIC RESTORATION AND MANAGEMENT: STREAM

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ABSTRACT

STREAM is a €1.4 million, four-year conservation project centred on the River Avon Special Area of Conservation and the Avon Valley Special Protection area in Wiltshire and Hampshire, England. The project is supported financially by the European Commission's LIFE Nature programme and contributes to achieving favourable status of the UK Natura 2000 network.

STREAM will address two key issues which influence favourable condition of the River Avon SAC and Avon Valley SPA: the need for a strategic approach to large-scale river restoration, and the need to integrate the management of the river and valley. The project is demonstrating and evaluating innovative river restoration and monitoring techniques, and methods for resolving river and floodplain management conflicts.

Key words: river restoration, floodplain, integrated management, designated sites, Natura 2000

1. INTRODUCTION

The River Avon and its major tributaries constitute some of the finest chalk rivers in the UK and Europe and support a wide range of fish, bird, mammal and plant species. They are designated as a) Special Area of Conservation (SAC) for their watercourse habitat characterised by water crowfoot, and populations of Atlantic salmon, bullhead, brook and sea lamprey, and Desmoulin’s whorl snail; and b) Special Site of Scientific Interest, supporting species and habitats such as otter, water vole, wet woodland and reed beds.

The Avon Valley includes one of the largest expanses of unimproved floodplain grazing marsh in Europe. It is designated as a) Special Protection Area (SPA) for gadwall and Bewick’s swan and b) Special Site of Scientific Interest floodplain grazing marsh supporting a complex mosaic of wetland habitats, breeding waders and wintering wildfowl.

The River Avon SAC is threatened by many factors, such as historical engineering work, pollution from agricultural and other sources, low flows, and abstraction. Conditions for breeding waders and wintering birds in the Avon Valley are currently unfavourable, largely due to neglect of the watercourse network and inappropriate water level management.

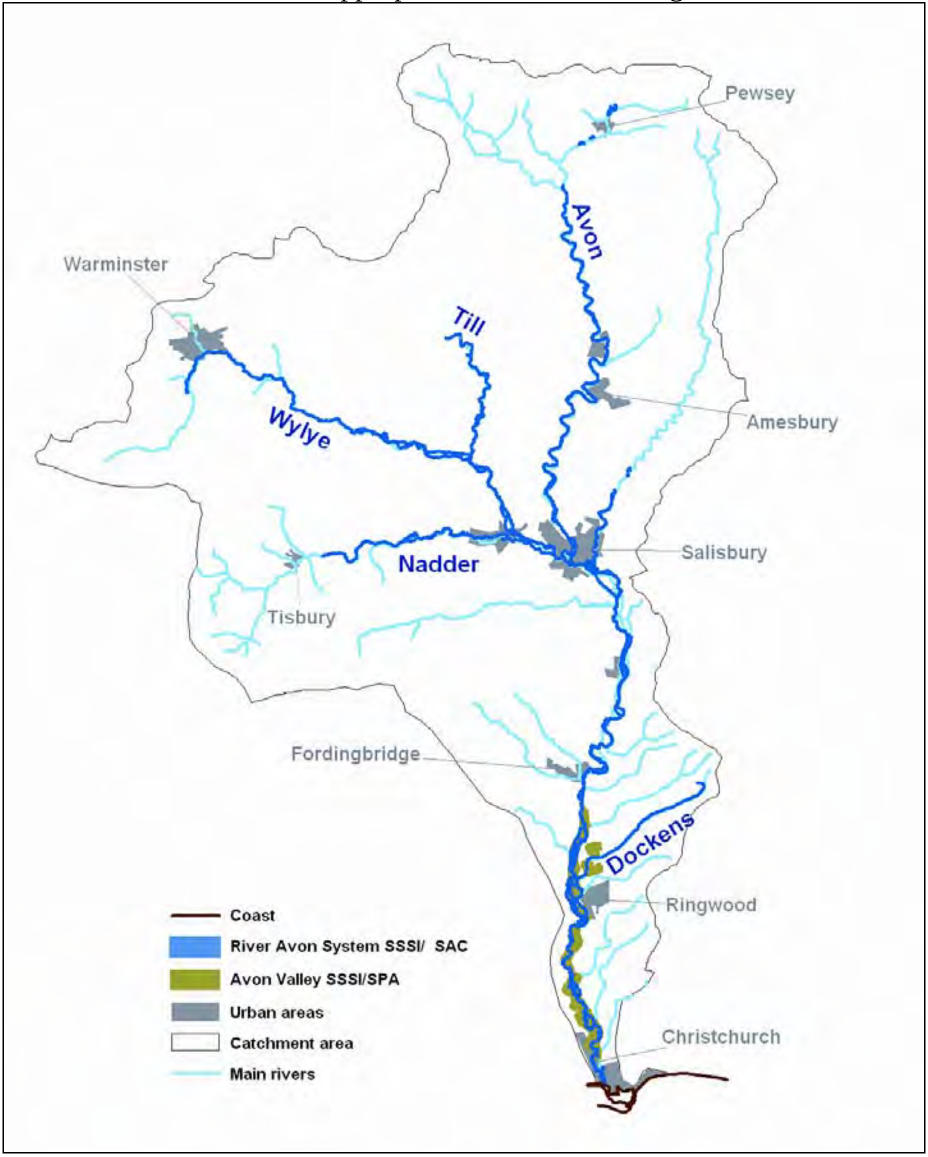

Figure 1- The River Avon catchment showing European and UK designated sites

1.1 River Avon Conservation Strategy

A Conservation Strategy for the River Avon Special Area on Conservation (Wheeldon, 2003) identified the main threats to the ecological health of the River Avon SAC, and agreed on a range of actions required to address them. It also highlighted the complex relationship between the River Avon and the Avon valley.

To address the outstanding threats identified in the Strategy, two major partnership projects were created: the STREAM Project focusing on restoration of the SAC (running since September 2005) and the Living River Project which focuses on wider biodiversity of the River Avon system and engaging communities with its conservation.

2. STREAM

STREAM will address two key issues which influence favourable condition of the River Avon SAC and Avon Valley SPA: the need for a strategic approach to large-scale river restoration, and the need to integrate the management of the river and valley. Between 2005 and 2009 STREAM will carry out the following actions:

1. River restoration - demonstrating restoration of seven kilometres of river on a total of six sites on the Avon, Nadder, Wylye and the Dockens Water. The works aim to address habitat degradation due to past engineering.
2. Monitoring the physical and biological effect of the restoration work in order to determine if is has been successful, and to inform future restoration work.
3. Linking river and valley - contributing to linking management of water levels in the river and valley by identifying ways to stop fish species getting trapped in the valley ditch networks, developing a prioritised programme of ditch restoration, and developing and testing operating regimes for key sluices.
4. Events - Organising open days and seminars for the public, land managers and river restoration specialists, raising awareness of the river system and sharing what we have learned during the project

2.1 River restoration

STREAM is restoring seven kilometres of river in the River Avon SAC to a more sustainable size and shape, improving its ability to support aquatic habitats and species such as Atlantic salmon and lamprey. The restoration of the reaches will contribute to achieving favourable condition of the European designated site. The project will demonstrate innovative techniques and proven habitat enhancement methods, and share best practice through advice notes, demonstration days, seminars and community conservation days.

River reaches most heavily damaged by historic management in the catchment were identified using the available survey, biological and physical data. With the help of the UK River Restoration Centre (RRC), six of theses reaches were then selected for restoration.

STREAM has completed 4 restoration projects to date, at Upper Woodford and Hale on the River Avon, Fovant on the River Nadder and in 2006. A further 2 projects will be done in summer 2008. A range of restoration techniques has been used at each site, and are summarised in Tab.1 and illustrated in Figs. 2, 3, 4 and 5.

Table 1 – Summary of river restoration techniques used by STREAM

Category of technique	**Techniques used**	**Site**
Varying flow direction and speed	D shape deflectors Islands Tree deflectors Large woody debris	Woodford Woodford Fovant Amesbury*
Low flow channel/narrowing	Chalk berm Aquatic ledge Bank re-profiling	Woodford 7 hatches Amesbury*
Raising river bed level	Riffles and woody debris Large scale riffle	7 hatch Hale
Stock watering points	Fencing and cattle drinks	7 hatches
Floodplain scrapes	Chute	Dockens water*
Water level management	Reducing impounding effect of sluices hatches	Fovant
* Planned for 2008		

A limited number of the structures were planted with vegetation., which grew rapidly. The islands, flow deflectors and causeway were not planted, but are effectively collection silt and colonising rapidly with vegetation, protecting them from high flows and stabilising the structures.

Figure 2 – Mid-channel islands (left) and chalk berm (right) at Woodford

Figure 3 – Vegetated tree deflectors (left) and reduced impoundment (right) at Fovant

Figure 4 – Constructing an aquatic ledge at 7 hatches (left) and ledge fully submerged in winter

Figure 5 – Installing the stone base (left) which was then topped with gravel to create a spawning riffle at Hale

At Fovant and Woodford, the in-channel vegetation community has responded well to the restoration work, with increased growth and diversity of plant species. The gravel riffles at Hale and 7 hatches have been successful, having been used for Atlantic salmon and brown trout spawning just three months after completion.

Technical details of the river restoration work will be published in the River Restoration Centre Manual of Techniques and on the STREAM project website in spring 2009. River restoration practitioners, land mangers and statutory bodies from the UK and Europe will also be invited to attend seminars and workshops to view and discuss the results of the project.

2.2 Monitoring

Restoration is seen increasingly as a means of attaining ecological integrity and habitat heterogeneity in river systems. STREAM has developed a cost effective monitoring protocol which sets out rapid and detailed techniques for assessing how successful the restoration has been against physical and biological criteria (Royal Haskoning, 2007). The protocol is summarised below, and available in full on the project website.

The River Restoration Centre is currently developing a framework capable of providing guidance about the range of river restoration monitoring methodologies available and the level of monitoring needed for a given project size and set of objectives. The STREAM monitoring work will inform the development of this framework.

In the UK, the condition of Natura 2000 sites is assessed every six years to inform the UK's reporting on the conservation status of European protected species and habitats. Common Monitoring Standards have been developed by the Joint Nature Conservancy Committee, and are applied across the UK. The overall condition of the River Avon SAC (including the restoration sites) and Avon Valley SPA will be assessed using this methodology in future.

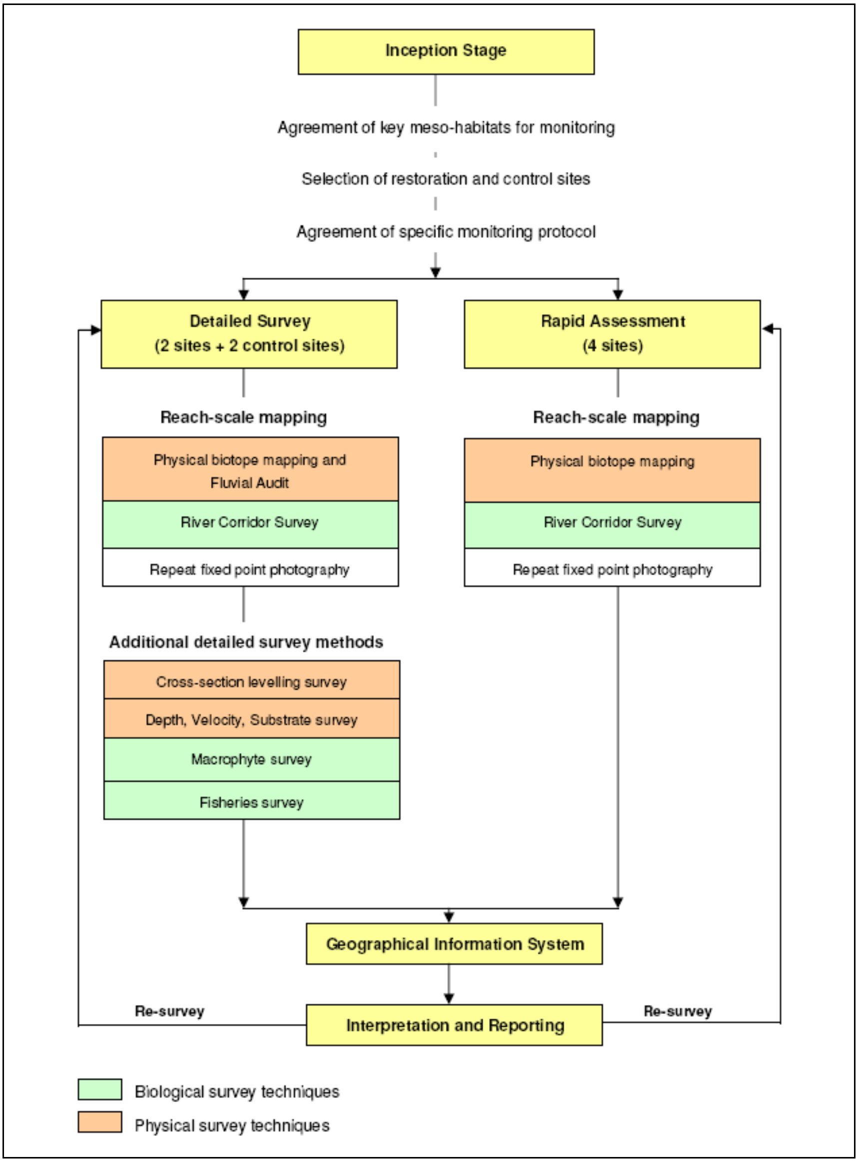

Figure 6 – Summary of the STREAM monitoring methodology

2.3 Linking river and valley

The management of the lower River Avon SAC is intimately linked with the management of the grazing marshes of the Avon Valley SPA. The breeding waders and wintering birds that use the valley are dependent on suitable conditions being created by controlling and retaining water on the floodplain at key times. Conditions for them in the SPA are currently unfavourable, largely due to neglect of the watercourse network and inappropriate water level management.

To restore favourable condition requires rehabilitation of the ditch network, tree and scrub removal, and restoration or installation of sluices or structures. However, all these activities potentially affect SAC fish populations. The STREAM project has commissioned a number of studies to help to overcome these conflicts and contribute to both the integrated management of water levels in the Valley, and the needs of migrating fish populations in the River Avon.

A method for prioritising floodplain restoration whilst avoiding fish entrapment has been published (Solomon D, 2007). The approach involves using available fishery data to generate colour coded maps, which can then be used to assess the potential impact of measures such as ditch reinstatement, new structures, and timing of structure operations.

STREAM is also developing pilot hatch operating protocols for typical structures in the catchment. The protocols will establish principles and provide guidance where there is a need to balance a number of river and floodplain interests.

The STREAM methods for prioritising floodplain restoration works and creating hatch operating protocols are valuable new management tools for managing Natura 2000 wetland sites.

3. AFTER-LIFE PLANNING

STREAM will not tackle all the threats that affect the River Avon SAC and SPA but focuses on the issues that cannot be addressed by UK statutory and policy measures. The project is contributing to addressing:

1. Historic land drainage and flood defence engineering which has damaged ecological function of the River Avon SAC.
2. Conflict between water level management and SAC fish interests.
3. Damage to watercourse habitat due to inappropriate water level regime and lack of ditch management.
4. Widespread lack of awareness and understanding of the SAC / SPA features and their requirements by key stakeholders and wider audiences.

Natural England, in conjunction with Project Partners and other stakeholders, will review the River Avon Conservation Strategy and outstanding threats to the SAC, and produce an “After-LIFE” plan in 2009. The Plan will describe actions required to address outstanding threats to the conservation status of the sites including both statutory and non-statutory measures.

4. SUMMARY OF PROJECT EXPERIENCE

The process of securing funding for, and delivering STREAM has highlighted particular issues relevant to large-scale restoration projects:

- organisational change - the nature of the partner organisations, and availability of staff involved, may alter. Splitting the work between internal staff and consultants minimises risk to the project, but still enables development of in-house expertise.
- restoration proposals contained in funding bids tend to be based on limited site information. The final design and implementation are influenced by constraints such as protected species, landowner aspirations, hydraulic controls, machine access routes, etc, but must still meet the ecological objectives for restoration.
- early consultation is crucial in obtaining the relevant permissions and often identifies a way to “design out” many issues. In a heavily regulated country such as the UK, particular areas to consider include: waste licensing, planning permission, environmental impact assessment, and flood risk assessment.
- procurement – for large projects, specialist construction contract management is required, and the contracting process can be lengthy. This must be incorporated into the project planning cycle.
- cost - site facilities, supervision, reinstatement, etc, require a larger proportion of the budget than for smaller-scale restoration projects and need to be budgeted for accordingly.
- partner organisations - staff may have done lots of river maintenance or hard engineering but little river restoration - clear communication and extensive site supervision are needed to ensure designs are feasible to build, and are implemented effectively.
- community awareness - local meetings, press releases and project briefing notes should all be used to communicate the aims of restoration and what people can expect to see in the short, medium and long term. This is particularly important where controversial action is planned *e.g.* felling large trees, or works in existing areas of high flood risk.

The experiences of the STREAM project are transferable to large scale restoration projects across Europe. STREAM will be disseminating its experience to UK and EC audiences in the remaining 18 months of the project at events, seminars and open days. For more information visit www.streamlife.org.uk.

5. CONCLUSIONS

Physical restoration of river channels and ditch networks, and integration of river and wetland management, is necessary to bring many SAC rivers and SPA wetlands into favourable condition. Restoration will also be needed across the wider European river network under the Water Framework Directive, to an extent dependent on the hydromorphological interpretation of Good Ecological Status, judgements of Heavily Modified Waterbody status, and the definition of Good Ecological Potential (Mainstone, 2007).

STREAM has taken a whole-river approach to restoration, demonstrating innovative river restoration and monitoring techniques, and developing methods for resolving river and floodplain management conflicts. The project will inform best practice for the management of river and wetland Natura 2000 sites and the wider European river network. The project experience will also inform the development of delivery mechanisms for achieving Good Ecological status or potential.

ACKNOWLEDGEMENTS

The STREAM project is supported financially by the European Commission's LIFE-Nature programme. Natural England is working with project participants the Environment Agency, Wiltshire Wildlife Trust, Hampshire and Isle of Wight Wildlife Trust and Wessex Water.

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CAMENCA RIVER RESTORATION – LESSONS LEARNED FOR RIVER RESTORATION IN THE EASTERN PART OF THE DANUBE RIVER BASIN

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ABSTRACT

Camenca river is a typical water course for the middle Prut river basin (Eastern part of the Danube river basin), which was significantly affected in the middle of the '70s by large drainage activities. A restoration project was funded by the World Bank in cooperation with the local authorities and was aimed at:

- restoration of wetland areas of the Camenca river basin to sustain the ecosystems of the protected area "Padurea Domneasca"
- development of the Action Plan and monitoring programs on the state of the protected area
- involvement of public organizations and NGO community in nature restoration activities in small river basins in order to mitigate negative consequences of deterioration of small rivers in the past.
- improvement of water quality and hydrological regime in the Camenca river basin

On the base of the undertaken activities, further issues were included in the development of the restoration project: 1. consultation meetings with local authorities; 2. closing of an artificial channel, which streamlined Camenca river; 3. flooding of former wetland areas with water of the Camenca river; 4. recovery of sediment transport; 5. development of activities for restoration of small rivers in other regions of the Eastern part of the Danube river basin (Prut River).

On the base of the activities undertaken in the project, several strategies for nutrient reduction through wetland restoration, and water quality improvement, are being developed. At the same time, the documentation required to designate this area as a Ramsar site is being prepared.

Key words: Camenca River, recovery, local authorities, wetlands

1. INTRODUCTION

The Camenca River represents a heavily modified and water course. Channel constructed in the ‘70^s dried the wetlands in the lower part of the river and reduced the river discharge into the Prut river. The channel length was reduced to 7 km, instead of the previous 50 – 60 km in natural conditions. Dried lands were used for agricultural purposes, and water covered surface were reduced of 90%. Sediment transport was also strongly modified, which led to the loss of habitats, interruption in river continuity, loss of biodiversity. It affected negatively the ecosystem conditions of the newly-created protected area “Padurea Domenasca” which has a unique flora and fauna, and hosts a relict forests (oak forest 30-400 years old), etc. A river restoration project aimed to support the ecosystems of the protected area Camenca through the restoration of the river flow in its natural bed and the flooding of wetland areas in the lower part of the river started in 2002-2004. The project was developed in cooperation with administration of the protected area “Padurea Domneasca”, local authorities and experts, and with the support of the World Bank.

In this paper main the results of the project related to the involvement of the local authorities in the river restoration activities are presented.

2. MAIN CHARACTERISTICS OF CAMENCA RIVER BASIN

The Camenca river is located in the middle part of the Prut river basin in its left side. It is 93 km long, with a catchment area of 1230 km^2, average slope of 1.5, density of rivers network in its basin 0.68 km/km^2, and meandering coefficient 1.6. The annual precipitation in the basin is around 500 mm.

Camenca river was streamlined in ‘70^s by the construction of a channel 5 km long with capacity of 10 m^3/sec. As a consequence the water of the river did not reach the wetland areas and was discharged directly into the Prut River. The water level the wetland areas decreased of 2.5 – 3 m. This led to the reduction of the biomass of the wetlands of 20-30% and to damages to the fauna and forests of the protected reserve “Padurea Domenasca”. Dry wetland areas were used for agricultural purposes and as a pasture for domestic animals.

According to the estimations of the involved research institutions, the restoration of the hydrological regime of the dried wetlands could take around 3-5 years. Restoration activities were organized in 2002-2004 with assistance of the World Bank. In order to rehabilitate the river, the gates of the channel were opened so that water of the river flowing through the channel flowed through the old river bed instead. Hydrological regime was restored for 3-5 years after opening of the channel gates. Around 50 km of the lower part of Camenca river bed were restored and water returned to the wetland areas (fig. 1). It has been estimated that around 60 ha out of the 125 existing ha of wetland are now permanently flooded, and bottom sediments are 0,6-0,8 m thick. River meanders were restored and e water storage in the floodplain was increased.

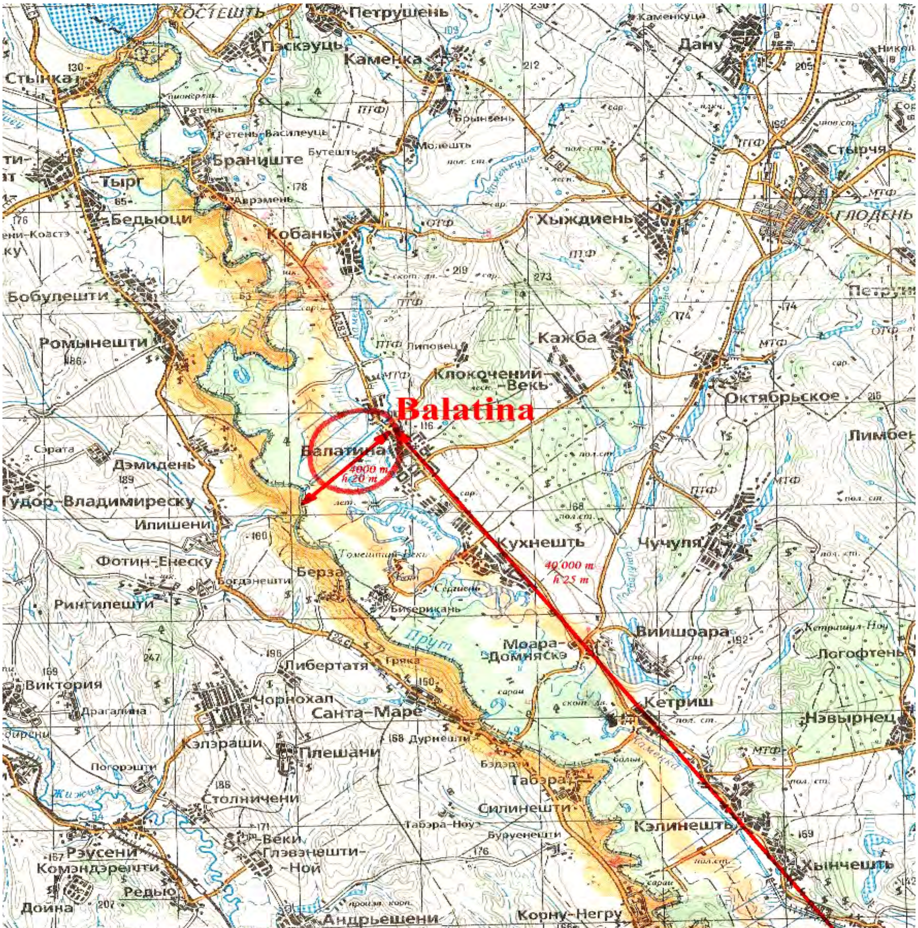

Figure 1 – Restored part of the Camenca River. (map provided by “Padurea Domneasca” protected area authorities).

3. MAIN PROBLEMS IN RESTORATION OF THE CAMENCA RIVER

The main problems with the restoration of the Camenca River were associated with the lack of experience in this field in Moldova. Restoration was organized by using available maps without GIS format. Data on biodiversity were also limited and targets for restoration activities were not properly set. There are no studies in the region on the estimation of historical and present river network, and of sediment transport. The biodiversity of the region is also poorly studied, and habitats capacities of wetland areas are poorly estimated. Water quality monitoring (chemical and biological) is not sufficient and needs strong improvement from the technical and institutional points of view.

GIS data acquisition for the area needs to be developed for further estimation of potential restoration and for further organization of the research activities. The assessment of wetland vegetation, macroinvertebrates, aquatic and riparian habitats and diversity, fish fauna, water quality and quantity has to be undertaken for further restoration activities in the region, for the implementation of the requirements of the Danube Convention, etc.

4. FURTHER OPPORTUNITIES FOR RIVER RESTORATION IN THE REGION

Results of the restoration activities in the Lower part of Camenca River were summarised and presented to local authorities. On the base of studies estimating the capacity of local authorities to implement river restoration activities, the following issues were identified as future priority:

- Cooperation of local authorities with relevant national, regional and international stakeholders for improvement of water management practices in such fields as drinking water supply, waste water treatment, sanitation, environmental protection etc.
- Large involvement of public institutions and NGOs in drafting the Integrated River Basin Management Plan for the Prut river basin and the program of measures for its implementation in 2009-2015.
- Analysis of the financial resources and mechanisms needed for the implementation of the best water practices and costs of different types of water use (drinking, industrial, agricultural, fisheries, etc).
- Development of educational programs for Universities and schools, development of a tool-box for the implementation of the plans and best water practices.
- Evaluation of the economic aspects of water supply and commitment of the local population to pay for different types of water services.

5. ENVIRONMENTAL ISSUES

Environmental issues in the region include: development of strategies for habitat restoration; restoration of wetland forests and meadow vegetation; introduction of best agricultural practices (development of organic farming in wetland areas represents a priority); development of a network of protected areas and green carcases in agricultural areas.

6. CONCLUSIONS

Based on results of consultation meetings with local authorities on the restoration activities undertaken i 2002-2004 in the Camenca river basin it can be concluded that local authorities are strongly committed to perform wetland and river restoration activities in the basin and the future strategies for river restoration should be based on :

- development of the network of protected areas and green carcasses in the floodplains of the Camenca and other rivers;
- development of nutrient reduction measures such as: promotion of organic farming, construction of platforms for stocking of organic wastes in rural localities, composting of organic wastes;
- development of integrated river basin management plans;
- improvement of regional cooperation.

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CHAPTER 5

Session 4

Flood Risk Management and River Restoration

Chairpersons

U. MENKE, H. NIJLAND

Introduction
FLOOD RISK MANAGEMENT AND RIVER RESTORATION

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Millions of European citizens are threatened by flooding events from rivers, estuaries and the sea.

Those events caused more than 700 casualties and damages of more than 25 billion Euros. Although many flood alleviation measures were implemented in the European river catchment's the last decennia, the ongoing urbanisation and changes in land use, as well as the social and economic development have increased the potential for flood damages. This significant increase of the flood risk is furthermore due to climate change and extreme weather events e.g. heavy rainfalls. Recent examples of flood events in Europe are: e.g. the Elbe River, various rivers in the United Kingdom, the Danube river, and just this summer in Ukraine and Moldavia and many others more.

Flood Risk Management (FRM) is a more holistic approach, which aims at multidisciplinary and integrated approaches in river catchments. Examples of this new approach versus the traditional engineering are the various "Room for the River", "Making Space for Water", "Living Rivers", and "Environmental River Enhancement" programmes in European countries.

A combination of FRM measures with restoration or rehabilitation measures can be more effective and more sustainable than just implementing stand-alone measures. A good multidisciplinary planning in an early stage of projects can contribute much to the finding of no regret measures etc. The water management sector has often more financial means than nature organisations for the implementation of works. In most cases flood alleviation measures are very technical constructions e.g. a retention polder, inlet- or outlet works, but also this concrete constructions can be adjusted to ecological functioning. Ecological floodings in retention areas and the implementation of fish ladders also in tributaries of the large rivers are good examples.

It is also quite clear that restoration measures depend on the climate of river catchments and also on the locations in a river. Upstream and downstream measures can vary. The approach to the planning and implementation of river restoration measures will also depend on the different functions of the river. The measures on more natural rivers, without the function of commercial navigation, will be more directed to maintaining the natural status and preventing a decline of naturalness The restoration of restrained rivers requires relatively large investments and the different river functions have to be taken into account, requiring an integrated approach.

The FRM session at the Venice conference emphasized once more the need for integrated approaches in river catchment Europe. Examples from the Rhone and the Rhine rivers demonstrated that the approach really works out well and that it is worth to put more attention and working hours into this kind of projects. In most European river catchments planning and implementation of FRM measures cannot be done without the support of the public. A good communication and community involvement becomes even more important in future.

The implementation of the Water Framework Directive means a chance for many European countries to combine those measures to reach a Good Ecological Status (GES) with rehabilitation measures. Therefore, nature development along main shipping routes will become an important issue in future. The development of riparian forests is valuable for retaining water in upstream areas of river catchments and therefore to lower the floodwater levels in the river. Another measure, which has an effect on the water level in the main river, is the construction of secondary gullies. But if those are planned very well, the positive effects are dominant.

To reach a GES in artificial water bodies, continuity in rivers and tributaries as well to the sea is of great importance. Measures such as the implementation of fish ladders and creation of spawning areas make a big difference in rivers. Many good examples are present in Europe; costs vary very strong due to scale and construction methods.

The examples showed that the FRM approach still needs to demonstrate its effectiveness and the greater value compared to the traditional working methods. If densely populated areas are at a risk, still heightening of dikes or the implementation of technical measures is a good solution.

Especially in urban areas space along the riverbanks is very much limited and therefore, barriers along the river promenade in combination with footpaths or other combination of functions can be a useful option. Cities along rivers should carefully look right now whether planning with the river or water in the city can prevent future problems. Maybe a new consciousness or attitude to floods of the people living in a catchment can contribute to this.

On the market, different materials can be bought and used for rehabilitation measures varying from concrete to (semi-) natural materials. Preference should be give to the more natural materials, if those can guarantee stability and functioning on a longer term.

Good planning of river restoration of rehabilitation measures needs a reference site or a reference situation. But sometimes this is very hard to find because of the big changes that rivers often faced the last centuries. Monitoring of implemented restoration projects could contribute to making good choices in future. But monitoring is costly and often not part of the restoration project. All attention, and of course, finances are focussed on the implementation and not on what comes behind.

Water managers, administrators, and researchers in all countries should preserve and conserve the natural rivers in their countries. Straightened rivers should be dealt with in river basin planning, which means that countries in a catchment should cooperate in planning and implementation of measures. Urban planning should be carried out “with the water” and “with the river” and not against it.

Holistic approaches will hopefully become “the” normal working method in river basin.

And please do not forget: Flood alleviation measures and river restoration measures are costly and often cannot create the former natural situation.

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THE INTEGRATION OF FUNCTIONAL SPACE IN FLUVIAL GEOMORPHOLOGY, AS A TOOL FOR MITIGATING FLOOD RISK. APPLICATION TO THE LEFT-BANK TRIBUTARIES OF THE AUDE RIVER, MEDITERRANEAN FRANCE

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ABSTRACT

In November 1999, a flash flood (1:30 year's return interval) severely damaged several areas of South France. Along the north tributaries (rank 4, Strahler) of the Aude River, the current system of flood-risk management proved to be rather inefficient during this flood. After the 1999 flood event, several plans were formulated to improve water flow and floodplain drainage. Two contrasting examples are illustrated. Along the Argent-Double tributary, the proposal chosen by the competent decision-making authorities (SIAHBAD, the community water association) consisted in restoring the capacity of the floodplain, occupied by extensive vineyards and local settlements. This does not account for mitigating the effects of larger floods, nor does it consider the vulnerability of the population living near the river. This option even leads to increase the human vulnerability locally in the floodplain. We proposed another option, based on the concept of stream-way or freedom space, which enabled us to quantify the optimal width for the channel to divagate and avulse in its floodplain, and the utilisation of the riparian trees as natural sediment traps, locally reinforced by low-cost structures. The two examples illustrate the two different concepts of river management: on the one hand, heavy (and costly) flood control structures in relation to the protection of local assets; on the other hand "environmentally friendly", low-cost structures, which should be encouraged where the rivers are still natural and free-flowing.

Key words: Extreme flood, Hydro-morphological impact, Water management, Stream-way concept, Semi-quantitative hydraulic model, Mediterranean France

1. INTRODUCTION

The management of river hydro-systems based on sustainable development implies that the hydraulic and engineering works carried out in the floodplain are of good quality, and that flood risk has been minimized (Werrity, 2006). During autumn 1999, extensive flooding affected southern France and raised public, political and scientific awareness of the large-scale consequences of low frequency, high magnitude events. It also highlighted the urgency of improving our knowledge on the significant measures to be taken to mitigate these events, and the need for a sustainable solution to flooding. The objectives of this paper are to define the flood hazards along the left-bank tributaries of the Aude catchment, namely the Argent-Double, Rivassel, Clamoux and Orbiel rivers, to show which measures have been considered to reduce the impact of the large floods to date, and to suggest which solutions would be better to apply in order to significantly reduce flood risk.

2. GENERAL CHARACTERISTICS OF THE CATCHMENTS

The Aude tributaries are small rivers (30-250 km^2), characterised by a meandering channel and by a torrential, Mediterranean regime; they flow from the north (mountain) to the south (piedmont; Fig. 1). In the Montagne Noire (schists), the rivers are deeply entrenched (>200 m), with a longitudinal slope (0.2-0.015 m/m) favouring a flashy response during flood events. On the piedmont, the rivers are 10-to-40-m deep entrenched into the Eocene (Bechtold and Basile, 2001; Gaume *et al.*, 2004; Verdeil, 1999) molassic bedrock or Quaternary alluvium. In the floodplains, various types of stakes are facing flood hazard: in fact, some rural market towns extend into the river floodplain. In the floodplain, agricultural practices are characterized by the predominance of vineyards and some localised fruit-tree orchards.

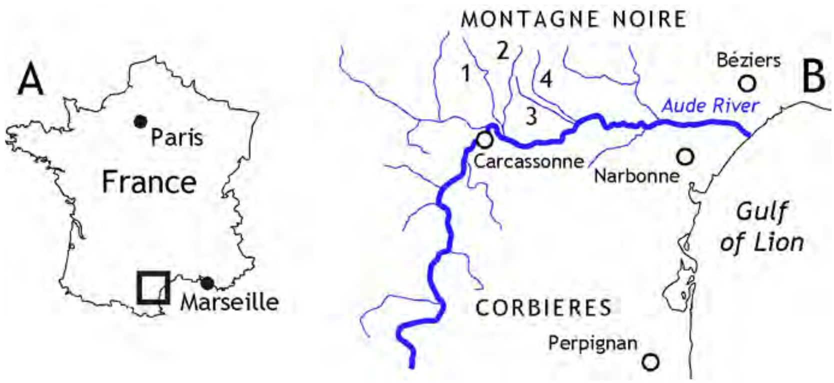

Figure 1 – Location of the studied area (A) and hydrography of the Aude catchment (B). 1=Orbiel River; 2=Clamoux River; 3=Rivassel River; 4=Argent-Double River.

As many others in the Mediterranean basin, the catchments are naturally prone to extreme river-floods and hydrological variability (Fort *et al*., 2001; Arnaud-Fassetta *et al*., 2002; Plet *et al*., 2002). Since June 1963, the hydraulic management of the Argent-Double catchment has been governed by the SIAHBAD (Intercommunity River Trust). Recently, a new agency was created, the SMMAR (Mixed Trust for the Management of Aquatic Environments and Rivers, that includes all river trusts of Aude's tributaries), spanning over administrative districts limits to include the entire territory subject to flood risk (i.e., the Aude catchment and its tributaries).

2. WHAT IS A CATASTROPHIC FLOOD EVENT ON THE LEFT-BANK TRIBUTARIES OF THE AUDE CATCHMENT?

In order to define and characterize the flood hazard in the Argent-Double catchment, one can rely on the experience and knowledge gained after the recent floods, and more specifically after the 12-13 November 1999 event (35 fatalities). Field investigations carried out just after the event (Fort *et al*., 2001; Arnaud-Fassetta *et al*., 2002) allowed us to evaluate the hydrodynamic functioning (e.g., hydraulic values) and to set up a systemic model (including triggering and aggravating factors, and hydro-geomorphic impacts) upon which strategies for rehabilitation of the hydro system can rely (Fig. 2).

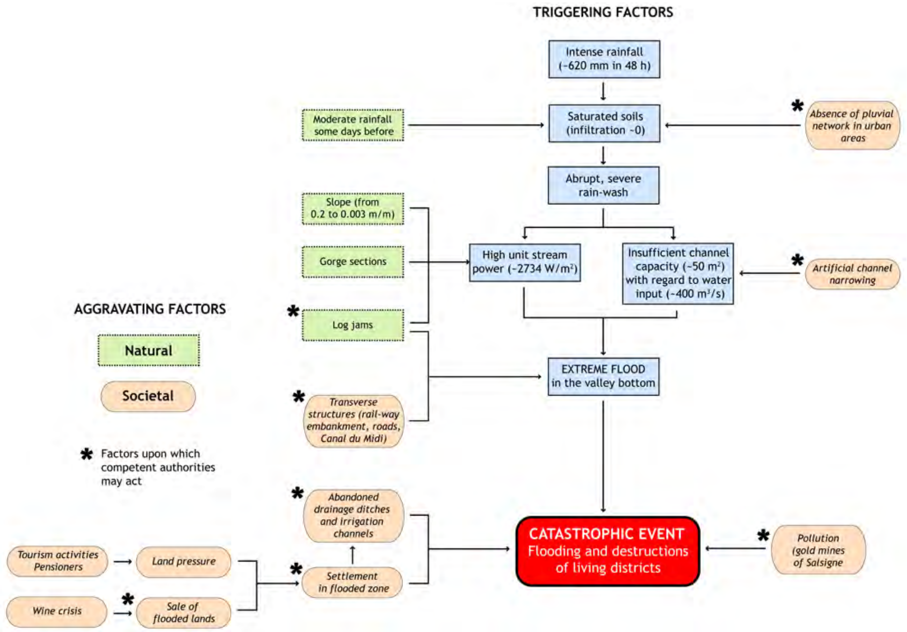

Figure 2 – Systemic approach of flood risk, left-bank tributaries of the Aude River.

The 1999 event had many fluvial morphological impacts. During two days (November 12-13), the Montagne Noire and its piedmont received more than 400 mm of rain, resulting in the flooding of the left bank tributaries of the Aude River. In the mountains underlain by schists, the talwegs were the most affected by localized debris flows, whereas the slopes remained relatively stable. In the piedmont, terrace scarps cut into the molassic bedrock were subjected to deep gullying (vineyards). Streams such as the Argent-Double occupied almost their entire floodplain (Fig. 3). As a consequence, many meanders were cut off, resulting in local incision of the main channel and/or in the accumulation of gravels, at the loss of substantial amounts of material along the river sides. These changes (metamorphosis), often amplified upstream of the confluences, reflect the normal, irregular behaviour of these rivers over the past few centuries, as shown by the superposition of the flood deposits constituting their alluvial plain.

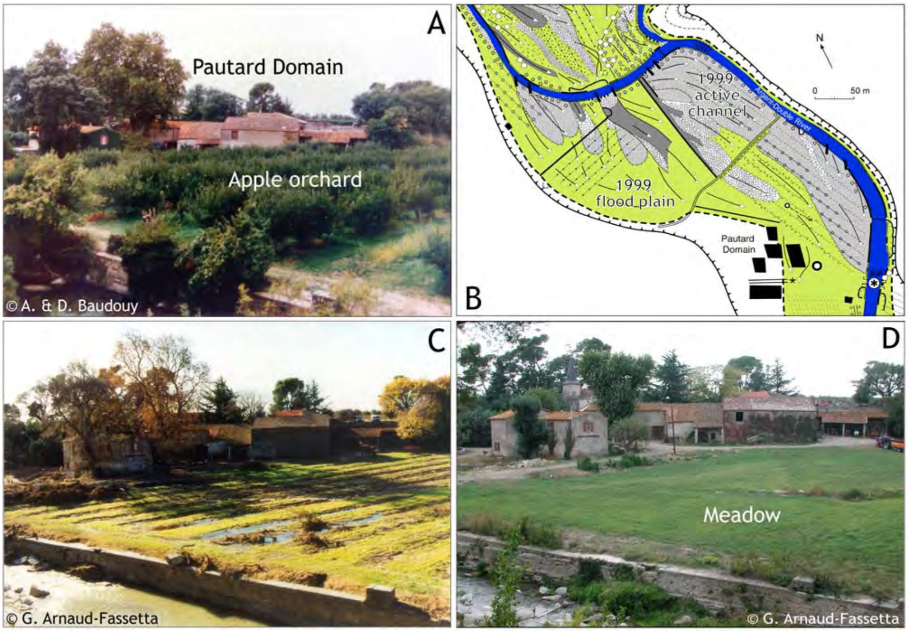

Figure 3 – Evolution of the Argent-Double floodplain (Pautard Domain) between 1998 and 2002. A: Apple orchard in the flood plain (July 1998). B and C: Hydro-morphological impacts in the floodplain of the rivers Argent-Double and Souc after the flood of November 1999. D: Meadow in the flood plain (September 2002).

The lack of maintenance of the flood protection structures by the local population and/or by the river trusts and the absence of coherence in the type and emplacement/succession of these structures has weakened the entire system, which thus could not resist the 1999 flood. Eventually, the bridges and walls have aggravated the impacts of the flood, by expanding the inundated areas and reinforcing the flood power by reflection against the walls (Fig. 4).

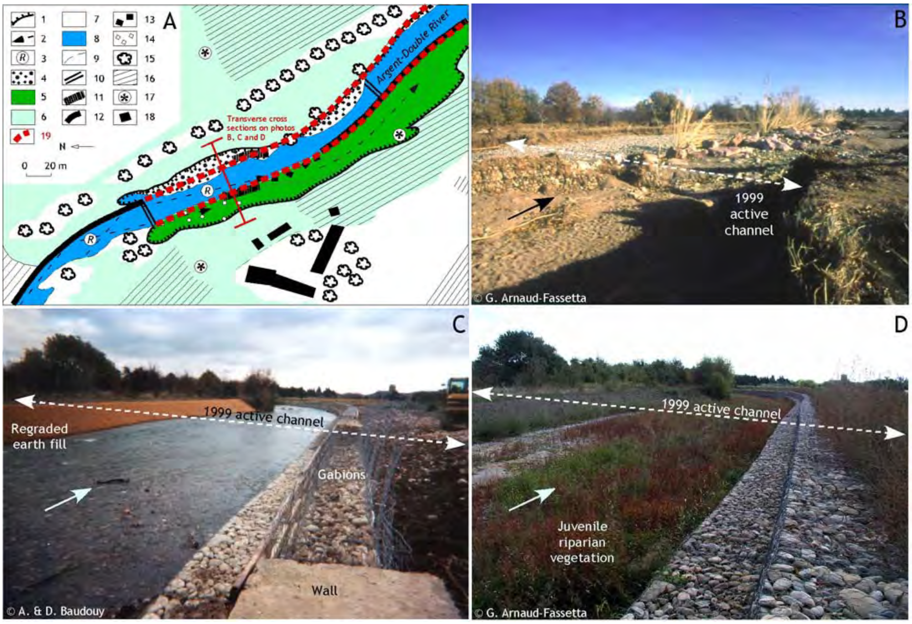

Figure 4 – Channel evolution of the Argent-Double River between 1999 and 2003. A and B: Impacts of hydraulic structures on the morphogenesis of the Argent-Double bed, upstream Peyriac-Minervois, during the 12-13 November 1999 flood (1: incision outlining the flooded channel; 2: direction of flood flows; 3: reflexion of the flood flows caused by the presence of the concrete wall; 4: gravel bar; 5: sand aggradation; 6: floodplain; 7: exondated zone; 8: low-stage channel; 9: limits of the channel after the flood; 10: concrete threshold; 11: gabion (not destroyed); 12: concrete wall (not destroyed); 13: wall destroyed or toppled over; 14: destroyed rocks; 15: riparian vegetation or hedgerows; 16: uprooted or buried vineyard; 17: uprooted vineyards or vineyards covered by debris; 18: houses; 19: channelisation 2002; December 1999). C: Channelisation works of September 2002. D: Vegetation development reduces the channel capacity and increases the roughness during low-magnitude floods (September 2003).

We analyzed the consequences of the flood with a diachronic approach that highlighted major flood geomorphic impacts and their spatial effects: breach opening along river banks, avulsion, meander cut-off, and braiding. It appeared that the rivers behaviour was well predictable, evidencing the same zones of disturbance and “weak points” such as meanders and confluences which are the most sensitive zones where any control measure could be repeatedly affected during floods.

3. TWO DIFFERENT CONCEPTIONS OF RIVER MANAGEMENT

3.1 Inefficient, expensive actions taken to reduce the impact of great floods

After the 1999 flood event, several plans were formulated to improve water flow and floodplain drainage. Among various proposals, the one chosen by the competent decision-making authority (SIAHBAD, the community water association, or river trust) consisted in restoring the channel capacity at low flow only. This does not account for mitigating the effects of larger floods, nor does it consider the vulnerability of the population living nearby the river (Fig. 4 C and D and Fig. 5).

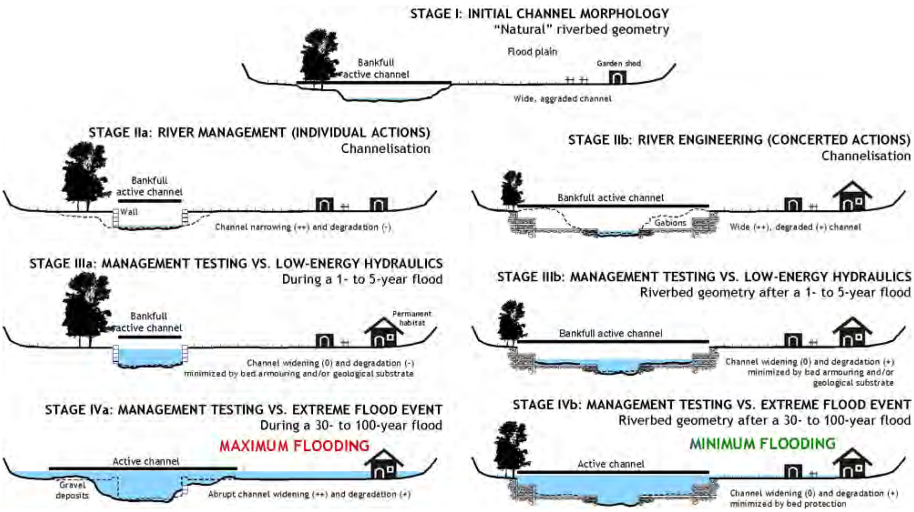

Figure 5 – Two conceptions (inefficient, expensive, left; ecologically friendly, right) of floodplain dynamics and channel restoration, left bank of the Aude's tributaries.

Various, "classical" options were chosen by local authorities. In the channel, the dimensions of the channel geometry were maintained (Caunes, Peyriac, Rieux) and the channel courses were restored with insufficient discharge capacity. Moreover, maintenance was done only along reaches visible from the road and villages centres (Rieux) because the regeneration of riparian forest is very rapid and its control requires expensive works.

In the floodplain, the active channels were recalibrated into a single channel, with a capacity adapted to low magnitude floods only. The flood deposits were retrieved or levelled, whereas they could be used as hydrological benchmarks to delineate the functional flooding area. In the villages, nothing was planned to reduce urban runoff whereas new housing estates were given permits to develop (Fig. 5, left).

3.2 Other inexpensive, ecologically friendly solutions to reduce the flood risk?

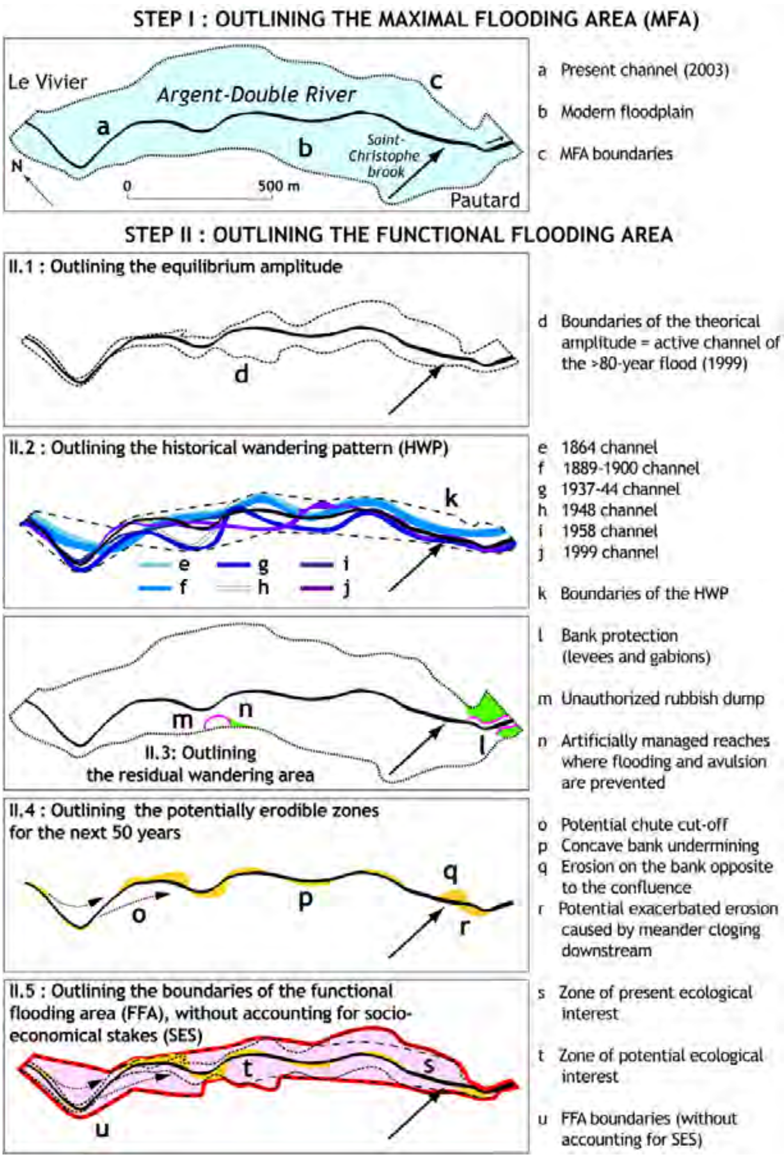

Figure 6 – The concept of "functional flooding area" [Malavoi *et al.*, 1998] applied to the Argent-Double River downstream to Caunes-Minervois.

A sustainable floodplain management generally requires a plan at the catchment scale, which accounts for the continuity of the upstream and downstream parts of the hydrosystem. In our inventory, we noted some common, recurrent weak points: discontinuities in the protection structures, with no consideration of the hydrosystem functioning and management before and after the 1999 event.

The concept of “stream-way” or “freedom space” (Malavoi *et al.*, 1998; Piégay *et al*., 2005) serves to maintain a “functional flooding area”, hence to restore a sufficient channel capacity. Outlining the functional space requires six steps (Fig. 6). This reach segmentation allowed us assessing what are the instable reaches and what are those susceptible to be affected by important changes in bed geometry. We quantified the optimal width for the channel to divagate and avulse in its floodplain (Fig. 5, right). Tested upstream of Peyriac-Minervois, this method showed that present stream-way width varies from 22 to 186 m (mean 124 m).

A recent management trend is oriented towards naturalness within a "living river" perspective. The native riparian vegetation is allowed to remain dominant, thus enhancing habitat diversity and acting as a sediment trap, especially along abandoned channels (Fig. 7).

Figure 7 – Example of management for naturalness along the Clamoux River. The breach opened during the flood of November 1999 was artificially increased to force the river temporally to cut-off the meander during the next floods.

In little populated areas, the flood channels are kept naturally open, allowing flood channel divagations. Several reaches were thus identified as natural, potential zones of expansion and dissipation of floods (so-called ZPEDOC; Fig. 8).

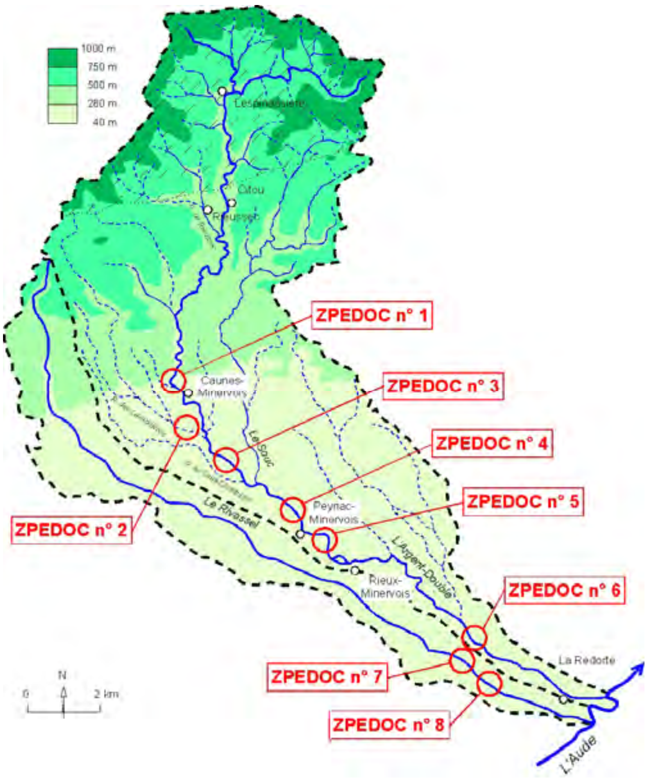

Figure 8 – Zones of expansion and dissipation of floods (“ZPEDOC”) along the river corridors of Argent-Double and Rivassel (after Arnaud-Fassetta *et al.*, 2004).

5. CONCLUSIONS

Our investigations led to evaluate the relevance of the present land-use and of the methods utilised by environmental managers to mitigate flood risk. We conclude stressing on the need for a concerted management of the river at the entire catchment scale and for a multi-disciplinary approach (engineering, hydraulics, and hydro-morphology), without which no serious protection against a real risk of flooding can be ensured to the local population.

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HYDROMORPHOLOGY AND RIVER ENHANCEMENT FOR FLOOD RISK MANAGEMENT IN IRELAND

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ABSTRACT

The Office of Public Works (OPW) is the lead authority for Flood Risk Management in Ireland. OPW maintains 11,500 km of watercourses for drainage & flood relief purposes and implements an ongoing programme of urban Flood Relief Schemes. In addition, a nationwide process of Catchment Flood Risk Assessment and Management Studies has been commenced.

Ireland's Article 5 Initial Characterisation Report under the WFD establishes that Hydromorphology is the 2nd largest pressure behind Diffuse Pollution. Hydromorphology accounts for 40% of the river waterbodies being designated either “At Risk” or “Probably At Risk” of failing Good Ecological Status (GES). Channelisation and Flood Relief structures account for over half of these pressures. Current understanding is that the majority of hydromorphological pressures will not cause failure of GES and these waterbodies are not being designated as pHMWBs (proposed Heavily Modified Water Bodies).

For Drainage/Flood Relief pressures in Ireland, the Programme of Measures under the WFD will focus on enhancement of drained rivers and sustainable flood relief practices. In addition, Ireland is incorporating River Continuity into the hydromorphological criteria, which will set a new framework to manage fish passage obstructions. A recent example of river continuity improvements is where the OPW replaced a weir obstacle with a new Rock Ramp structure as part of an urban Flood Relief Scheme.

Drainage Maintenance operations in Ireland have evolved to minimise environmental impact and incorporate various river enhancement techniques. This year, the OPW commenced a more focussed long-term project on river enhancement known as the Environmental River Enhancement Programme (EREP). The Irish Central Fisheries Board are contracted to commence a nationwide strategy of reviewing Irish drained catchments, identifying river reaches that will yield the most benefit and design of the relevant enhancement techniques. OPW are fully funding the programme and will implement the actual works.

This first EREP Contract is a 5-year programme, which is the start of a long-term strategy for environmental enhancements to Flood Risk Management assets.

Improvements in Hydromorphology are to be measured and results will be integrated with the River Basin Management Plans. In parallel, gains in Biodiversity will be monitored to assist compliance with both the EU Biodiversity Action Plan and Ireland's National Biodiversity Plan.

Key words: Hydromorphology, Biodiversity, River Enhancement, Flood Risk.

1. INTRODUCTION

Ireland by its nature is liable to flooding and drainage problems principally due to the fact that the country has a relatively low-lying interior surrounded by coastal highlands. Many major rivers are sluggish in character and this coupled with relatively high rainfall inevitably leads to chronic drainage problems. Accordingly, drainage works have a long history in Ireland stretching back to the mid 19th century.

In present day, there are a range of both European and national legislation and policies all of which in some form strive for a more holistic and sustainable approach to modern flood risk management. This paper sets-out how Ireland is approaching the Water Framework Directive (WFD) in terms of flood risk management and how progress is being achieved on implementing the WFD while integrating the same with river enhancement programmes and improving biodiversity.

2. FLOOD RISK MANAGEMENT

The Office of Public Works is the body through which Central Government exercises its statutory responsibilities in respect of river drainage and flood relief. It derives its statutory authority from the Arterial Drainage Act, 1945 and the Arterial Drainage Amendment Act, 1995. The Report of the Flood Policy Review Group, which was adopted by Government in 2004, sets out the new national policy on flood risk management. The OPW are the lead agency, supported by a number of other public bodies and implementation of this new policy has recently been commenced.

Between 1948 and 1995 the OPW completed Arterial Drainage Schemes on thirty-four river catchments. In total, 253,000 ha of lands benefited from these schemes. In the same period, five Estuarine Embankment Drainage Schemes were carried out where some 10,000 ha of land benefited from these embankment schemes. To date under the 1995 Amendment Act, thirteen Flood Relief Schemes have been completed with a number currently at design stage. Maintenance works are carried out on these Arterial Drainage Schemes in fulfilment of the statutory requirement. This entails maintenance of 11,500 km of channel, 730 km of embankments, some 18,500 bridges and 750 ancillary structures such as sluice gates, pumping stations and tidal barrages.

The new National Flood Policy 2004, sets out a more holistic approach to Flood Risk Management, which includes the use of both traditional structural and more modern non-structural methods. Emanating from this, a nationwide system of Catchment Flood Risk Assessment and Management Studies (CFRAMS) is being commenced by the OPW which will assess flood risk and in consultation with stakeholders, will set out the framework for holistic flood risk management in each catchment. To assist integration between the recent Floods Directive with the WFD, current proposals in Ireland are for the role out of CFRAMS to be project managed at River Basin District (RBD) level.

3. HYDROMORPHOLOGY

The republic of Ireland is subdivided into seven RBDs i.e. four wholly in Republic of Ireland and three International RBDs with Northern Ireland. Freshwater surface waters have been categorised into 4,465 river waterbodies and 217 lake waterbodies (>50 hectares). Initial Characterisation of Ireland's waterbodies found that Hydromorphology is the 2nd largest pressure behind Diffuse Pollution on freshwater surface waterbodies. Hydromorphology accounts for 40% of the river waterbodies being designated either "At Risk" or "Probably At Risk" of failing Good Ecological Status (GES) by 2015. Channelisation and Flood Relief structures account for over half of these pressures.

Further characterisation works for freshwater morphology has been completed, risk assessment techniques have been further refined, monitoring has commenced and measures are currently being devised for inclusion in the RBMPs due for publication in 2009. A new method for assessing Hydromorphology has been developed in collaboration with Northern Ireland. This is known as the Rapid Assessment Technique (RAT) and is a methodology for measuring hydromorphology in the field. The method involves assessing a number of attributes of the river corridor with the quality of the hydromorphology being presented as a ratio of the maximum possible score versus the actual score. The score can range between 0 to 1 with <0.6 being less that Good Hydromorphological Status and >0.8 representing High Morphological Status.

In respect of the drained rivers in Ireland, current understanding is that while a large portion will result in a less than Good Hydromorphology, in accordance with expert opinion on other biological water quality elements, the waterbodies will be able to achieve Good Ecological Status and hence will have the objective of GES. A portion of the drained rivers have a potential for enhancement works and these waterbodies will be targeted for improved hydromorphology under the new Environmental River Enhancement Programme as discussed in the next section. However, a large fraction of drained rivers due to their low gradient and other properties have very limited potential for cost effective enhancement options. In this case, it is still the objective to achieve GES despite that fact that the morphology will most likely always be less that Good.

In respect of Heavily Modified Water Bodies (HMWB), a similar approach is being adopted i.e. despite the fact that many waterbodies may be subject to a hydromorphological pressure, in the majority of cases these waterbodies were judged by expert opinion to be capable of achieving GES. Accordingly, at present there are <1% of surface waterbodies in Ireland that are being provisionally designated as HMWB. This is markedly different to the relatively high percentages of pHMWBs by many other Member States.

4. RIVER ENHANCEMENT

Research and staff training on the broader environmental aspects to Arterial Drainage Maintenance operations has been ongoing with the Central Fisheries Board (CFB) since the 1990’s. This research contract was known as the Environmental Drainage Maintenance (EDM) Programme. It was funded by the OPW through the CFB who coordinated with the Regional Fisheries Boards. Through this EDM programme, an environmentally friendly approach to drainage maintenance has been implemented and is continuously supported by an ongoing programme of on-site audits and staff coaching.

The EDM programme is now superseded by the Environmental River Enhancement Programme (EREP). The first contract is with the CFB for five years 2008 – 2012. Again this programme is being funded by the OPW and will focus on the enhancement of drained rivers in Ireland. The project is commencing with a fisheries focus to take advantage of the fisheries enhancement expertise built up on drained channels but is envisaged that this scope will broaden in the future. Two forms of enhancement will take place, i.e. Capital Enhancement and Enhanced Maintenance.

Capital enhancement allows for capital expenditure to import materials. CFB identify and agree with OPW and environmental stakeholders, annually in advance circa fifty kilometres of scheduled scheme channel on individual sub catchments which will have optimum enhancement potential in terms of gradient, flow and bed regime for salmonids, utilizing existing fishery survey data, water quality information and augmenting with further surveys as appropriate. Enhancement designs are prepared by CFB e.g. in channel structures, introduction of spawning gravel and riparian fencing. Works are implemented by OPW through the use of the direct labour workforce, OPW mechanical fleet and materials imported as required. Enhanced Maintenance works differ in that capital expenditure is not required as works will not require importing materials but will utilise on-site materials e.g. altering bed profiles by excavation of the existing gravel channel bed on salmonid rivers.

Enhanced maintenance works have similar design requirements to the Capital Enhancement works.

Monitoring of the enhancement works will take the form of Hydromorphological and Biodiversity. Works consist of carrying out pre and post Hydromorphological assessments on representative reaches with the resulting improvements being reported through the RBMPs. In parallel, pre and post works biodiversity assessments at representative reaches scheduled for development are to be carried out which includes provision for survey of macroinvertebrates; river corridor vegetation; other dependent river corridor animals and birds as appropriate. Relevant fisheries/salmonid data is available in many instances but is to be obtained if not already available. Gains in biodiversity will be reported through the framework of Ireland's 2nd National Biodiversity Plan (NBP) which is due for publication in late 2008.

5. RIVER CONTINUITY

Ireland is incorporating River Continuity into the hydromorphological criteria which will set a new framework to manage fish passage obstructions. A pilot study has recently been completed by the Southern Regional Fisheries Board on the River Nore Catchment (which is a medium sized catchment in the southern Ireland). This study has identified a substantial number of fish passage obstacles of varying degrees of blockage severity and range from obvious obstacles such as weirs through to less obvious obstacles like concrete bridge aprons. Current proposals are for this type of river continuity assessment to be expanded nationally and to be completed by the relevant Regional Fishery Boards. Obstacles will be required to be prioritised in some form and improvement / removal measures for a number are to be integrated in to the forthcoming RBMPs.

A recent example of river continuity improvements is where the OPW replaced a weir obstacle with a new Rock Ramp structure as part of an urban Flood Relief Scheme. In Kilkenny city, within the Nore catchment, an existing concrete weir had a Denil Fish Pass that proved to be an obstacle to Salmon migration. Various solutions were considered and culminated in the construction of the first large scale Rock Ramp in Ireland in 2006. To date, the Rock Ramp has proved very successful in terms of fish migration. In addition, it is considered that this type of more natural structure is more aesthetically pleasing, embodies a more natural hydromorphology and is biodiversity friendly.

6. CONCLUSIONS

Ireland is now striving for a more holistic approach to flood risk management and as far as practicable, is setting a framework for integrating the Floods and Water Framework Directives. The drained rivers in Ireland are setting the challenging objective of Good Ecological Status and taking a minimalist approach to Heavily Modified designations. A long-term proactive programme for river enhancement on drained rivers is now in place and in parallel, river continuity improvements are being actively progressed through the WFD framework.

Ultimately, these activities will strive towards widespread hydromorphological improvements and increases in biodiversity on many Irish river corridors.

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Freshwater Morphology Programme Of Measures & Standards national steering group.

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NATURE DEVELOPMENT AND FLOOD RISK MANAGEMENT COMBINED ALONG THE RIVER RHINE – EXPERIENCES FROM A TRANSNATIONAL CO-OPERATION WITHIN THE SDF-PROJECT

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ABSTRACT

The catchment of the River Rhine, especially in Germany and the Nether-lands is densely populated. Here, flood alleviation needs an integrated and trans-national approach in order to manage the present and future changes in water discharge. In the meantime, "pure" nature developments projects are difficult to implement, because along a *restrained* river such as the Rhine, all measures include costly engineering re-constructions.

Certain stretches along the River Rhine require different flood protection measures and as a consequence offer another potential for nature development. In the Upper Rhine area, measures to "rehabilitate" floodplains comprise dyke relocations and construction of retention polders. Dyke relocations means that the flood area in a river section is widened and the floodplain is naturally flooded depending on the water level in the river. The measure leads to a more dynamic reconnected floodplain area in the mid- and long-term and should create a good quality riverine habitats and improve the ecological networks along the river. Retention polders are controlled flood-retention basins. They are used to reduce the flood peaks in the River Rhine during critical moments. These controlled areas are most of the time not only kept natural, but also used by agriculture, which affects the quality of rehabilitation in the former floodplain.

In the River Rhine delta, fast discharge of high waters plays a crucial role. Water retention is less important in the main river, therefore the development of floodplain forests and other dense vegetation cover in the Rhine floodplains is not very much wanted. The reconnected floodplains, created for example by the development of secondary gullies, etc., do incorporate some kind of maintenance. In

the Netherlands, large grazers (cows, horses) are used to keep the vegetation growth in acceptable limits for the water managers and for controlling flood risk.

The results of the "Sustainable Development of Floodplains/SDF" project showed that transnational co-operation (with a good understanding and solidarity among partners) contributed to a better safety level along the Rhine, resulted in cost savings and more efficient project implementation as well as a quality improvement of developed floodplains. Pressures on the land in catchments like the Rhine are very high, so fast action and good spatial planning are needed to implement further flood alleviation and nature projects.

Key words: flood risk, nature development, River Rhine, integrated approach

1. INTRODUCTION

The Rhine River basin covers about 200,000 km^2 and 58 million people live in the area in 9 different countries. Large floods in the past led to a new approach on dealing with future high floods. Recovering costs after high floods are extremely high; therefore sustainable measures are necessary in order to reduce the increased risk of future high floods by extreme rainfalls and climate change. The Sustainable Development of Floodplains (SDF) project (www.sdfproject.nl) has started to work on an integral approach to ensure sustainable development of the River Rhine floodplain. The SDF-project is a EU-funded, transnational cooperation among seven partners in the Netherlands and Germany. Mutual respect and understanding are gained through the development of measures with transnational impacts and solving common issues by transnational teams. SDF encompasses twelve pilot projects with an operational focus. SDF partners share knowledge relating to project management, technical solutions and public participation processes. SDF is co-financed by the European INTERREG III B programme, which contributes to the accelerated implementation of various flood prevention plans. After 6 years of implementation and planning, an overview of the results reached will be presented.

2. FLOOD PREVENTION AND NATURE DEVELOPMENT - COMBINED

The SDF project comprises project from the Upper Rhine in Germany down to the delta area in the Netherlands. Main objectives of the SDF project are to implement flood prevention measures and to contribute to nature development and sustainable nature conservation. The pilot actions that are part of the SDF project all contribute to the European policy of NATURA 2000: conservation and restoration of the biodiversity in the EU. The SDF project contributes to the survival of specific habitat type and (bird) species which are protected in the Bird Directive and the Habitat Directive.

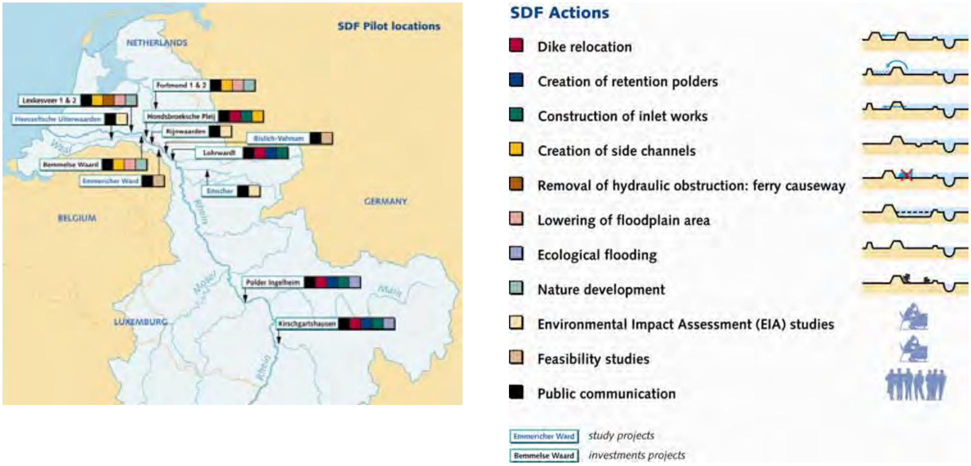

Figure 1 – SDF Pilot locations and activities.

The projects in the Netherlands are essential in the creation and enlargement of the Ecological Network. Some pilot projects are part of the programme of nature development in the Dutch River region, which will result in 7,000 hectares of river-related nature development.

In all the projects, during the planning and implementation phases it is possible to link different interests and objectives. With measures aiming at flood prevention, especially those with a spatial character, it is often possible to create conditions for nature development and improvement of the landscape qualities. These new qualities result in added value for recreational use of the area in which the measures take place, but often for a wider region too. By a smart use of possible ore extraction, some projects also have chances for extra revenues that lead to lower investments by the responsible government.

For this reasons, flood prevention measures almost never have a one-sided approach but are part of an integral approach for the whole area. The SDF project implements different types of flood prevention measures combined with different types of nature development or nature restoration (Nijland and Menke, 2006).

3. EXAMPLES OF COMBINED MEASURES

The implemented measures along the Rhine vary from retention polders, side channels, lowering of existing floodplains and dyke relocations (Figure 1). The suitable flood prevention measures depend on the location in the catchment area. In the Upper Rhine area, retention of water has a high priority. This means that floodplain forest development is favoured due to the fact that the vegetation blocks the peak discharge. In the Lower Rhine area, a fast drainage at peak discharge is preferred which means little vegetation covers in the floodplain. Therefore, in the Netherlands the river manager (*Rijkswaterstaat*) does not allow too much vegetation growth, which might block peak discharges. For this reason there is a restrictive policy for the development of soft and hard wood forest in the streaming parts of the floodplains. In German, the development of forest is stimulated in floodplains of the Upper Rhine area as well as in the newly-created retention areas,. In some cases certain species of trees are even planted.

3.1 Retention polders/dyke relocations and ecological flooding

In the Polder Ingelheim near the city of Mainz, two new dykes with a total length of 1,500 m and an inlet structure were built to create a retention area of 160 hectares, with a retention volume of 4.5 million m^3. In the area of Kirschgartshausen, a dyke will be reconstructed to reconnect parts of the former floodplain to the River Rhine. An old Rhine branch will be connected to the main river as well, thus solving the problems of algal blooming and fish mortality in the branch.

In both areas the method of ecological flooding is used. Through ecological flooding, nature values can be improved and flora and fauna become preparesd for flood events. Ecological flooding differs from retention, because it occurs more often, for shorter periods, with water levels that are lower than in the case of retention and of course not in periods of flooding risks.

In an ideal situation, ecological flooding shows the same pattern as natural flooding. In practise, however, ecological flooding often has to be restricted in its spatial effect and operational period. These restrictions, caused by practical circumstances, are the reason why there are different and sometimes conflicting approaches in conducting ecological floodings. In Baden-Württemberg, for example, the period in which the flooding takes place and the level of inundation used are considered very important. In France, however, ecological flooding is practised in the same system every year, during fixed periods, and with the same water level, which is independent of the water level in the Rhine.

Monitoring programmes for some ecological flooded areas, like for example the Polder Altenheim in Baden-Württemberg (Figure 2), show that ecological flooding has a strong effect on natural fluctuations of groundwater level, causes changes in species of trees (some species die while others develop very fast by rejuvenation), in vegetation structure and in presence of fish, mammals and amphibians species. In this polder it was demonstrated that the changes brought by ecological flooding were very successful and highly valuated as a nature and floodplain protection measure.

The experience with ecological flooding in the German projects is important for projects in the Netherlands where bypasses and "green rivers" are foreseen in the national programme "Room for the River".

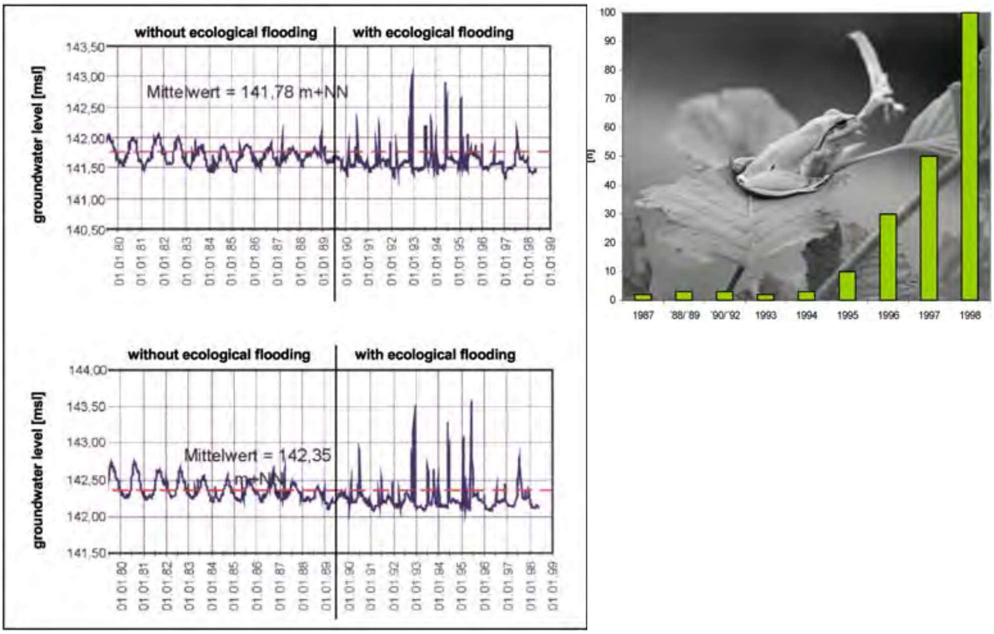

Figure 2 – Dynamic of groundwater levels at two monitoring stations in the Polder Altenheim (Upper Rhine) and the increase of Tree Frog (*Hyla arborea*) since the ecological floodings.

3.2 Side channels and natural dynamics

Side channels are implemented mainly for two reasons: safety (by enlarging the run-off capacity of the floodplain) and ecological development and restoration. In the Netherlands and in Germany, many projects were planned (Lexkesveer, Fortmond, Bemmelse Waard, Bislich-Vahnum, Emmericher Ward) and some were implemented (e.g. Gameren, Vreugdenrijkerwaard in the Netherlands), see Figure 3. The monitoring programme of the side channels showed that:

- Navigation problems in the main channel did not occur;
- The maintenance of the floodplain area with side channels was not a problem, although problems with uncontrollable sedimentation was expected;
- The biodiversity in the side channels increased (especially rheophilic fish);
- Along the shores of the side channels a continuous rejuvenation is going on which continuously creates pioneer habitats;

- Most of the sediments are sandy instead of clayey. The area is very dynamic and a high local heterogeneity exists;
- The newly developed floodplain with side channels was re-colonised very quickly by a great variety of aquatic species.

Figure 3 – Bislich-Vahnum proposed site for side channel (left) and implemented side channel near Gameren along the river Waal (right)

3.3 Lowering of floodplains and natural development

The lowering of floodplains is practised quite often in the Netherlands. This means sometimes the construction of side channels but in many cases also the excavation of sand and clay from the floodplain. This gives again more space for water during peak discharges.

Another consequence is that natural vegetation can re-grow in these areas. The thick clay layer of many Dutch floodplains is due to the artificial dyke built for centuries, which have led to the silting-up of floodplains and therefore a disconnection of the floodplain from the main river for most of the year.

In the German floodplains, the initial planting of forests is quite common, whereas in the Netherlands natural vegetation is allowed to grow only on the excavated floodplains, but under control of the Dutch water managers.

In many Dutch floodplain projects, herds of specific breeds of horses and cows are used as natural grazers. They are left alone in the nature area without shepherds. Although in Germany grazers are also used in some nature areas a similar type of “nature managers” as in the Netherlands is not yet known. There is always the fear of spreading of animal diseases and of potential danger for the people who want to recreate in the new nature areas.

3.4 Dyke relocations and floodplain extension

Dyke relocations are carried out in the River Rhine catchment to create more “Room for the river”. Within the SDF project, dyke relocations were carried out e.g. in Kirschgartshausen and Lohrwardt (Germany), and in Hondsboeksche Pleij in the Netherlands.

In the case of Kirschgartshausen, nature development plays a major role. In Lohrwardt, local farmers will manage the new floodplain area, but rivers banks will become more natural and also a fish ladder will be installed to allow fish migration. In the area of Hondbroeksche Pleij, the 120 hectares extended floodplain is used for a high-water gully inclusive and adjustable weir to divide the water more equally through the Rhine branches in the Netherlands (Figure 4). Moreoover, the floodplain will become more natural, with natural grasslands attractive to birds because a large composting plant will be removed from the floodplain. The area is very much used by inhabitants for recreation (biking and walking).

Figure 4 – Present and future situation at Hondsbroeksche Pleij, bifurcation Lower Rhine and IJssel

4. SPATIAL PLANNING AND FLOODPLAIN DEVELOPMENT

In the Netherlands flood protection still has a high national priority, that is the reason why the programme “Room for the River” will be implemented until 2015. The Room for the River programme has combined spatial planning and water management measures as well nature development and improvement of landscape quality very well.

In Germany, flood protection is a task of the individual federal states, thus making an integral approach sometimes difficult to achieve. A good instrument to compensate ecological losses is the principal of eco-account that was set up. Eco-account can be described as a pool of (executed) ecologically-valuable measures or actual areas that are available for such measures. These measures (for example the transformation of agricultural land into floodplain forest), will be put to the credit on the eco-account. When later on, interventions which damage nature will actually take place, there will be a write off on the credit of the eco- account.

The basis of eco-account is that before the beginning of activities like building for industry or housing, the potential loss of ecological values has to be compensated and/or substituted by developing new nature on another location than the one where the intervention takes place. If the development of nature takes place long before the building activities starts, there is (almost) no loss in ecological value during the building time.

Parts of Kirschgartshausen are executed as a result of practising the system of eco-account for building of structures such as the big arena and a shopping centre in Mannheim and the future extension of the city of Lampertheim.

5. CHECK ON SUSTAINABILITY OF MEASURES

The SDF project contains the word "sustainable" in its name. The standard definition of sustainable development is the Brundtland definition: "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987).

The ILA New Delhi Declaration (2002) expresses the view that: "the objective of sustainable development involves a comprehensive and integrated approach to economic, social and political processes, which aims at the sustainable use of natural resources of the Earth and the protection of the environment on which nature and human life as well as social and economic development depend and which seeks to realize the right of all human beings to an adequate living standard on the basis of their active, free and meaningful participation in development and in the fair distribution of benefits resulting there from, with due regard to the needs and interests of future generations…".

To evaluate this requirement a study was carried out. It appeared that few methods exist to evaluate sustainable river development (projects). One Austrian example was found within the so-called Mölltal project that worked with a matrix (Ömer and Strigl, 2000).

5.1 Outcomes of the Sustainability analysis

For the analysis within the SDF project, we wanted to know whether the project could fulfil the goals and indicators of sustainability and/or sustainable development. Therefore project-specific indicators/criteria in ecological and socio-economic categories were used for the evaluation. The evaluation was done with a comprehensive questionnaire. Table 1 gives an overview of the outcomes.

The results showed that all people and organisations involved discussed and implemented the "sustainable flood alleviation measures" in a broad and interdisciplinary manner. Strategic differences in measures exist due to the geographic location in a river catchment. The change of the goals of some single SDF projects into a more ecological direction was positively valued because it means more dynamic development and flexibility.

5.2 Advices for improvement

Monitoring of implemented measures is necessary in order to evaluate the successes for flora and fauna and to help improve comparable planned measures in future. In many floodplains, agricultural use is still present. But a change to extensive grazing (management) contributes to more natural conditions.

Table 1 – Final analysis of the fulfilment of sustainability criteria within the SDF project (Fehrenbach et al., 2008)

Sustainable Development of Floodplains SDF	Criteria **good to very good** fulfilled	Criteria **partly** fulfilled	Criteria **not** fulfilled
Goals of Project fulfilled			
Project as a whole	x		
Single Projects	x		
Fulfilment of ecological criteria			
Implementation of ecological measures	x		
Monitoring of success of implemented measures		x	
Protected areas	x		
Implemented strategies to solve conflicts		x	
Fulfilment of socio-economical criteria			
Existing potentials of use and realisation	x		
Future sustainable use of project areas	x		
Realisation and use of synergetic effects (win-win)		x	
Realisation of successful strategies in case of conflicts		x	
Internal communication and interdisciplinary knowledge exchange	x		
Public participation and acceptance in public and politics	x		

The recreational use of floodplains was not highly stimulated within the SDF project. People can enjoy parts of the area by biking or walking. Other parts are protected areas for flora and fauna. Zoning is a useful tool here.

Public participation (and/or involvement) was applied in most projects. Therefore the acceptance of projects was quite good. Of course, it is still not easy to find alternatives for certain stakeholders such as the farmers in floodplain rehabilitation projects.

6. CONCLUSIONS

Based on an integrated implementation and planning of projects along the River Rhine, the SDF project resulted in a better protection against floods and contributed to the natural development and/or hydrological connectivity of floodplains and old Rhine branches.

Flood alleviation measures implemented in the running time of the SDF project differ a lot. The creation of a retention area is essentially different from measures in existing floodplains or new floodplains that have an open connection to the river. Different effects on the process of nature development and results of this process on flora and fauna will occur and persist. The experience gained from one project is therefore not automatically applicable to other projects. Nevertheless, the numerous similarities in the problems that have to be solved make necessary to continue and even intensify cooperation on the aspect of nature development and flood protection measures. Cooperation in one river catchment is extremely valuable, as demonstrated by SDF project. The EU funding worked as a major catalyst and gave a positive boost to the implementation of flood prevention projects in combination with nature development (e.g. Kirschgartshausen).

Issues for further attention and discussion are:

- Dynamic river management and consequences on discharge capacity;
- Discussion on the concepts of compensation and nature management;
- Adjustment and cooperation in order to create boundless ecological networks and to reach the objectives of Natura 2000 and other EU Directives.

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URBAN RESTORATION OF VALSTAGNA RIVERSIDE RELATING TO ITS PRESENT HYDRAULIC RISK PROBLEM

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ABSTRACT

Basin planning is the instrument used to identify and define the interventions and actions necessary to achieve a rational and congruent setting of a territorial unit such as a hydrographic catchment

Among the various main issues of a river basin, hydraulic defence and the achievement of a relative degree of safety are the first priority. This need is particularly acute in the basin of the Brenta River, where the river streams across a densely populated lowplain, of high economical and social interest.

Flood events in the basin there have low frequency, nonetheless the Brenta River shows alarming risk conditions. Several risks factors exist in both the mountain watershed, especially upstream of Bassano, and in the remaining floodplain. The river has a hydraulic bottleneck near the densely populated city of Valstagna, where the urban area reaches up to the riverbanks and space for flood alleviation measures is therefore limited. Here, a strong need for implementing flood alleviation measures exists; in this case with a strong engineering component.

In this context, it cannot be overlooked the importance of a correct use of the city and the territory. The study discussed here is based on a thorough investigations of the territory aimed to identify its carrying capacity, and it proposes a planning and structural answer to the hydraulic risk problem in Valstagna.

The planned interventions to protect the territory should at the same time recover and revitalize the urban structure, and protect the landscape and environmental identity. The measures must fit into the river system and should promote the integration of river and territory.

Key words: Hydraulic risk, Brenta River, urban restoration

1. INTRODUCTION

The Brenta River is characterised by a low recurrence period of flood events, but shows alarming hydraulic risks. This flood risks occur in the mountainous part of the catchment, upstream of Bassano, rich of historical sites, and from Bassano to the sea, with lowplains full of industrial areas. The presence of important infrastructure works and towns immediately behind the watercourse hinders the upgrading of the cross section and requires to study structural and non-structural interventions.

In order to select and define operational plans for hydraulic risk reduction it is necessary to identify and characterize the so-called "project discharge" that usually is referred to an extraordinary well-known flood event, or to the artificial hydrographs generated from the synthetic distributions of precipitations with a given return period.

In the River Basin Plan the “project” flood event was generated by synthetic precipitation characterized by critical duration and a return period of 100 years (Rinaldo *et al.*, 2002), but the strength of the chosen structural and non-structural solutions was evaluated by comparing with the discharge data of the most recent flood disaster occurred in November 1966, reconstructed for the natural Brenta system by Water Authority of North Eastern Italy. The natural Brenta system is the river network without dams or any other structure capable to modify flood generation and propagation.

Such hypothesis allows verifying the actions produced by the existing works, possibly assessing appropriate structural adjustments or management, and evaluating the new storage capacity for flood mitigation.

In this context, a peak value of 2,500 m^3/s and 2,700 m^3/s was estimated respectively at Valstagna and Bassano where the flood generating area of the Brenta watershed comes to an end and with flows of about 320 million m^3 of water.

The comparison of such flood waves with the Brenta cross-sections, shows a flow capacity of about 1,500 m^3/s for Canal del Brenta. Due to the geographical conditions, the modelling showed an hydraulic bottleneck at the city of Valstagna, where a flow capacity of 950 m^3/s was calculated (Fig. 1).

When identifying possible actions to achieve flood-security in Canal del Brenta, it is essential to define the maximum flow capacity (so-called design discharge) that is supposed to be actuallky occurr in the river in the reach between its confluence with Cismon Stream and Bassano del Grappa, i.e. the section of the Brenta River with most critical hydraulic conditions.

This choice affects either the intervention strategies to be carried out in the mountain basin, or those to be conducted in plain, i.e either active defence (limiting discharges) or passive protection (increase defences).

The actual basin plan tends to favour those combinations of actions which are widespread in the territory and occur gradually over time.

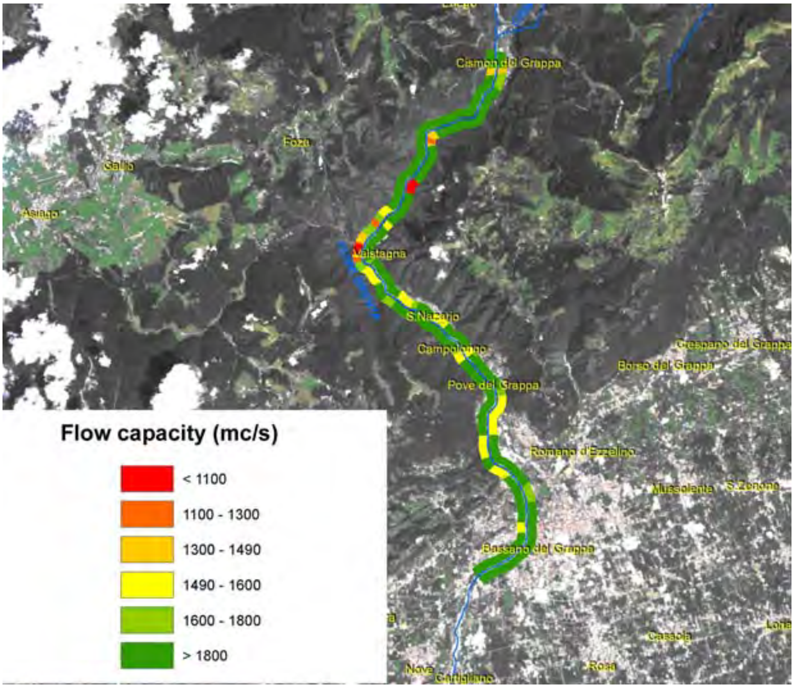

Figure 1 – Flow capacity in Canal del Brenta.

The presence of a large number of dams for hydropower production in the Cismon tributary suggests to use temporarily such existing volumes as the first strategic option for hydraulic risk mitigation. Corlo reservoir has the largest storage capacity, and can be used to test the reduction of peak discharge in autumn. This is a multipurpose reservoir for irrigation, water supply, recreation and downstream minimum flow regulation during the dry seasons. This action could make the Brenta discharge compatible with the current flow capacity of whole Brenta river network from the source to the sea, except for some critical sections characterized by a conveyance well below the reference or design discharge.

Undoubtedly, the greatest hydraulic bottleneck is located along the town of Valstagna:, where the minimum outflow capacity is associated with the presence of a significant human settlement.

However, even the use of the entire Corlo storage capacity can not alone ensure the hydraulic safety of Valstagna town unless any other structural measure are undertaken In fact, the availability of additional volumes in the reservoir, obtained by lowering the water level in the lake before the flood event allows the safe containment of a 70-years flood event.

Therefore it is necessary to act locally, trying to prioritise the actions that increase the flow capacity of the river at Valstagna.

Numerous and diverse solutions exist and can be summarized in the following actions (*Autorità di bacino dei Fiumi dell'Alto Adriatico*, 2008):

- a new set of different cross-sections that consider a wider channel form and a deeper bed-form in Valstagna;
- partial diversion of discharge, through the implementation of a tunnel able to intercept the water upstream of the settlement and return it to the Brenta further downstream;
- the execution of temporary works e.g. flood barriers in the city area to cope with intense weather events and being able to prevent flooding of the city.

Given the opportunity to realize interventions which would achieve a significant security degree, it can be considered that the discharge of 1,500 m^3/s represents the flow capacity value to be achieved by the implementation of measures. Figure 2 shows the difference in level between the road along the Brenta river and corresponding to the threshold discharge value defined above , that will be from now on called “project level.

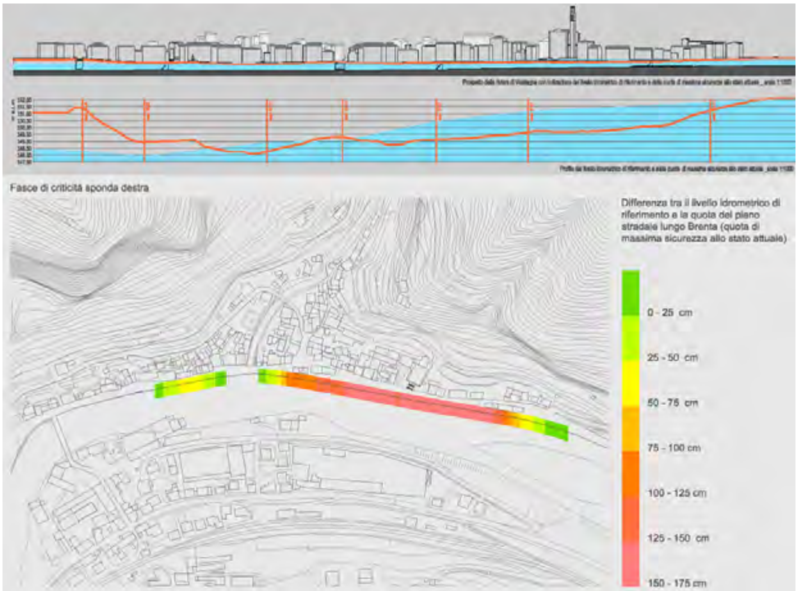

Figure 2 – Hydraulic bottleneck along Valstagna riverside.

The following proposal gives an overview of a new urban planning that allows to protect from the hydraulic risk in Valstagna and that at the same time allows to recover and revitalize the urban structure, by acting on the protection of landscape and environmental identity. Furthermore it is a systematic approach and promotes the riverine system being a part of the city.

2. THE BUILD UP AREA OF VALSTAGNA

For a good planning, detailed knowledge of the area under consideration must be collected and analysed first. Several data, covering the different urbanistic and territorial aspects of the area were used. From these studies it was possible to synthesize the structural aspects of the territory and its problems, and therefore to define the territorial invariants and suggest compatible transformations.

A peculiar element is the strong and symbiotic bond that the local communities have always had with the river. in fact, Valstagna originated around the year 1200 A.C. like a fluvial harbour and the city developed thanks to the possibilities offered by the navigation on the Brenta River, an important communication way of the past with the Pianura Padana, and by the exploitation of hydropower generation. Today the local population is still strictly linked to the river and its behaviour.

The analysis of the territory conformation shows a longitudinal course which is emphasized not only by the river, but also by the Strada Provinciale Campesana on the right hydrographic bank and by the Strada Statale Valsugana n. 47, the Trento-Venezia Railway and the riverside Passeggiata Guarnieri on the left hydrographic bank. The transversal axes are numerous but not as strong as the longitudinal ones, with the exception of the Frenzela torrent, the Rialto Bridge at the beginning of the town and the street in front of the railway station.

The Valstagna riverside is characterized by a continuous building front. The structure of the inhabited area has not changed very much during the centuries, which is a direct consequence of the particular topographical conformation of the Canale di Brenta, that contains the city growth that results limited to the bank area. The San Marco Square represents the town centre, one of the most important markets in the past in the Vicenza territory. the ancient fluvial harbour was localized next to the square. Various appreciable buildings are located along the river, such as the 18th century Perli Palace or the Archpriest Church, signs of the economic prosperity achieved by these communities through the past fluvial business on the Brenta river course. Most part of this territory is classified in the municipal plans as a zone of relevant historical and environmental interest.

Almost the entire Valstagna riverside has is divided in the same three longitudinal zones. The first zone, which is the largest one, is reserved to driveways; the second one functions like a car parking and finally the last, smallest one, is the footpath.

Figure 3 – The present situation of Valstagna riverside.

Figure 3 shows exactly the present situation: the riverbank area has been used as a big parking place and the pedestrian way is confined to a narrow pavement. This highly compromises the quality and the liveability of the system: the beauty of a walk along the river is suffocated by the heavy presence of cars. The same thing happens to the most dynamic areas, potential meeting-places, like the areas near the restaurants, bars and shops, or the spaces closest to the most important public buildings.

A very significant part of the right hydrographic bank is structurally constituted by a gravity wall, the top of which comprehends a small wall that functions like a parapet for the street. When evaluating the flood capacity, the level of the roadway was taken into account because this parapet, with an elevate thickness but pierced by some windows, is not a safe enough element to guarantee hydraulic defence.

The differences in levels between the roadway and the correspondent project levels are not constant. The confluence of the Frenzela Stream into the Brenta and the Church area is the most critical situation because height differences can reach 1.5 m in specific points. At the same time, this is one of the most dynamic area of Valstagna, the majority of shops and public offices are localized here and this area has all the characteristic of a meeting-place. This work has therefore paid a specific attention to the area.

3. THE PROJECT

The proposed actions on the Valstagna urban structure, being necessary in order to guarantee the safety of the city and the revitalization of the area as well, are based on the quantitative and qualitative evaluations emerged in the previous hydraulic and urbanistic analysis.

The planning solution thus represents the natural prosecution of the present detailed and critical study of the territory, finalized not only to identify the technical aspects, but also the deep ties between the Brenta river and the population that lives along it.

The perfect project doesn't exist without these premises. It must include all the aspects of the delicate balance between the natural and the anthropic systems. It cannot just aim to the safety of the territory, but it has to be guided by an attentive knowledge of it, it must guarantee (and improve!) the quality of life of the population living in the area, sustain the compatibility of hydraulic and urbanistic needs, respect the naturalness of the system and has to be feasible.

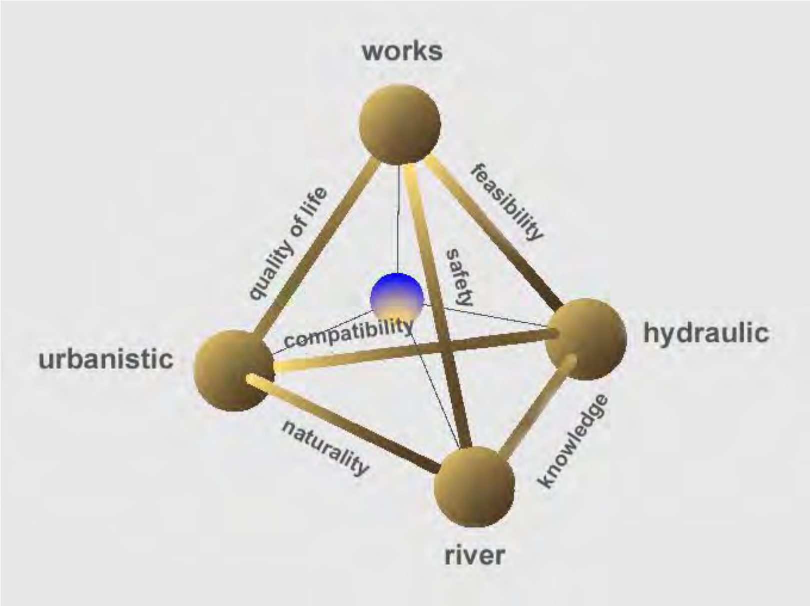

Figure 4 – Strategic location of the project.

The proposed solution combines the hydraulic safety interventions with a new viability order that wants to eliminate cars along the riverside and to transform it into a new space with a new urban quality, a space destined only to the people, a space where the pedestrian, not the car, is the master.

The need for hydraulic protection is satisfied by a rise of the actual pavement to a reference level and this operation has to be combined with the creation of a new pedestrian way along the riverside that substitutes most of the existing parking area. Two new underground garages located out of the town centre and sized to support the town demand guarantee car parking. The restriction of the driveway street and the dislocation of the park areas grant more dignity to the footpath obtained with the reduction of the traffic circulation in the town: the car transit would still be guaranteed, but it will be submitted to the pedestrian one.

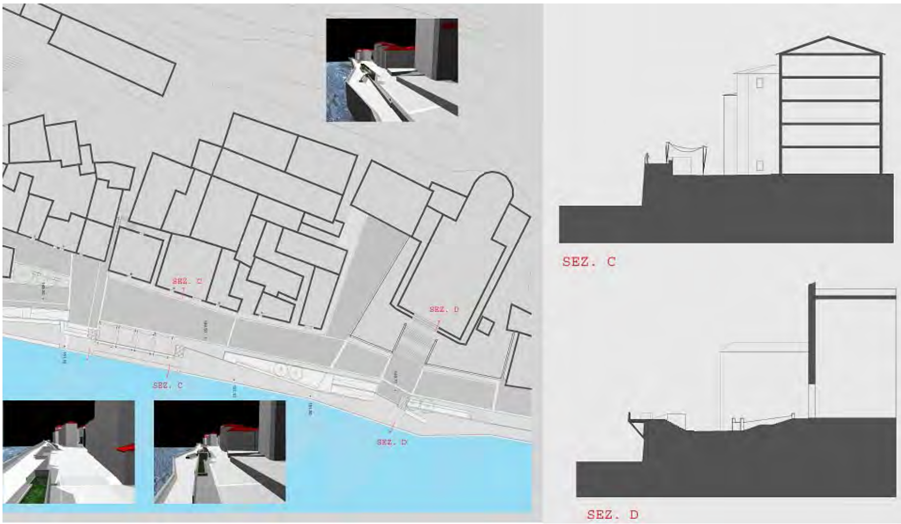

Figure 5 – The new pedestrian way at the riverside.

The difference in the level of the new footpath and the roadway is not always the same along the riverside, but it changes with respect to the correspondent hydraulic safety altitude. Numerous stairs lead to the footpath and lights follow the axis of the most important pedestrian fluxes. In fact, i there are many stret crossings in the town by which it is possible to reach the houses that are located behind the first line of buildings along the riverside. The new pedestrian viability wants to respect the existing dynamics of the town and create new meeting-places, so the footpaths are larger in the most interesting areas, in front of the important buildings, for example in front of the church, or simply in the most lively places.

To guarantee a greater safety the footpath is protected by a concrete parapet riverside. In the same conditions it was hypothesized to use a transparent parapet made of glass and to guarantee the same level of safety using a mobile device: a hydro-airbag located in the new riverside body. The hydro-airbag is a mobile protection device that can block the water in case of necessity. If the water of the river is rising, the hydro-airbag swells up and doesn't allow the waters to pass and to invade the street, whereas during the normal situations it is invisible because it remains hidden in the pavement. The advantages of this kind of solutions are evident: it provides security with the minimal environmental impact.

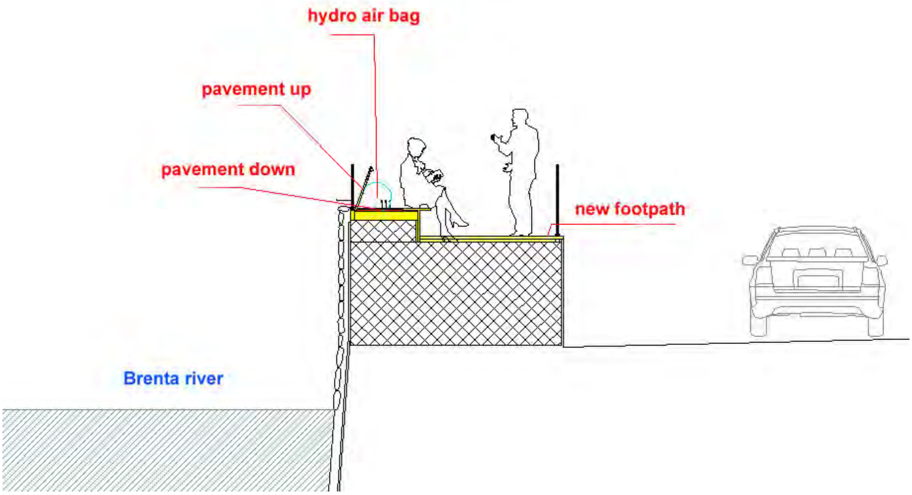

Figure 6 – Application of the hydro air bag.

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CAN FLOOD RISK MANAGEMENT RESTORE ECO-GEOMORPHOLOGIC FUNCTIONING OF FLUVIAL MARGINS ALONG THE LOWER RHÔNE RIVER (FRANCE, SE)?

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ABSTRACT

Over the last centuries, the Rhône River has been severely modified by numerous activities, including navigation, irrigation, flood-control, and hydroelectricity production. Over time, the cumulative effects of engineered structures including embankments, dams, groynes, and diversion channels modified the connections between channels and their floodplain ecosystems and altered the natural flow regime, particularly during periods of floods. The altered ecosystem hydrology induced morphological changes such as channel degradation and narrowing, bank stabilization, and terrestrialization of former channels.

In order to address this situation, the CNR (Compagnie Nationale du Rhône, i.e. the Rhône River manager) intends to carry out a restoration project along the downstream reach of the Rhône River (southern France, 100 km length upstream from the mouth). The dual goals are to reduce the local flood risk (e.g., increasing flood-carrying capacity) and enhance geomorphological and ecological functioning of the reach (e.g. sediment transport, pioneer species regeneration).

The Rhône River is a good case study of complex and severely-altered systems. Indeed, important issues have to be integrated: (i) flood risk for the major city along the reach (Arles), (ii) bank erosion control near cultivated areas, (iii) former channels loss of diversity due to terrestrialization processes and floodplain forest disconnection because of the channel degradation, (iv) pollution risk if toxic sediments are reworked (contamination by metals, PCB and radionuclides), (v) navigation, and (vi) sediment deficit that impacts coastal evolution downstream the reach (Camargue delta).

We present a step-by-step strategy to reach a balance between human activities and ecological purposes. Within this framework we integrate concerns that span science, history, and current management of the Rhône River. For example, can the historical state be considered as a reference-state? How can we choose sites to test the actions? How to design these actions? Which monitoring strategy should be

developed? What kind of ecosystems can be expected within a Mediterranean climate (e.g. community composition, recovery rate, presence of exotic species)?

Key words: sedimentation, morphological adjustment, floodplain rehabilitation, flood management

1. INTRODUCTION: A RECENT CHANGE IN FLOODING CONDTIONS

Over the last decades the Rhône River has undergone significant morphological adjustment, including channel stabilization, narrowing and deepening in several reaches (e.g. see Arnaud Fassetta, 1998; Antonelli, 2002; Raccasi, 2008 for the lower Rhône River). As a result of floodplain evolution and channel configuration, we now observe significant changes in flooding conditions. For example, during the 2003 flood event (maximum discharge 11,500 $m^3.s^{-1}$) some reaches experienced higher water level in the channel (for example +0.3 m upstream of Arles city, cf. figure 1) than during the 1856 flood (maximum 12,500 $m^3.s^{-1}$). These observations led the Compagnie Nationale du Rhône (CNR, the agency responsible for the Rhône River management) to plan some rehabilitation projects along the upper and middle Rhône River (Bravard *et al.*, 2008). Over the last decade, the CNR also initiated some rehabilitation actions in order to improve ecological function and diversity of the Rhône's floodplain through opening and excavating the former channel (Henry *et al.*, 2002; Amoros *et al.*, 2005).

The aim of this paper is to present the framework developed since 2007 for rehabilitation of the fluvial margin along the lower Rhône River reach. Due to the complexity of management issues and stakeholder goals (e.g. flood risk, bank erosion, pollution, navigation, riparian ecosystems, sediment transfer to coastal area), a framework tailored specifically to the Rhône River was required.

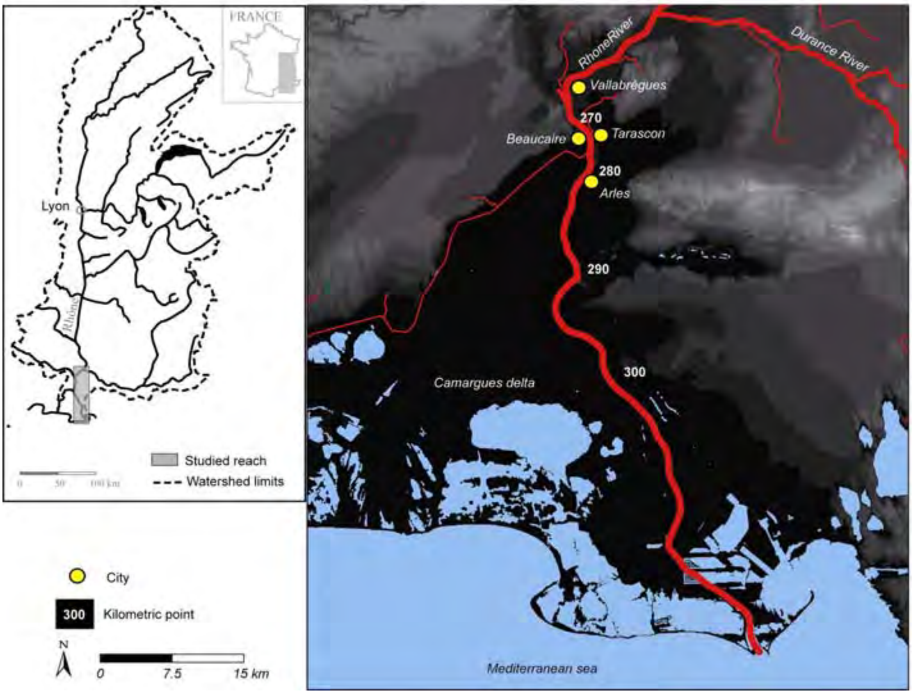

Figure 1 - Location map.

2. REHABILITATION OF THE LOWER RHONE RIVER MARGINS: A GENERAL FRAMEWORK

The main goal of the rehabilitation project for the 70 km of lower Rhône River (from Vallabrègues to the sea) is to limit inundation during flood events, notably nearby the very sensitive areas such as Arles and Beaucaire-Tarascon (Fig. 1). To tackle this question, we plan to increase the channel's capacity to evacuate floods by eroding fluvial margins that have been deposited since the 19th century. Several strategies could be employed to initiate the erosion process, including opening former channels and removing groins.

The project is composed of two steps: first, test the effects of rehabilitation actions at a limited number of sites, and second, extend actions to other potential sites along the reach. The first step began in 2007 and will be achieved in 2010. It can be divided in seven successive steps (Tab. 1). The first one, the bibliographic analysis, has been completed, the second and third ones are still in progress.

Table 1 - Framework of the lower Rhône River rehabilitation project.

Steps	Detail, intermediary steps	Goals
1. bibliographic analysis	Inventory of available data for the reach (hydrology, morphology, ecology)	To analyze the recent evolution of the reach To identify missing data and understudied sites within the reach
	Acquisition of additional information	To have homogeneous knowledge for the reach
2. selection of the sites	Identification of area filled by sediments during the 20th century (notably former channels)	To identify all the sites that can be rehabilitated = potential sites (geomorphological criterion)
	From the potential sites list, identification of ownership constraint (exclusion of private sites)	To select sites on which the CNR can act quickly (legal criterion)
3. initial state	Implementation of the initial state: - historical evolution (from aerial photos, old plans) - current topography - sedimentation (thickness, grain size, associated pollutant) - hydraulic conditions (water level during floods…) - vegetation (species, habitats)	To describe selected sites for rehabilitation before works
4. design of actions	- Description different potential methods (scenario, type of works and expected decrease in water level), - Identification of risks associated to each scenario - Financial estimation	To choose rehabilitation methods according to selected sites and constraints
5. implementation of actions	Implementation of works according to selected methods	To rehabilitate fluvial margins
6. monitoring	Monitoring implementation: - topography - sediment deposits - hydraulic conditions - vegetation (recovery cartography, communities characteristics)	To monitor the effectiveness of the selected methods
7. adjustment	Adaptation of the actions (depending of the results of the monitoring process)	To improve method effectiveness

3. DIAGNOSTIC: MORPHOLOGICAL CHANGES AND THEIR CAUSES (1876-2006)

To achieve the rehabilitation project a precise evaluation of both historical changes in floodplain topography and flood carrying capacities is needed.

3.1. Morphological changes (1876-2006)

Historical data analysis (old maps and surveys) clearly demonstrate that the lower Rhône River underwent several changes in channel geometry and bank position over the last 150 years. Changes include channel incision and narrowing, bank accretion, and sedimentation of former channels. For example, at the kilometric point (kp) 275.5, the channel degraded by 2 m and narrowed by 500 m between 1876 and 2006 (Fig. 2). For the same discharge (5,800 $m^3.s^{-1}$; 2 years return period), the increase in water level at this point is close to 0.5 m.

Be comparing the two DEMs from 1876 and 2006, we have quantified the magnitude and spatial distribution of sedimentation. Between Beaucaire and Arles (9 km), $9x10^6$ m^3 of sediment have been accumulated over the last 130 years. These modifications occur mainly in the channel and its vicinity, whereas the external part of the floodplain was quite stable over the period.

3.2. Causes

The current channel geometry results from the evolution of external controls and local constraints. Both flood event frequency (Pichard, 1995) and sediment supply from tributaries decreased since the 19th century because of dam construction and natural and artificial hillslope afforestation (Vallauri, 1997; Landon, 1999; Bravard, 2002; Kondolf *et al.*, 2002; Marston *et al.*, 2003; Piegay *et al.*, 2004). Consequently sediment transport decreased from 900,000 m^3y^{-1} to 200,000 m^3y^{-1} during the 20th century (BCEOM, 2003), whereas during the same period, mean discharge was constant (Pardé, 1925; François, 1937; Anselmo *et al.*, 2005).

Flow regulation structures such as dikes and groynes, which were built downstream of Beaucaire between 1870 and 1938 to improve navigation, also contributed significantly to the observed channel adjustments. For example, from kp 293 to kp 297 groynes and submersible dikes were built since 1867 (Fig. 3) to limit lateral mobility at outside meander bends and to close off side channels. These actions resulted in very rapid channel narrowing of 80 m from 1867 to 1869.

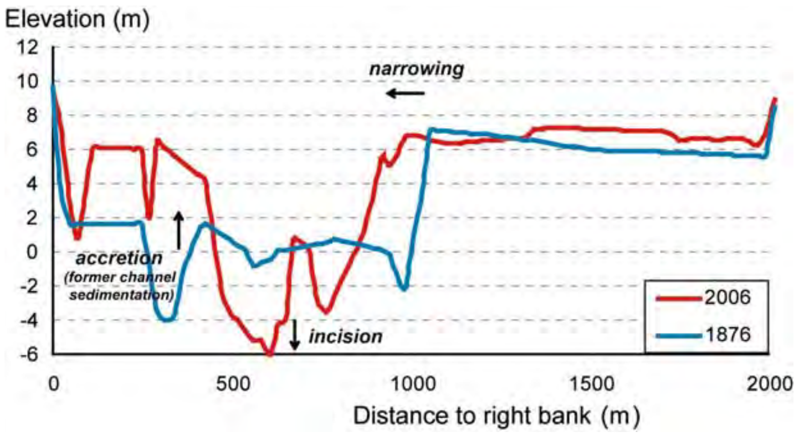

Figure 2 - Channel cross sections at the kilometric point (kp) 275.5 in 1876 and 2006. Main changes are illustrated here: channel degradation and narrowing, sedimentation in former channels.

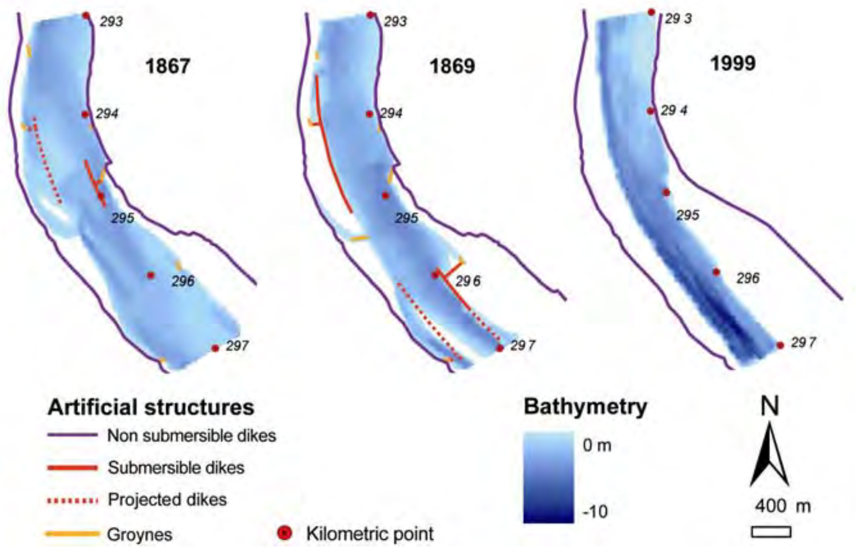

Figure 3: An ex. of regulation impact on channel geometry (incision and narrowing).

4. SITES SELECTION AND MULTIPLE ISSUES MANAGEMENT

The rehabilitation project of the lower Rhône River concerns a 70 km length reach where several issues are overlaid (Tab. 2). On one hand, the re-introduction of sediments stored in the floodplain could have unintended negative consequences such as erosion of private land, impaired navigation, and remobilization of polluted sediments. On the other hand, this action could improve the sediment supply to coastal area or the ecological functs of the floodplain. Moreover, only portions of the total 70-km reach are favourable to implement actions. Indeed, the vulnerability to inundation is concentrated only in the first kilometres of the reach and not in the Camargue delta. Furthermore, the channel gradient is sufficient to induce erosion only upstream from Arles. As a result, relative few sites appear to be good candidates for rehabilitation (2 to 4 sites along 70 km).

Table 2 - Summary of issues to take into account in the rehabilitation project.

Issue	Positive consequences of the rehabilitation	Potential negative consequences or constraints
Sediment transfer	Sediment reworking can increase sediment supply to coastal area (in deficit)	Current deficit is higher than potential available sediment During flood events a large part of the sediments moves to the sea and does not participate to the coastal alimentation
Ecology	Improve ecological functioning of the floodplain and increase biodiversity by former channel rehabilitation	Expected habitats are not known because of a deeply and formerly impacted system with very few reference sites Increase in exotic species frequency (*Amorpha fruticosa* L., *Ludwigia* spp.)

Pollution		Sediment reworking can re-introduce pollutants in the systems (PCBs, mineral pollutants: metals and radionuclides)
Navigation		Actions must be limited to preserve the navigability of the reach: conserve a water level high enough and no change in channel position
Bank erosion		Rehabilitation actions should not increase bank erosion in private areas

5. CONCLUSION: IS THE REHABILITATION OF THE MARGINS A DURABLE SOLUTION FOR THE LOWER RHÔNE RIVER?

Along rivers that have recorded narrowing processes over the last decades, sediment remobilisation could be used to decrease water level during flood events. From a theoretical point of view, this is particularly efficient in floodplains which present a high accretion rate. But, as for many rehabilitation projects, the technical limitations are not the largest impediments to implementation. Along the lower Rhône River, taking into account all the issues led to a drastic reduction of the number and spatial extent of experimental sites. As a result, we expect a limited effect of actions upon flooding conditions; an evaluation is in progress. If these results are confirmed, a negative feedback could be generated and would make the extension of these actions to other sites or reaches more difficult.

To reconcile flood management and ecosystem functioning, several questions must be solved. The first is fundamental and complex: which kind of ecosystem may we expect? In our situation, the human impacts are ancient and strong; the reference condition cannot be a “natural” one. Nor can the reference condition be a historical one; we clearly acknowledge the impossibility of returning the channel to its conditions during the 19th or early 20th century. A new reference must be identified, but how?

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DRAINAGE AND FISHERY NEEDS IN THE RESTORATION OF AGRICULTURAL BROOKS

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ABSTRACT

Drainage of agricultural and forest areas requires dredging of brooks to allow sufficient drainage depth and water flow in order to prevent local flooding. In Finland, straightening and deepening of brooks has led to the weakening of ecological diversity in watercourses. New drainage and restoration techniques have been investigated in a research program. The aim of the research was to improve both the flow of water and the ecological condition of the channels. Restoration for fishery and new drainage methods were investigated at nine research sites in different parts of the country. Some experience were promising but also challenging, such as dredging cases in which channel discharge capacity was increased with the help of flood terraces. Based on examples in southern Finland, the restored streambeds may provide good conditions for fish including trout in agricultural streams.

Key words: drainage, dredging, flood control, restoration, erosion, fish, streams

1. INTRODUCTION

Drainage of agricultural areas is a prerequisite for cultivation in the Finnish climate and lowland conditions. Almost all brooks and ditches in farming lands have been widened, deepened and straightened to allow sufficient drainage depth and prevent local flooding. Regular dredging has weakened the ecological condition of brooks and increased erosion, sedimentation and invasion by aquatic plants of the downstream sections. Decreased water flow and poor water quality also cause problems. In addition, biodiversity suffers and the form of the streambed becomes monotonous. Only few species can live in straightened and deepened streams.

Brooks are important breeding and living environments for many species and even valuable salmonid fish species can survive in agricultural areas.

European water policy directs water management to consider ecological diversity. In order to improve the ecological status of watercourses, new maintenance practices are needed to combine the goals of drainage with restoration of rivers and streams.

2. RESEARCH OF NEW DREDGING AND RESTORATION METHODS

New restoration and drainage practices have been investigated in a research program called "Sustainable management of dredged agricultural streams." The study was coordinated by the Finnish Environment Institute and was carried out from 2005 to 2007. It was executed in co-ordination with some Regional Environment Centers. The main aim of the program was to devise and test environmentally friendly drainage practices. Another goal of the program was to investigate farmers' attitudes and conceptions on drainage and restoration issues. In addition, the study sought to increase people's awareness of the small streams' significance through communication.

Research sites in different parts of the country were studied for restoration of fish populations and for environmentally friendly drainage methods. The research sites were divided into two groups based on their observable problems: one included the restoration of dredged brooks with special interest for fish and the other those cases cases of maintenance dredging.

2.1 Restoration for fish populations

Possibilities for improving the living and breeding conditions of fish in agricultural brooks were tested in four dredged streams in southern Finland. The restoration measures were executed without harming the drainage of the farmland. All four brooks are breeding environments for the endangered sea trout of the Baltic Sea.

The conditions for fish were restored by increasing the diversity of the streambed. Fish habitats were improved by creating gravel beds and sand traps and by adding large stones, all of which help to manage erosion and vegetation. Other methods employed were restoation of meanders and increase of depth variety in the channels.

The most extensive restoration measures were executed in the Longinoja brook (Fig. 1), an important breeding area for sea trout in the Vantaanjoki river in Helsinki city. The straightened brook flows through both a densely populated area and along farmland. The aims of restoration were to increase the breeding possibilities for migrating fish and also to improve the area's landscape. Restoration measures were carried out in an ecologically monotonous straightened section (300 m) of the brook. Stones and gravel riffles were added to the brook bed, which increased the diversity of the channel and created new spawning habitats for salmonid fish. Depth variety was increased and stone material was added for erosion protection. The curving outline of the brook was restored by excavating meanders and floodplains.

The restoration plan was made with a photograph-based method to illustrate the measures. An old map from 1870 was used as a model for meander length. The restoration was accomplished in winter 2006 by the regional environmental centre and the city of Helsinki.

Figure 1 - The straightened Longinoja brook was restored with new slight meanders and stone material.

2.2 Environmentally friendly drainage methods

Dredging methods were tested with practical drainage cases in different parts of the country. The main purpose was to investigate the use of a two-stage cross section (Fig. 2). The rate of water flow can be increased by excavating flood terraces above the normal water level on the upper part of the slopes. The bottom of the stream can be left generally untouched and deepening of the bed is necessary only if drainage depth must be increased. Other environmentally friendly drainage methods that were tested included erosion control with stones and vegetation and construction of weirs, sedimentation ponds, and wetlands.

The two-stage cross section was tested at Juottimenoja brook in southwestern Finland. The surrounding of Juottimenoja is intensively cultivated and the latest dredging was in 1970. The brook suffered severe erosion and siltation problems due to erosion-prone soil, intensive farming, and previous straightening. A trout population is present in the brook. The aim of the two-stage profile was to maintain the brook morphological and ecological diversity and self-purification capacity while meeting the drainage needs of the farmland.

The dredging of Juottimenoja was implemented in July 2007, mainly with a two-stage profile. The level of the terrace was adjusted to be as low as possible, allowing high water flow to easily rise onto the terrace. Herbal vegetation and roots of trees were left where possible to protect slopes (Fig. 3).

Figure 2 - In the two-stage profile of Juottimenoja brook the naturally enhanced bed was preserved as low flow bed. Only flood terraces on both banks were excavated. The bed is not affected and the water area remains narrow and deep enough for fish.

Figure 3 - Drainage pipes coming to the flood terrace in Juottimenoja brook. Herbal vegetation and roots of trees protect the slopes from erosion.

3. MONITORING

The effects of the restoration were examined in a monitoring program at the research sites. Monitoring started in 2005 before implementing the restoration measures. In order to find out the long-term effects of the restoration, it is necessary to continue monitoring at least five years after executing the measures.

Morphological changes of the channels were evaluated by measuring five cross sections at distances of 10 meters at each restoration site. The various species and vegetation coverage on the banks and streambed were evaluated in a two-meter zone at each cross section. Changes in the fish population were monitored by electrofishing in the restoration areas valuable for fish. The research sites were accurately photographed each year.

4. COMMUNICATION

The project also sought to increase people’s awareness of the ecological significance of the brooks and of the possible improvements of the state of small watercourses through communication. A guide and brochure were published to provide advice on brook restoration and environmentally friendly dredging projects. The aims and results of the project were introduced in many public forums such as seminars, newspapers, TV and radio.

5. RESULTS

5.1 Increase in trout populations

Electrofishing at the research sites was first carried out in 2005, before restoration began. This monitoring was continued yearly by the Game and Fishery Institute in October before trout spawning. Comparison of the 2005 and 2007 results showed an extensive increase in the trout population of two monitored brooks, Longinoja and Kocksbybäcken.

The electrofishing at Longinoja in 2005 revealed only a few trout in the restored section, less than in the reference sections upstream and downstream (Fig. 4). No change was found in autumn 2006, the year of the restoration. In autumn 2007 a significant increase in the trout population was observed throughout the brook, due in part to a good water year.

The number of juvenile trout in the restored section (black bars in figures) was as large as 140 trout per 100 m². A large number of the juveniles had been introduced and self-migrated from the main stream of Vantaanjoki river. The increase in the number of trout was larger in the restored section than in the reference sections, showing the positive influence of restoration on habitat diversity.

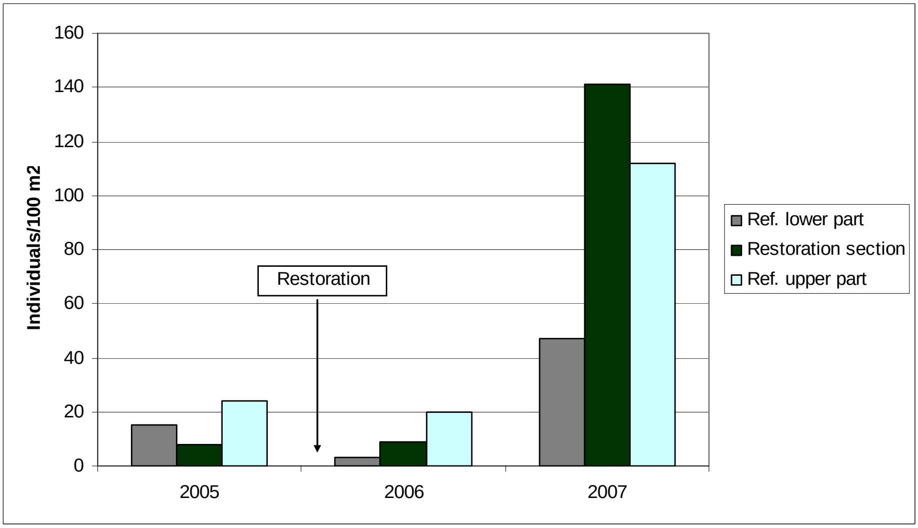

Figure 4 - The number of juvenile trout in the restored section of Longinoja brook (black) exceeded the numbers in the reference sections in 2007. (Data: Saura, A.)

In the case of Kocksbybäcken broo, only few trouts were found in the research section in 2005 before restoration. However, the number of juvenile trouts in the reference section downstream was exceptionally high, with 300 juveniles per 100 m² (Fig. 5). After restoration in 2006, only few trouts were found in the reference section and none in the restored section. One reason was that the year was too dry for juvenile trout production. In 2007 trout number increased in the restored section. There were half as many juvenile trouts in the restored section as in the well-populated reference section.

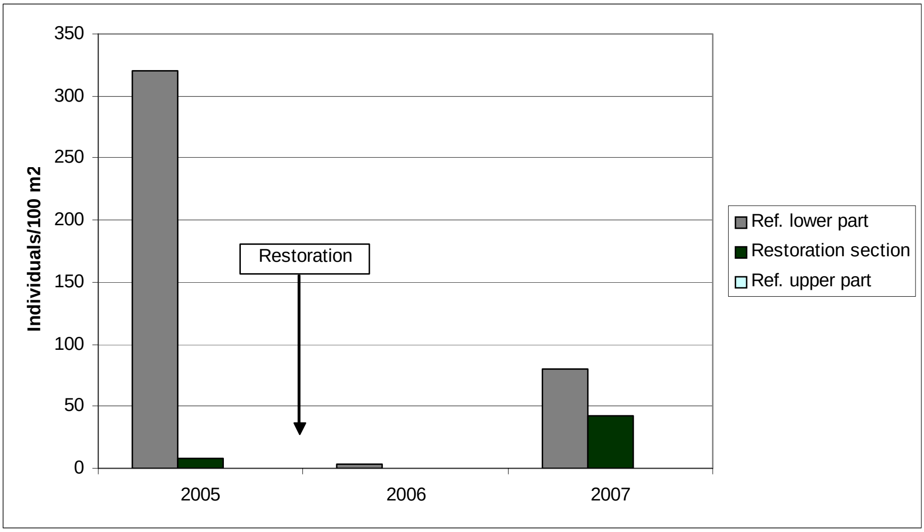

Figure 5 - In Kocksbybäcken brook the juvenile trout population in the restored section (black) increased in 2007 and was half of the well-populated reference section (grey). (Data: Saura, A.)

5.2 Finding suitable excavation methods for the two-stage profile

In the case of Juottimenoja brook suitable excavating methods were developed on site. Problems in the first phase of dredging were erosion and mixing of the soil with the water, which made the construction of flood terraces difficult. As a result, more accurate instructions were given. The excavators were to dig flood terraces only on one side of the stream, leaving the streambed and opposite bank untouched while protecting bank vegetation. Once learned the technique, the excavation of flood terraces did not require more time than the traditional excavation methods and thus did not increase costs. The area of the flood terraces was not remarkably broader than in traditional excavation. Digging from both sides or only from one side of the stream must be considered when planning and contracting with landowners. In addition, trees providing cover for the streambed should be preserved and considered when choosing from which bank the excavator will work.

5.3 Effects on water, morphology and vegetation

The low-flow bed remains underwater when the water flow is at its lowest level. When excavating the terraces, the low-flow bed remained undisturbed. When electrofishing one month later one trout was found in the excavated section. Floodwaters had risen to the flood terrace and modifications to the bed were observed. On most banks, vegetation was preventing erosion. Some banks with little or no vegetation had collapsed. The streambed was widening and a narrow terrace at the summer water level was beginning to develop. Riffles of gravel and stones will be constructed for erosion control and to enhance fish habitats.

6. CONCLUSIONS

The results of electrofishing clearly demonstrated that even small-scale restoration can highly increase the reproduction of salmonid fish in agricultural streams. Small brooks can be both important breeding areas for adult fish and living environments for juveniles.

Environmentally friendly management of agricultural streams has many ecological benefits compared with traditional dredging practices. The use of a two-stage profile improves the habitat diversity of the stream bed, the channels water quality, and rural landscape. It also prevents water turbidity during excavation. Experiences in different conditions and monitoring of the measures are still needed. Education and awareness are also needed for drainage planners and excavator drivers.

The study proved that agricultural brooks can contribute to effective basic drainage and also provide valuable environments for diverse flora and fauna.

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BIO-COMPOSITE REVETMENT SYSTEM FOR RIVER RESTORATION IN URBAN AREAS

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ABSTRACT

In the present study, a bio-composite revetment block was designed and tested in laboratory and field in order to determine its various characteristics. The block is proposed to be used for flood mitigation projects and also for river restoration. The dimensions of proposed bio-composite revetment block are 400 mm x 400 mm x 100 mm (length x width x thickness) and has a central opening with a dimensions of 280 mm x 140 mm and this opening contain a 10 mm layer of coconut husks (biological material) as a media for promoting grass growth. The bio-composite revetment block consists of tongue and groove to provide self interlocked between system blocks. The coconut husk was selected after testing the ability of three types of the biological waste for growing grass in the laboratory. Beside the coconut husk the other tested types of biological waste were sugar cane husk and oil palm husk. Field test on selected stretch of a stream located inside the campus of University Putra Malaysia, Selangor, Malaysia showed that the rate of grass growth was 15% per week and it is affected by slope of the stream banks. The proposed revetment system showed that it is friendly to the environment and can give a good aesthetic appearance to the stream. Field tests revealed that the proposed revetment system is durable since there are no signs of failure after more than one year of continuous monitoring. For a given water depth, the hydraulic tests showed that the value of Manning coefficient of roughness for the bio-composite revetment system depends mainly on the rate of grass growth. The average value of Manning coefficient of roughness after the installation for the bio-composite revetment system was found to be 0.043. Based on the above tests, it is recommended to use the bio-composite revetment system for river restoration projects.

Key words: Bio-composite block, river revetment, design, testing, environment

1. INTRODUCTION

In last decades, Malaysia is subjected to rapid development and as a result, severe flooding has occurred particularly in urban areas. Flood mitigation measures were taken to reduce the flood damage and channel improvement is main solution proposed by engineers for this purpose. Usually, consultant engineers proposed a rectangular concrete section for improving the channel of the flooded river. So, it often happens that the undersized natural section of a river is changed to a wider and deeper rectangular concrete channel to reduce the impact of flood on public. This solution is proposed by the designer because of the limited available river reserve and possibly the lack of environmental awareness. The consequences of replacing the natural river channel with a concrete channel are reduction of aesthetic and recreational values of rivers and damaging the river ecosystem. Recently, there is an increasing emphasis on restoration of rivers as a solution to control degradation and to bring back their natural conditions, aesthetic value, biodiversity, and rivers ecosystem. The use of environmentally friendly revetment system in flood mitigation project is a good solution to balance between the environmental and engineering requirements. This will help to get a green section with required geometrical shape and dimensions. However, many types of revetment blocks are widely used for flood mitigation and river restoration projects but the configurations of the blocks are designed with small opening for grass growth. So, such revetment blocks are not an effective solution for river restoration projects. It is required to develop a revetment block with a bigger area for grass growing at the mean time it will be effective in protecting riverbanks from scouring during flood. In the present study, a revetment block which composed of concrete and biological material (coconut husk) and called bio-composite revetment block is designed to be environmentally friendly. The bio-composite block is tested in both laboratory and site in order to determine its properties and also to check its durability after construction.

2. REVETMENT SYSTEMS AND RIVER REHABILITATION AND RESTORATION

Escarameia (1998) categorised the revetment systems which are used for river rehabilitation and restoration into three main types namely, bio-engineering (vegetation), structural and bio-technical engineering. Bioengineering revetment system is used mainly used for rehabilitation and restoration of rivers. The challenge in bioengineering is to protect the bank from erosion until the vegetation becomes established and it takes more than a year. Allen (1978) discussed five mechanisms through which vegetation can aid erosion control: reinforce soil through roots; dampen waves or dissipate wave energy; intercept water; enhance water infiltration; and deplete soil water by uptake and transpiration. However, from the engineering perspective, the use of vegetation alone on streambanks is not always ideal. Excessive foliage can lead to the reduction in channel capacity and a greater flood potential upstream. Trees planted on certain parts of levees may have roots undermining the levee stability (USACE, 1999). Coppin and Richards (1990) have analyzed engineering functions of vegetation and determined that its effects are both adverse and beneficial, depending on the circumstances. Therefore, it is important not to solve a stream bank problem by employing a single measure. The structural revetment system was widely used in 1950 to 1980 (Bakker et al, 2004). Various protective structural linings have been used to face the erosion problems. These hard-armoring methods, such as stone riprap, concrete pavement, rock gabions, concrete or aluminum, sack revetments and asphalt mixes reinforced stream bank shear strength (Keown and Oswalt, 1984). Many governmental agencies favored stone or concrete riprap because over time, a high degree of precision and confidence in construction has developed from research and analysis. In engineering viewpoints, these methods have been successful for their immediate protection. Combining different bioengineering techniques even with structural components is actually more effective than using any specific one alone (Henderson, 1986). Bio-technical is a technique for bank stabilization that incorporates the use of vegetation and engineering structures to increase slope stability (Ming and Karen, 2002). The vegetation increases the soil strength through their root structure while the bio-engineered structure provides additional support. Also, it rehabilitates the river and improves the ecological life. However, it can be used as an effective solution for restoration projects.

3. THE BIO-COMPOSITE REVETMENT BLOCK

The proposed bio-composite revetment block is a concrete block which is designed to be used for protecting river banks from scouring, improves hydraulic capacity, gives aesthetic value and enhances the ecological habitat of rivers. The bio-composite block can give a good solution to balance the engineering and environmental requirements. The block can be used for river restoration projects. The block is square in shape and its dimensions are 400 mm x 400 mm (length x width) while the block thickness is 100 mm. The block is designed to have central opening with dimensions of 280 mm x 140 mm (length x width) and interlocking system which consists of tongue and groove (dovetail arrangement). The central opening of the block contains a layer of coconut husk protected by two layers of plastic mesh (above and below the coconut layer). The mesh is embedded in concrete in order to fix the layer of the coconut husk in its place. The thickness of the coconut husk layer is 10 mm. The configuration of the block is shown in Figure 1.

4. BIOLOGICAL MATERIAL AND RIVER BANKS PROTECTION

As mentioned above the coconut husk is used in the central opening of the bio-composite revetment block for promoting the grass growth. It was selected among many available types of biological materials. These materials are considered as biological waste. In this study, only three different biological materials are tested and these materials were coconut husk, sugar cane husk, and oil palm husk. Figure 2 shows the types of tested husks. The laboratory test included monitoring the performance of each type of husk to allow vegetation to grow. The effectiveness of the tested husks for growing vegetation was carried out by constructing an overshadow area as shown in Figure 3.

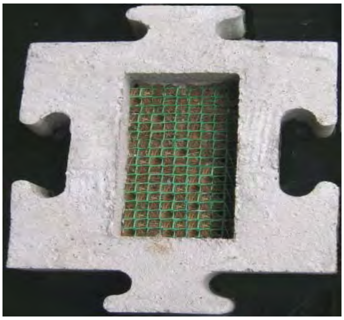

Figure 1- The bio-composite block

Figure 2 – Biological materials used to promote vegetation growth.

Figure 3 - Monitoring the effectiveness of various types of husks for promoting grass growth.

The experiments showed that the coconut husk is the best biological material that can be used in the central opening area of the bio-composite block since it showed the fastest rate of grass growth compared with the other tested types of husk (sugar cane husk and oil palm husk). Laboratory experiments showed that the maximum rate of grass growth per week were 5 cm, 3 cm and 2 cm for coconut husk, sugar cane husk, and oil palm husk respectively. Figure 4 shows the rate of grass growth using various biological wastes as growing media. This is attributed to the fact that the coconut husk is composed of millions of capillary micro-sponges that absorb and hold water up to eight times its own weight and has very high water holding capacity and good air porosity (Piggot, 1964). The coconut husk contained about 80% to 85% moisture on oven drying (Basak et al, 1983). As an organic material, the coconut husk could be used as organic fertilizer material and has been tested on several crops (Thampan, 1981). This supported the use of coconut husk as a suitable media for grass growth in bio-composite revetment block. A 10 m stretch of a selected stream was used to conduct field tests after the banks of the stretch were lined with bio-composite revetment blocks. The stream was located inside the campus of University Putra Malaysia, Serdang, Selangor, Malaysia. The main objective of the field test is to monitor the performance of the bio-composite revetment blocks after installation. One of the important criteria to be observed during the monitoring period was the effectiveness of the bio-composite block for promoting the grass or any type of vegetation to grow independently (the block environmental performance). Most of the produced blocks of similar function were definitely not subjected to systematic field tests, evaluation and monitoring after construction (Ming and Karen, 2002). As the vegetation matures, root systems will bind soils, inert materials and vegetation altogether on the stream banks. This will increase the safety factor of banks stability and its resistance to scouring. Figure 5 shows the relation between the rate of bank vegetation and soil loss as given by Coppin and Richard (1990).

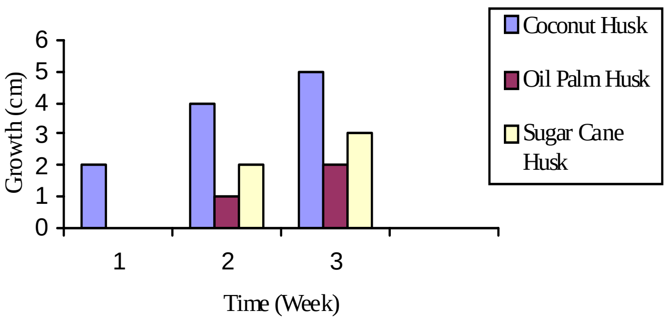

Figure 4 - Rate of growth of three different biological materials.

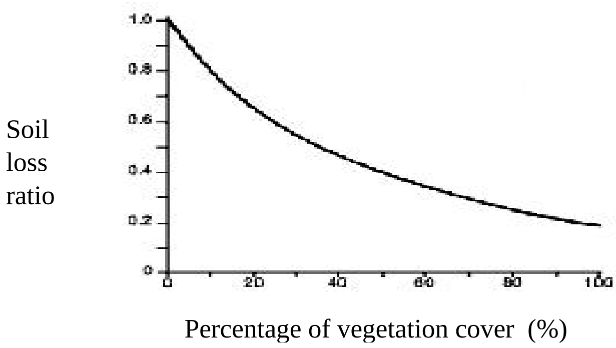

Figure 5 – Impact of vegetation on scouring (Coppin and Richard, 1990).

5. ENVIRONMENTAL PERFORMANCE AFTER INSTALLATION

The monitoring for grass growth was done weekly by measuring the percentage of the area covered with grass to the total surface area of the stream banks lined with the bio-composite revetment blocks. Result obtained from the monitoring of grass growth is shown in Figure 6. An average percentage growth of 15% was recorded per week. The rate was nearly equal to growth rate in commercial grass production, which was estimated to be no more than 2.6% per day as reported by Busey and Center (1979). The monitoring period was extended to 6 month after the date of construction. The plant growth through the block opening will provide armoring to the block since it will anchor the underneath soil. Vikaneshwaran (2002) categorized the revetment blocks according to it capability for growing grass. The capability is affected by the size of the opening in the block as shown in Table 1.

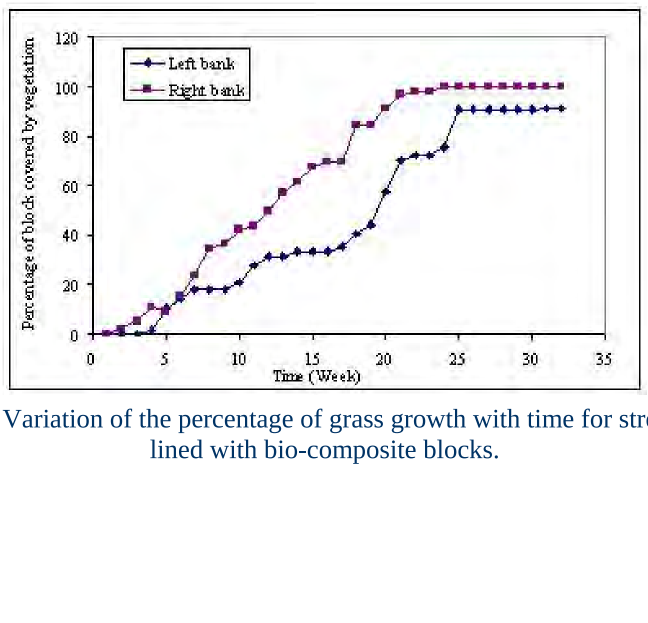

Figure 6 - Variation of the percentage of grass growth with time for stream banks lined with bio-composite blocks.

Table 1 - Rate of vegetation growth for various opening sizes (Vikaneswaran, 2002).

Rectangular opening size (%)	Rate of growth
<10	Slow
10 – 18	Moderate
18 – 30	Fast

For example, the rate of vegetation growth is fast for blocks with opening size between 18 to 30 % from the block gross area. The bio-composite revetment block has a central opening which forms 25 % from the total block area and this place it under the category of blocks with fast grass growth rate. Busey and Center (1979) reported that grass growth rates for various periods were not strictly exponential but sigmoidal. From the recorded data, it is found that the rate of grass growth for the bio-composite revetment blocks is in agreement with the finding of Busey and Center (1979). The different growth areas on left bank and right bank of the stream can be attributed to the different side slopes of the stream banks. Bank with mild side slope gave faster rate of grass growth compared with bank of steeper side slope. The milder side slopes will be more moist and sediments carried by water can be deposited which allows vegetation to re-establish and this gives better environment for grass growth. In this study, the side slope of the right bank for the selected stream is 1:1.5 while the side slope for the left bank is 1:1. Figure 7 shows the grass growth at both right and left banks which are lined with the bio-composite blocks. Long term monitoring was conducted to check the environmental performance of the bio-composite blocks. The monitoring period was 6 months started from beginning of September 2005 up to the end of February 2006. The blocks showed good environmental performance since the grass grew on both side of the lined stretch of the stream as shown in Figure 8.

a.Left bank with 1(V):1(H) side slope

b.Right bank with 1(V):1.5(H) side slope

Figure 7 - Variation of grass growth at banks with different side slope.

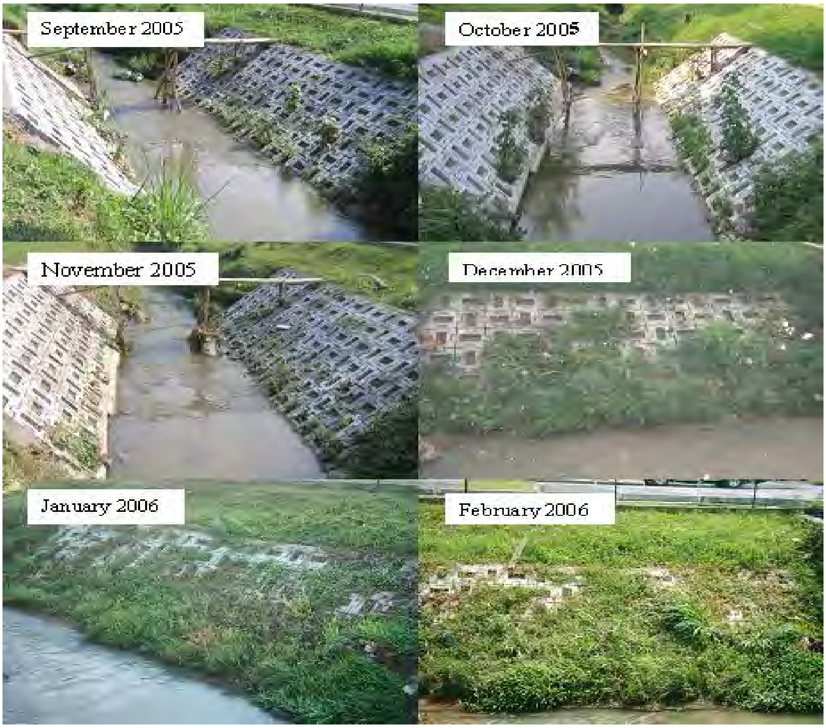

Figure 8 - Condition of protected stream at a given period.

6. FIELD WORK

It is required to know the impact of the materials used for bank protection on river roughness. Most of the revetment blocks used for river restoration and rehabilitation are not subjected to field hydraulic tests. So, the value of Manning coefficient of roughness for such materials are not known and usually it is estimated by engineers based on the experience. But for the proposed bio-composite block, field hydraulic tests were made to determine the Manning coefficient of roughness. A field survey was conducted to determine the cross section and longitudinal slope of the stream. Digital current meter was used to measure the velocity at various points along a cross section of the stream and also vertically at various depths of the stream. Knowing the average velocity of flow, slope and depth, the Manning roughness coefficient can be easily computed using the Manning's formula. Variation of Manning coefficient of roughness (n) with flow depths for the stream with and without the bio-composite blocks and also with and without vegetations were measured. Figure 9 shows the variation of Manning coefficient of roughness for the various conditions. The value of the Manning coefficient of roughness was computed at various stages of grass growth and with various flow depths. It was found that the values of the

Manning coefficient of roughness were changed from 0.0394 to 0.0381 when the grass growth increased from 5% to 20%. Also for 30% grass growth, the value of the Manning coefficient of roughness is not much different from the above range. This showed that the effect of vegetation on Manning coefficient of roughness is negligible when the bio-composite blocks were covered with vegetation by less than 30% from its total area. However, the effect of vegetation on Manning coefficient of roughness is considerable when the percentage grass covered the lined banks with bio-composite blocks is more than 30%. For example, a difference of 32% in the value of Manning coefficient of roughness was obtained between the case of the stream without grass and that with 40% of grass growth.

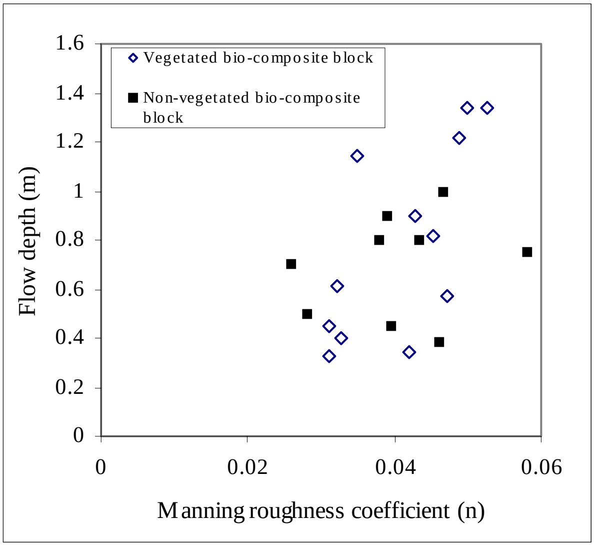

Figure 9 - Impact of grass area on of Manning coefficient.

7. SUMMARY AND CONCLUSIONS

In this study, bio-composite revetment blocks that can be used for river restoration and rehabilitation are subjected to field tests to assess its environmental and hydraulic performances. The environmental performance includes on the ability of the block to promote the grass growth while the hydraulic performance mainly involves the determination of Manning coefficient of roughness. The test showed that the average rate of grass growth was 15% per week. This makes the bio-composite block environmentally friendly and increases the aesthetic appearance of the river protected using the blocks. On the other hand, the Manning roughness coefficient for the blocks ranges from 0.0310 to 0.0548. The values of the Manning roughness for the banks lined with bio-composite revetment blocks are affected by the percentage of grass coverage, grass height, and the flow depth.

ACKNOWLEDGEMENT

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CHAPTER 6

Session 5

Restoration and management of physical processes and sediments

Chairpersons

M. RINALDI, G. GRANT, M. KONDOLF, H. PIEGAY

Introduction
RESTORATION AND MANAGEMENT OF PHYSICAL PROCESSES AND SEDIMENTS

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Physical processes, including those of sediment production, flux, and storage, are fundamental to the ecological functioning of fluvial systems. The geomorphic dynamics of rivers are increasingly seen as vital for creating and maintaining physical habitats and aquatic and riparian ecosystems. Sediment transport, bank erosion, and associated channel mobility represent key physical processes, and their understanding is of crucial importance for defining river restoration and management strategies.

As a consequence, river restoration in Europe and other parts of the world is increasingly taking geomorphic processes into account as a necessary condition for enhancing river conditions and promoting channel recovery. River restoration now considers management of basic fluvial processes such as bank erosion, sediment transport, channel incision, and water flows among others. The objective of this session was to explore the state-of-the-art with respect to these issues, and examine recent examples of river restoration - including projects, experiments, experiences, and strategies - aimed at integrating geomorphic understanding with restoration and management of fluvial ecosystems.

Twenty-eight presentations were given in the session (12 oral in two sub-sessions with the remaining as posters). Two oral presentations (Brierley & Fryirs, Simon) gave a broad overview of geomorphic approaches and associated controversies in Australia and USA respectively. The remaining twenty-six presentations can be divided into two topical areas:

1) The study of geomorphic adjustments and processes (including case studies, new methods and models) and their potential applications to river management and restoration. This topic included fifteen presentations (Fryirs & Brierley, D'Agostino & Vianello, Rinaldi et al.(a), Hoyle, Bizzi et al.,

Czajka, Egozi, Shellberg & Brooks, Simon & Bankhead, Surian, Rinaldi & Gumiero, Keesstra et al., Nieznanski et al., Alber et al.).
2) Specific examples of restoration projects or management plans involving some kind of geomorphic restoration or recovery of physical processes, including the monitoring or modelling of their possible effects. This topic includes eleven presentations (Hornich et al., Rollet et al., Kail et al., Brooks et al., Grant et al., Kloesch et al., Comin et al., McCormack, Haas et al., Pargament, Rinaldi et al.(b), Krapesch et al.).

The fact that most papers focused on preliminary studies of the potentially relevant geomorphic processes and actions rather than on specific interventions reflects the current state-of-the-art, at least in Europe (where most presentations were geographically based). European river restoration using geomorphic principles is still in its infancy in most cases, emphasizing analysis (i.e., assessment of problems, proposition of strategies and interventions based on comprehension of processes, etc.) rather than implementing specific interventions. There are exceptions to this general trend, such as some examples of reconstructing geomorphic features along channelized rivers, particularly in Austria (see Hornich et al., Kloesch et al., Krapesch et al.), dam removal in USA (see Grant et al.), or experiences of sediment reintroduction (see Rollet et al.). Nineteen of the twenty-eight presentations are included as papers in the following section of the proceedings.

Despite the diversity of presentations, approaches, and geographies, a number of common themes emerged from this session:

1. <u>The importance of a clear spatial and temporal context for restoration strategies</u>. The watershed itself is seen as an appropriate spatial scale, as it incorporates influences operating outside of an individual reach, while a decadal time scale offers the opportunity to include consideration of geomorphic processes with longer time horizons (i.e., major floods, mass movements, fluvial adjustment). There is an increasing effort to widen geomorphological studies and management strategies to the scale of entire catchments or river basins, while introducing considerations of floodplain features and hyporheic zones along with the channel proper in order to improve habitats and geomorphic processes. Local scale geomorphic interventions - for example individual reaches only several channel widths in length - are less appropriate; while they can potentially enhance local habitat conditions they typically do not address underlying causes of problems, and therefore benefits are in most cases temporary and not sustainable. The best approaches are those where proposed management strategies are evaluated within the context of long-term trends of channel adjustments.

2. <u>Extending form-based solutions towards process-based approaches</u>. Historically, river restoration has emphasized using empirical approaches

based on classification and considerations of channel geometry and dimensions, such as is commonly termed "natural channel design" in North America. A complementary and increasingly popular (at least among the presenters) approach emphasizes process-based models and linkages, relying less on classification and more on physical relationships among river variables. While process-based approaches may require more investment up-front in research to understand the system, they are likely to be more sustainable and yield greater ecological benefits in the long run. Both approaches claim successes and adherents, and as the field of river restoration matures, there will be more opportunities to evaluate them (provided we invest adequately in post-project appraisal). This leads directly to:

3. The need for a range of approaches. Many of the projects and studies described made use of a combination of different disciplinary tools and a wide range of approaches (numerical modelling, flume experiments, field based validation, analysis of historical geomorphic changes). This variety of approaches is very appropriate for dealing with complex problems involving restoration of physical processes.

4. The need for restoration to involve interdisciplinary groups. There were many examples of projects involving interdisciplinary groups that appeared to be stronger or more comprehensive as a result of these collaborations. In such context, the involvement of social scientists to evaluate the socio-economical benefits of different management and restoration options can enrich restoration projects but has been lacking in many programs.

5. A critical need is to integrate geomorphology and ecology. Although there is increasing recognition of the importance of interactions between physical and ecological processes, only a few studies actually achieve this integration. The integration itself is a two-way street: geomorphic processes and forms affect ecosystems, but ecosystems themselves can modify the physical environment and influence rates of processes.

6. Integrate process understanding with morphological interventions. Although morphological interventions are still limited (particularly in Europe), it is encouraging that many of the early projects discussed here included components of process understanding, monitoring, and modelling. Promoting natural channel recovery through attention to key processes may be a better strategy than morphological reconstruction, particularly in environments with relatively high sediment transport and stream energy (as in alpine basins).

7. The emergence of "soft" engineering. Among the types of restoration interventions, there is an increasing focus on "soft" engineering and use of native materials. In particular, reintroduction of wood is becoming a common practice to enhance morphological diversity and habitats in many parts of Central Europe and Australia.

SPACE, PLACE AND A HEALTHY DOSE OF REALISM: GROUNDING THE PROCESS OF RIVER REPAIR

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ABSTRACT

The process of river repair has a very different complexion in different parts of the world. Regardless of context, coherent scientific guidance is required to guide this process. Geomorphic considerations provide a physical platform with which to perform this task. Five geomorphic principles that underpin this premise are outlined here, namely: recognize and work with the inherent diversity of river forms and processes, differentiate behaviour from change, appraise evolutionary trajectory, place each reach in context of catchment-scale (dis)connectivity, and determine prospects for river recovery. These notions are hierarchically linked within the River Styles framework. Conservation planning is applied at the *ecoregion* scale. Rehabilitation planning is undertaken at the *catchment* scale, strategically addressing processes that threaten conservation priorities. *Reach* scale relationships provide the understanding with which to design and implement rehabilitation measures. The *geomorphic unit* scale provides the critical link to process considerations, ensuring that rehabilitation measures address the underlying causes rather than the symptoms of river adjustment. Finally, the *hydraulic unit* scale provides the key link to functional habitat relationships.

Key words: River rehabilitation, integrative river science, nested hierarchy, River Styles, landscape connectivity

1. INTRODUCTION: RELATIONS TO PLACE IN RIVER REHABILITATION PRACTICE

Prospects for river repair vary markedly in differing parts of the world, reflecting the imprint of past human activities, ongoing pressures upon river systems, and societal capacity/desire to address these concerns. Endeavours to improve river health are contingent upon our efforts to manage land and water use more effectively, minimizing the negative consequences of human disturbance to river systems. Ultimately, what we seek to achieve in the process of river repair reflects our relationship to 'place' – perceptions of identity and meaning that are attached to a given river system. The aesthetics of placeless universalism fly in the face of the inherent diversity and complexity of the natural world (Kondolf, 2006). Regardless of the diversity of values, meaningful and sustainable rehabilitation practices must to be guided by scientific insights that relate to the system under investigation, rather than prescriptive applications of generalised relationships (cf., Simon et al., 2007).

Among many factors, the effectiveness of our efforts to facilitate river repair is determined by the quality and coherence of cross-disciplinary insights into river structure and function, and the use of this information to guide management actions (e.g. Wohl, 2004; Brierley & Fryirs, 2008). While discipline-bound scientific perspectives provide significant insight into system components, understanding of the operation of the system as a whole is the key to effective management actions. In recent years, notable advances in cross-disciplinary endeavours have included increased understanding of ecohydrology and/or ecohydraulics (e.g. Palmer et al., 2005) on the one hand, and broader catchment-scale relationships such as riverscapes (Wiens, 2002) and fluvial landscape ecology (Jungwirth et al., 2002) on the other. A geomorphic template provides the critical basis with which to integrate and ground these principles in a coherent manner.

In this manuscript we highlight five geomorphic principles with which to guide the process of river repair: 1) Respect diversity; 2) Differentiate behaviour from change; 3) Frame the trajectory of river adjustment, and responses to human disturbance, in relation to system evolution; 4) Appraise system (dis)connectivity; 5) Determine the potential for river recovery.

This is followed by a brief discussion of the use of nested hierarchical frameworks as a tool with which to frame river management activities.

2. GEOMORPHIC PRINCIPLES THAT UNDERPIN PROSPECTS FOR GENUINE RIVER REPAIR

2.1 Respect river diversity

Managing to a 'norm' is unlikely to provide an appropriate basis to protect biodiversity and engender sustainable practices. Indeed, departures from the norm are often the very things that we seek to protect. It is a basic premise of conservation practice that we must know what the resource is before we can protect it. Hence, systematic baseline data are required to develop a coherent information base that captures the range of river diversity in any particular landscape, and their patterns within catchments.

In capturing information on the inherent geodiversity of river systems, efforts must be made to assess what is 'representative' for any given system, such that unique and/or rare attributes can be identified. Are remaining relatively intact sites unrepresentative of the inherent diversity of that system, such that we over-represent uniqueness at the detriment of ‘commonness’? Many remnants may merely reflect serendipity, such that conservation plans may place undue emphasis upon unrepresentative remnants. This has significant implications for the selection of reference sites. Notions of ‘naturalness’ should be framed relative to the contemporary river type, rather than some unattainable (and potentially irreversibly altered) river type of the past. In addition, emphasis should be placed upon procedures that link characteristic landforms of this river type to the processes that created and reworked these features. Understanding relationships between structural and functional attributes of river systems is required to interpret the behavioural regime of any given reach. From this, target conditions for rehabilitation programmes can be realistically framed, ensuring that due regard is given to the underlying mechanisms that fashion river behaviour, rather than simply what the river looks like.

2.2 Differentiate behaviour and change

River systems continually adjust to disturbance events. In geomorphic terms, river behaviour can be interpreted from the assemblage of channel and floodplain geomorphic units that occur along a reach (Brierley & Fryirs, 2005). Each of these features reflects a characteristic set of process-form associations. Collectively, these features are indicative of the manner and ease with which the river adjusts its form, providing a measure of the capacity for adjustment and the sensitivity or resilience of a reach.

Under some circumstances rivers may experience a wholesale shift in the assemblage of geomorphic units. Adoption of a new behavioural regime, termed river change, may reflect progressive evolutionary adjustments or threshold-induced alteration and can result from responses to ‘natural’ or ‘human-induced’ disturbance. Most importantly, in rehabilitation terms, assessment of the (ir)reversibility of change determines the most appropriate target condition for rehabilitation efforts. Is it possible (or desirable) to return the river to the type of system, and associated behavioural regime, that existed in the past, or should rehabilitation efforts enhance recovery for a different river type? Clearly this is a system-specific and reach-specific issue, as it reflects the trajectory of adjustment of each river and societal values placed on the system.

2.3 Frame the trajectory of river adjustment, and responses to human disturbance, in relation to system evolution

Analyses of river evolution enable system responses to human disturbance to be framed in relation to natural variability and the evolutionary trajectory of any given reach. System to system variability in response to disturbance events is an inherent complication of geomorphic inquiry. Geomorphic factors that complicate interpretation of past evolution and the forecasting of future trajectories of adjustment include river sensitivity to disturbance, closeness to geomorphic thresholds, and triggers and lag effects. For example, the sensitivity to change of a reach partially reflects the extent to which it has been ‘primed’ to change, such that a seemingly small event can breach threshold conditions and induce dramatic responses. Rehabilitation planning must give due regard to these complexities, framing designs for the future in relation to prevailing (and future) fluxes. This requires consideration of the connectivity of biophysical fluxes at the catchment-scale.

2.4 Appraise system (dis)connectivity

Conveyance of water, sediments, nutrients and seeds through river systems reflects both the behavioural regime of individual reaches and the way in which these reaches fit together at the catchment scale (i.e. their downstream pattern and tributary-trunk stream relationships). River networks are generally characterized as highly inter-connected systems, fashioned largely by gradient-induced linear relationships. However, many landforms or human impacts may disconnect (or inhibit/alter) these relationships (Fryirs et al., 2007). For example, discontinuous watercourses act as natural filters in river systems. Dams and weirs inhibit ‘natural’ connectivity of rivers (Kondolf et al., 2006). In appraising the natural variability of system connectivity, due regard must be given to historical and evolutionary factors that induce lagged, off-site responses. In some instances, the legacy of these impacts may not be felt for hundreds or thousands of years.

A key consideration in appraisal of system connectivity is the role of boundaries. Once lines are drawn on maps, they seemingly assume a significance that belies their ‘real’ meaning. In biophysical terms, many boundaries are permeable and their role may change over time. All too often, boundary selection is an exercise that pigeon-holes reality. Effective rehabilitation practice requires practitioners to think relationally about connections to other parts of the system, in both spatial and temporal terms, considering whether boundaries are fixed or transient, under differing sets of circumstances.

2.5 Determine the potential for river recovery

Cost-effective approaches to river rehabilitation planning apply measures that help the river to help itself. Precautionary management requires that conservation areas are set aside as a first priority, and strategic measures are put in place to address any threatening processes that may threaten these geoecological values. In many instances, application of low cost measures or even the 'do nothing' option may suffice. Measures may include fencing off, restricting development, or simply leaving the river alone. Beyond this, enhancing natural recovery mechanisms provides the most effective way to maximize prospects for rehabilitation success. This requires a solid understanding of river behaviour and evolution, and the impact of limiting factors and pressures on the potential for system recovery. Working to enhance river recovery yields environmental benefits as well as bolstering community confidence in the process of river repair.

Unfortunately, most reaches with significant prospects for geoecological recovery lie some distance from population centres, in less disturbed parts of the landscape. However, recovery in these areas is integral to the prospects for future rehabilitation success in more populated areas, most of which lie in downstream parts of catchments. For example, concerns for flow, sediment and nutrient fluxes must first be addressed in upstream areas.

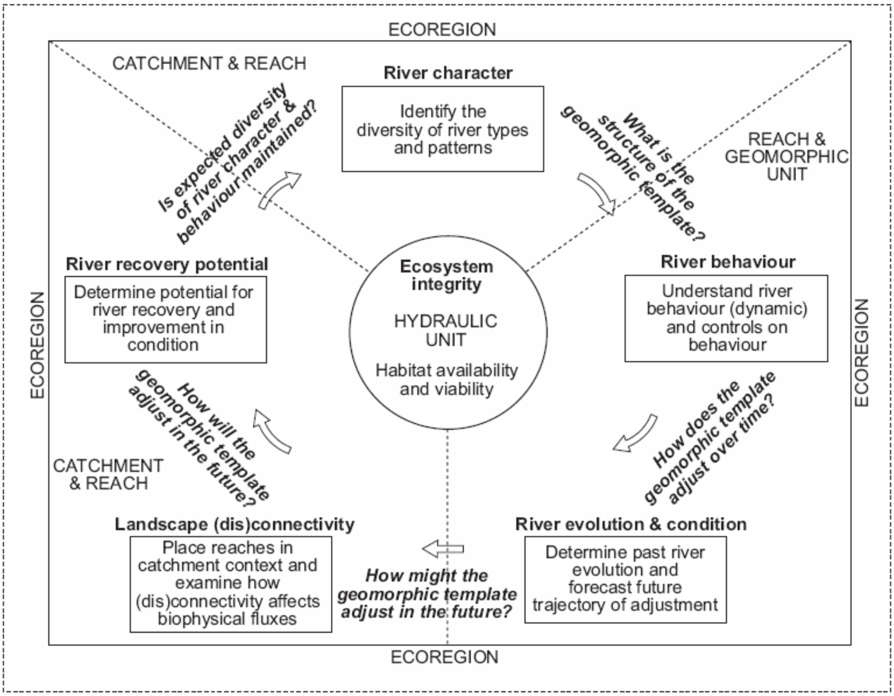

Figure 1 – Cross-scalar geomorphic considerations in river rehabilitation planning.

Ultimately, rehabilitation planning is a catchment-specific exercise, linking differing scales of geoecological relationships as a coherent whole. Figure 1 links the five geomorphic principles documented here, highlighting their combined use in efforts to address concerns of ecosystem integrity (centre circle). Information collected for each box links across several spatial and temporal scales, providing a coherent package with which to guide vision generation, identify reference reaches and prioritize on-the-ground activities. Hence, nested hierarchical frameworks provide a key tool for river planning.

3. USE OF NESTED HIERARCHICAL FRAMEWORKS AS A TOOL FOR RIVER CONSERVATION AND REHABILITATION PROGRAMMES

Spatial considerations in river rehabilitation planning reflect not only the pattern of differing types of rivers within a catchment and their biophysical interactions, but also the differing scales with which we analyse river systems. Spatial scales of river analysis are most appropriately framed in terms of nested hierarchical arrangements (Frissell et al., 1986; Petts & Amoros, 1996; Bohn & Kershner, 2002; Rogers and O'Keefe, 2003; Brierley & Fryirs, 2005). The cross-scalar flexibility of these frameworks enables management applications to interrogate controls upon biophysical relationships at higher (or lower) scales (see Tab. 1).

3.1 Ecoregion-scale applications

As biodiversity values often relate to particular ecoregions, they are most appropriately managed at the ecoregion scale. Conservation and rehabilitation plans must identify and protect unique and/or rare attributes, tackling threatening processes that may impact upon these values. Applications at this scale enhance the prospect for transferability of knowledge in areas of relatively equivalent climatic, topographic and biogeographic conditions, enabling the derivation of representative (bio)monitoring and auditing programmes tied to reference sites. Prospectively, broad-scale approaches to rehabilitation planning could select a (sub)catchment to trial and develop catchment-scale applications, showing what can be achieved by concentrating efforts rather than spreading them too thinly. To date, far too little use has been made of demonstration sites at this scale.

3.2 Catchment-scale applications

Management applications at the catchment scale promote a coherency of actions based upon an understanding of biophysical interactions in landscapes. Meaningful vision generation is framed in terms of 'what is physically achievable' in terms of human impacts and prevailing biophysical fluxes at this scale. Critically, these insights are directly related to place, enhancing prospects to link this understanding to community values, thereby aiding determinations of what is socially acceptable. In addition, effective prioritisation of conservation and rehabilitation initiatives must be applied at the catchment scale. This process must give due regard to strategic sites that protect conservation priorities (e.g. rare or endangered species) and promote recovery.

Table 1 - Cross-scalar applications of the River Styles framework

Scale	Examples of applications
Ecoregion	• Tool for conservation planning (e.g. identification or unique or rare attributes) • Enhances the prospect for transferability of knowledge in areas of relatively equivalent climatic, topographic and biogeographic conditions • Frames representative (bio)monitoring and auditing programmes tied to reference sites • Could be used to select a (sub)catchment to trial and develop catchment-scale approaches to rehabilitation planning, showing what can be achieved by concentrating efforts rather than spreading them too thinly
Catchment	• Promotes coherency of actions based upon our understanding of biophysical interactions • Vision of 'what is achievable' o Relation to place - Critical platform with which to link to community values o Link to what is socially acceptable • Prioritising rehabilitation initiatives o Strategic sites to protect conservation priorities (e.g. rare or endangered species) o Work with recovery
Reach	• Frame on-the-ground actions in relation to prevailing fluxes • Address differing 'problems' for particular River Styles, focusing upon the underlying causes of change, rather than their symptoms • Target key problems in a strategic (proactive) manner • Link reaches to enhance prospects for sustainable success (e.g. consideration of sand slugs, head cuts, etc) • Aids in auditing the effectiveness of rehabilitation works for particular problems in certain types of river
Geomorphic unit	• Link physical to ecological integrity and measures of ecosystem functionality (i.e. process-based) • Habitat associations (platypus, fish, macroinvertebrates, etc) • Riparian vegetation planning (differing associations on differing surfaces)
Hydraulic unit	• Habitat availability – link to viability = basis of heterogeneity paradigm, based on ecohydraulic links

3.3 Reach-scale applications

It is at the reach scale that practitioners must determine what is realistically achievable in management terms. As differing river types are subjected to characteristic degradational tendencies, reach-scale investigations such as the River Styles framework (Brierley and Fryirs 2005) enable rehabilitation measures to address the underlying causes of adjustment, rather than the symptoms. Appraisal of the effectiveness of rehabilitation works for particular problems in certain types of river provides a key basis for the transferability of knowledge to different reaches of the same type. Critically, such applications, and the setting of target conditions, must be framed in relation to prevailing biophysical fluxes at the catchment scale.

3.4 Geomorphic unit scale applications

As geomorphic units represent particular process-form associations, appraisals of their assemblage in any given reach provide insight into reach-scale river behaviour. From this, likely sensitivity to disturbance and trajectory of river adjustment can be assessed. These process considerations are vital components of rehabilitation design. Just as important, however, are the habitat considerations that are manifest at this scale (whether for macroinvertebrates, fish, platypus, etc). The presence and pattern of geomorphic units are vital components of rehabilitation applications that link the physical and ecological integrity of a reach, ensuring that rehabilitation measures relate directly to ecosystem functionality.

3.5 Hydraulic unit scale applications

Concerns for ecohydraulics and ecohydrology are manifest at the hydraulic unit scale. This has major implications for the management of flow, sediment and nutrient fluxes, and the availability/viability of habitat. Environmental flow allocations must link these concerns to the assemblage of instream geomorphic units along a reach (e.g. pools, runs, riffles, etc). Flow and sediment interactions, in particular, form the basis for appraisals of instream heterogeneity, the maintenance of which is a vital component of ecosystem functionality.

4. IMPLICATIONS FOR RIVER FUTURES

The prospects for success in the era of river repair are contingent upon the effective use of coherent scientific insights, utilising our best available understanding to derive and implement integrative river planning procedures (Brierley and Fryirs, 2008). Few would argue that our actions in river rehabilitation best reflect what we know. Appropriate mechanisms for information sharing, training and knowledge transfer are required, viewing scientific understanding as a learning tool, rather than a generator of prescriptive, categorical insights. For example, there are inherent limitations in relating products on paper (such as boundaries of river types on maps) with field observations at a given locality. An ability to ‘read the landscape’ should always take precedence over a perceived reality on paper.

Many challenges are faced in the derivation of spatially and temporally grounded information bases with which to guide the process of river repair. However, we cannot always wait until we have appropriate information in-hand before we set out to manage a problem. In many instances, threatening processes may require immediate attention, and inaction may simply exacerbate the problem. While a precautionary approach to rehabilitation practice is encouraged on the one hand, due regard must also be given to appropriate documentation of management actions on the other. It is only in this light that we can truly learn from our actions. All efforts should be made to discuss why adopted measures did/did not work, highlighting the prospects for meaningful transfer of insights to sites elsewhere. For this to work, we must have a meaningful basis to compare like with like, and determine the representativeness of our understanding with which we inform and monitor the process of river repair.

Information management is a key component of effective practice, and all efforts should be made to ensure that information bases are coherent, readily accessible and easily updateable. Leadership and appropriately trained personnel are needed to inform and guide the process of river repair. There are numerous limitations in becoming ‘locked into’ a particular management approach or mindset, as circumstances are forever changing. For example, many monitoring programmes proceed on the basis of traditional applications and measures, the scientific underpinnings of which may have been replaced, such that the original premise for data collection is now largely redundant. Critically, this represents a significant opportunity cost, as we could be doing so much more!

River rehabilitation is not a simple undertaking. Given the remarkable diversity and complexity of the natural world, and our interactions with it, there are many inherent dangers of over-simplification. Having said this, we cannot afford to make things unduly complicated. We must be realistic, remembering that each river system is different - no two areas are exactly the same. Geographic considerations in river rehabilitation planning emphasize the importance of place and spatial relationships in framing the process of river repair. As emphasized by the main dictum used in the River Styles framework (Brierley and Fryirs, 2005), a key premise for effective river conservation and rehabilitation planning is the imperative to “Know your Catchment”.

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THE CONTROVERSY IN APPROACHES TO RIVER RESTORATION IN THE UNITED STATES: PROCESS VS. FORM

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ABSTRACT

Over the past 10 years the Rosgen classification system and its associated methods of ‘‘natural channel design’’ have become synonymous to many in the United States with the term ‘‘stream restoration’’ and the science of fluvial geomorphology. Since the mid 1990s, this form-based approach has become widely adopted by U.S. governmental agencies, particularly those funding restoration projects. The primary thesis is that alluvial streams are open systems that adjust to altered inputs of energy and materials, and that a form-based system largely ignores this critical component. Problems with the use of the classification are encountered with identifying bankfull dimensions, particularly in incising channels and with the mixing of bed and bank sediment into a single population. Its use for engineering design and restoration may be flawed by ignoring some processes governed by force and resistance, and the imbalance between sediment supply and transporting power in unstable systems. That similar channels composed of different bed and bank sediments adjust differently and to different equilibrium morphologies in response to an identical disturbance is described. This contradicts the fundamental underpinning of ‘‘natural channel design’’ and the ‘‘reference-reach approach.’’ The Rosgen classification is probably best applied as a communication tool to describe channel form but, in combination with ‘‘natural channel design’’ techniques, are not diagnostic of how to mitigate channel instability or predict equilibrium morphologies. For this, physically based, mechanistic approaches that rely on quantifying the driving and resisting forces that control active processes and ultimate channel morphology are better suited as the physics of erosion, transport, and deposition are the same regardless of the hydro-physiographic province or stream type because of the uniformity of physical laws

Key words: Geomorphology; fluvial processes; rivers⁄streams; restoration; sediment; Rosgen classification.

1. INTRODUCTION

Over the past 10 years the Rosgen classification system (Rosgen, 1994) and its associated methods of ‘‘natural channel design’’ (Rosgen, 1996) have become synonymous to many in the United States with the term ‘‘stream restoration’’ and the science of fluvial geomorphology. The term ‘‘natural channel design’’ (NCD) has been adopted by Rosgen (1996) and others advocating and using the Rosgen system (Hey, 2006) will be used here as such even though channel designs often rely heavily on artificial structures. Since the mid 1990s, this form-based approach has become widely, and perhaps dominantly adopted by governmental agencies, particularly those funding restoration projects (Malakoff, 2004). For example, in a request for proposals for the restoration of Trout Creek in Montana, the Natural Resources Conservation Service required ‘‘experience in the use and application of a stream classification system and its implementation’’ (MDFWP, 1998). Most notably, highly trained geomorphologists and hydraulic engineers are often held suspect, or even thought incorrect, if their approach does not include reference to or application of a classification system (Malakoff, 2004).

At Level I, the Rosgen classification system consists of eight major types of streams (Rosgen, 1996), based on hydraulic-geometry relations and four other measures of channel shape to distinguish the dimensions of alluvial stream channels as a function of the bankfull stage (A, B, C, D, DA, E, F, and G). Six classes of particle size of bed and bank material are used to further subdivide each of the major categories, resulting in 48 stream types. Additional subtypes have also been identified (i.e., Aa+, Gc, Cb, Bc, etc.) representing intermediate cases between the eight major stream types and making for as many as 94 possible types.

In part, the success in popularizing the NCD approach has been due to Rosgen’s ability to attract practitioners to his short courses across the nation and to disseminate a plethora of manuscripts in conference proceedings and books published by his own company. For years, Rosgen has been encouraged to publish the NCD methodologies in the peer-reviewed literature and thus take advantage of the time-tested means of critical review for dissemination of scientific investigations. However, to date only the original paper on classification (Rosgen, 1994) has been through the peer-review process. None of the NCD methodologies, including most recently WARSSS (Watershed Assessment of River Stability and Sediment Supply; Rosgen, 2006a), which includes the sediment-transport predictors FLOWSED and POWERSED have benefited from this traditional approach to scientific investigation and dissemination. In response to criticisms that the NCD approach largely ignores the process dynamics of unstable stream systems (Simon et al., 2005), Rosgen writes that the authors were essentially unqualified to make such a judgment because ‘‘*A two-week course is* *required to teach professionals (including individuals who have graduated from college with advanced degrees in engineering, geology, hydrology, fisheries, etc.) how to conduct a watershed and stream channel stability analysis''* (Rosgen, 2006b).

2. CHANNEL FORM, PROCESS, AND TEMPORAL VARIABILITY

The primary criticism of the Rosgen Classification. NCD and WARSSS methodology (Rosgen, 2006a) is that the use of this form-based approach is not, and cannot be used to predict stable morphologies in currently unstable alluvial systems. The strongest evidence for this is that the same initial form (or stream type) can adjust to different stable morphologies for similar disturbances (Simon et al., 2007). This is in part because under these time-independent approaches, the stable form that the practitioner seeks cannot be calculated as it accounts for sediment supply and flow energy at only one point in time and space, yet this supply is changing not only spatially, but over periods of years or decades as well. The target design should be one that represents a condition where over a period of years sediment transport is in a general balance with sediment supply. Associated with this condition is an acknowledgment that natural, stable streams are not static but are open systems where changes in geometry do occur but at very low rates. Although supplementary features (such as sediment supply and streambank contributions) have been added since Rosgen (1996) and incorporated into the overall NCD and WARSSS approaches, fundamental flaws exist and the application of these additional features do not stand up to analytic scrutiny, field testing, and validation. These flaws include: 1. Multiple stream-type succession end points for a given initial type; 2. Flaws in the sediment-transport equations and their application; 3. Inability to predict changes in channel width; 4. Inability to predict stable morphologies within a currently unstable system; 5. Inconsistent and erroneous determination of stream types; 6. Mixing of bed and bank-material properties; and 7. Sediment-supply calculations based on a single snapshot in time and space.

2.1 Multiple Stream-Type Successions

In the case of an unstable system with excess transporting power or shear stress relative to the critical power or stress, channel change will occur. The question becomes how will the channel change over time, at what rates and magnitudes, and what will be the resultant stable morphology? These are all central issues to restoration of stream reaches within unstable systems. It is one thing to measure the size and shape of streams and place these into a number of stream-type ''successions'' to describe channel evolution during the course of adjustment (Rosgen, 2001, 2006a; b). It is quite another matter to be able to predict these stream-type successions a priori with the type of measurements and analyses specified in the NCD and WARSSS approaches. We contend that this cannot be accomplished using NCD or WARSSS.

It is important to note, however, that if changes in channel form over time are used to identify dominant channel processes (as in stages of channel evolution) (Simon and Hupp, 1986; Simon, 1989) that eight of the nine ‘‘successional stream-type scenarios’’ (Rosgen, 2006a; b) collapse into one sequence of processes – namely incision, widening, and filling. The critical problem with relying on the form-based stream-type succession is that in some cases, a given Rosgen stream type that undergoes adjustment in response to disturbance can equilibrate to different forms and thus stream types. Whether a C-channel equilibrates to a Bc, C or D (Rosgen, 2001) cannot be predicted. Rosgen (1996; p. 6-8 to 6-9) similarly showed different stream-type successions for an E4 stream type, which equilibrates to either a D4 (braided channel) or the same E4 (Miller and Ritter, 1996).

2.2 Flaws in Sediment-Transport Equations and Application

Troendle et al. (2001) proposed the following sediment-transport formulas for ‘‘good ⁄ fair’’ streams:

for bed load: $y = 0{:}09 + 0{:}76x^{3.08}$;

for suspended load : $y = 0{:}58 + 0.36x^{3:48}$;

where y is dimensionless bed load or suspended-sediment transport and x is dimensionless discharge.

WARSSS uses a constant exponent in the dimensionless bed-load transport relation even though it has been shown that the exponent varies from one stream to another, even for undisturbed streams that appear to be close to a steady state. Forcing a constant exponent to the transport data will cause substantial error in estimating transport rates, especially for flows larger than bankfull (Peter Wilcock, written communication, 2006). The exponent values can vary widely from stream to stream and can be as high as 10. The same holds true for the suspended-sediment relation. In fact, the current form of these dimensionless equations now use *different* constant exponents for ‘‘good ⁄ fair’’ streams; 2.2929 for bed load and 2.4085 for suspended load (Rosgen, 2006a; 2007).

2.2.1 Application of Sediment-Transport Calculations

In WARSSS (Rosgen, 2006a) annual, sediment-transport capacity calculated using POWERSED and annual, sediment supply calculated using FLOWSED are compared. It is then determined whether sediment supply is similar, in excess, or less than transport capacity resulting in stable conditions, aggradation, or degradation, respectively. The problems with this budgeting approach is that (1) the results only indicate whether erosion (in the case of excess transport capacity) will occur and if so, it can only occur along the bed, and (2) that it is time independent. WARSSS (Rosgen, 2006a) assumes that erosion will only occur on the channel bed, but how this is used to predict future geometry is unclear because calculations represent only a single year. The following year, geometry and hydraulic conditions are different, and the upstream supply has probably adjusted as well. This introduces the same bias as in the numerical model HEC-6 where only vertical changes are simulated. The serious implications of this problem were clearly demonstrated in Simon et al., 2007, and raise the question as to whether NCD can predict stable morphologies in a specific unstable reach within an unstable alluvial system.

2.3 Inability to Predict Changes in Channel Width

Although WARSSS (Rosgen, 2006a) includes an empirical calculation of average streambank erosion rates, the magnitude and composition of these materials are not included in calculations of sediment supply. Furthermore, criticisms have been leveled by Harmel et al. (1999) regarding the procedure recommended to compute annual streambank erosion rates Rosgen, 2006a). In this case the authors concluded that integration of the bank-erosion potential ratings and near-bank stress estimators (Rosgen, 1996) were poor predictors of bank erosion for the studied streams in northeastern Oklahoma. In fact, regressions between erosion rates and NBS estimates were found not to be significant Harmel et al. (1999).

2.4 Inability to Predict Stable Morphologies in an Unstable System

Channels representing the same stream type and similarly disturbed (sediment supply reduced by 50%) were shown by Simon et al (2007) to adjust to similar rates of energy dissipation (energy slope) for a given initial slope, yet eroded their boundaries completely differently and reached different stable morphologies because the composition and resistance of the channel banks were different. For an initial slope of 0.005 m/m and width / depth ratio of 13.5, degradation ranged by about an order of magnitude (0.35-3.5 m), widening from 0 to 13 m, and stabilized width / depth ratios, from 5.6 to 16.4. The implications of these results for NCD cannot be stated more emphatically and remain central to the criticisms of the NCD approach.

Another example that exposes this critical problem is taken from streams in the Midwestern United States (Simon and Rinaldi, 2000) where, similar streams, disturbed by the same perturbations (channelization) resulted in different equilibrium morphologies because of differences in bed-material properties. These streams would not fit into any of the stream-type classes (Rosgen, 1994) because although their cross-section geometry places them in the G category, their sinuosities and slopes are too low for a G-type channel. Still, if we forced these streams into the Rosgen classification, a G6 classification would be the closest fit. Because the sand-bed G6 streams contain hydraulically controlled sediment (sand), the channel is able to aggrade, thereby reducing bank heights and helping to stabilize channel banks. Conversely, the silt-bedded G6 channels remain deep because material eroded by incision and bank erosion exit the watershed as wash load, keeping bank heights high. In this case channels continue to widen until flows are no longer effective at eroding bank-toe material, permitting the banks to flatten, support establishing riparian vegetation, and stabilize.

2.5 Inconsistent and Erroneous Determination of Stream Types

The previous discussion highlights another problem with the classification system, that being inconsistent determination of stream type among observers (Roper et al. 2008), where an A channel (in northeastern Oregon) was misclassified as a B channel according to observer measurements five out of eight times. This was due in part to observer differences in bankfull and entrenchment estimates. These are particularly difficult to determine in incised and braided streams (Johnson and Heil, 1996; Ferguson, 1987). Juracek and Fitzpatrick (2003) found similar difficulties. Johnson and Heil (1996) showed how a range of stream types could be determined at a single location depending on the interpretation of the bankfull level. These difficulties need to also be considered in light of the physical meaning (and effects) of the bankfull flow where the recurrence interval has been shown to vary between the 0.5 and the 50-year flow event (Williams, 1978). Roper et al. (2008) go on to state that *‘‘…the classification system…appears to do little to improve communication among practitioners beyond what the raw measures of channel attributes would have done.’’* They further suggest as Simon et al (2007) have that it would be more beneficial to use raw-data measurements of channel dimensions and particle-size distributions for modelling of stream processes.

2.6 Mixing of Bed and Bank Materials

This issue of differing absolute resistance of bank materials and relative differences between bed and bank materials impacts the usefulness of the classification (Rosgen, 1994) itself. Rosgen and proponents of NCD are the only group since Schumm (1960) that mix two different populations of sediments in their sampling regimen. The failure to distinguish between bed and bank material properties and, therefore, resistance to erosion has several implications. The first, relating to the absolute and relative resistances of the bed and banks has been described in detail above and clearly has profound implications for the ‘‘reference’’ reach approach NCD, and WARSSS. Second, it can result in incorrect classification of stream type because the practitioner is instructed to sample channel material, starting at the bankfull level, moving down the bank, across the bed, and up the opposite bank (Rosgen, 1996; 2006a). For instance, a channel composed of a gravel bed and silt-clay banks or, a sand bed and sand banks would both classify as a 5.

Clearly, these two channels would maintain very different sediment-transport regimes. Kuhnle and Simon (2000) showed how channels in Washington and Mississippi can be mis-classified as a consequence of different sampling regimes. Because of this, many of the particle-size datasets collected under NCD cannot be used for incipient motion analyses.

2.7 Sediment-Supply Calculations Represent a Snapshot in Time

Natural rivers are inherently dynamic and assessments of stability should be based on evaluation methods that explicitly aim to characterize changes in channel characteristics over time, either directly (e.g., Rhoads, 2003) or through the use of predictive tools (e.g., Darby et al., 1996; Simon and Darby, 1997; Langendoen, 2000; Langendoen and Alonso, 2008; Langendoen and Simon, 2008). Stream-restoration practitioners are not dealing with ‘‘static’’ streams but are usually concerned with unstable, dynamic channels where hydraulic conditions, sediment supply, and boundary conditions may be changing over decadal (or shorter) time scales. Although Rosgen (1996) claimed that spatial variability is accounted for by identifying different stream types along a stream corridor, input parameters and results using NCD and WARSSS represent only a single snapshot in time and space. This approach ignores the fundamental issues of temporal and spatial variability as channels adjust as open systems. Even if one assumes that WARSSS can provide a prediction of future transport and conditions within the reach, which condition within the range of temporal variability will it represent?

Numerous researchers have shown that the response of an alluvial system to disturbance can be defined by nonlinear decay functions that asymptotically approach minima with time. This concept is summarized in Fig. 1A, which shows idealized adjustment trends for a site with excess energy or stream power. The curves represent trends in important controlling variables representing a single discharge based on relations from the literature for periods of 10-100 years. The upper part of the figure represents nonlinear decreases in available force, energy or sediment load with increasing time after disturbance, while the bottom part represents nonlinear increases in roughness and resistance to entrainment. That is why rates of morphologic adjustments and consequent sediment transport to a reduced sediment supply are nonlinear (Parker, 1977; Simon, 1992; Simon and Thorne, 1996; Simon, 1999).

The problem that arises in the application of the time-independent NCD and WARSSS methods is that the practitioner cannot determine if (for example) they are making measurements and calculations at time 1, 2 or 3 in Fig. 1. One would obtain very different results in the Prediction Level Assessment phase of WARSSS (i.e., sediment- transport rates) based on what part of the curves the input data were derived from because both sediment-transport capacity and sediment supply are changing with time (Fig. 1).

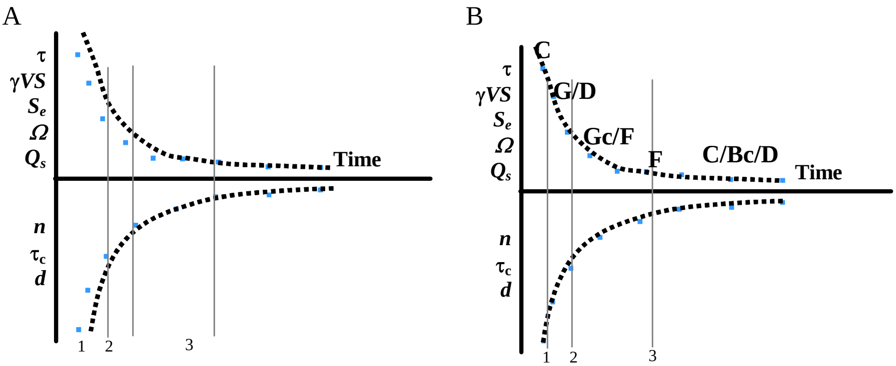

Figure 1 – Idealized representation of adjustment trends in a reach with excess flow energy or shear stress relative to sediment supply (A). Trends in controlling variables with Rosgen stream types superimposed (B). Note: τ is boundary shear stress; γVS is unit stream power; S_e is energy slope; Ω is total stream power; Q_s is sediment load; *n* is Manning's roughness; τ_c is critical shear stress; and *d* is the characteristic diameter of bed sediment. Vertical lines labelled 1, 2 and 3 represent different conditions during adjustment where the imbalance between available force and resistance are markedly different.

A continuous simulation model would provide deterministic solutions to channel evolution and stable morphologies because they account for both vertical and lateral processes, and update these parameters at each time step as geometry and sediment supply change. This temporal evolution of controlling variables simply cannot be accomplished with the time-independent NCD and WARSSS approaches unless the calculations of sediment supply and transport are conducted for many time steps (*n*; represented by the black dots in Fig. 1) and included: (1) a direct accounting for bank-material properties and resistance, (2) bed and bank erosion, and (3) updated geometry, hydraulics, transport capacity and sediment supply for the $n + 1$ time step. This approach is how static or time-independent models would be used to simulate mutually adjusting channel response over time. The predicted stable morphology is determined when morphologic change is minimized as the curves become asymptotic.

3. CONCLUSIONS

Observations of channel form (stream types) placed in a series of temporal sequences (Rosgen, 2001, 2006a, 2006b) is not the same as being able to predict these sequences and, therefore, stable morphologies. We maintain that this cannot be accomplished under the NCD and WARSSS approaches in an unstable system that is dynamically adjusting. The physics of sediment transport, erosion, and deposition are governed by natural physical laws regardless of what physiographic province the stream is located in or what the stream type may be. Nevertheless, contingent effects that can vary by region, such as differences in relations between driving and resistive forces associated with relief, channel materials, and riparian vegetation, can produce differential adjustments for channels that display virtually identical morphological conditions. The mutual-adjustment of processes and forms in a system that is changing both spatially and temporally can be predicted using deterministic approaches if initial boundary conditions are adequately accounted for. This has been is well established in the refereed literature. Adjustment processes and stable morphologies can be quantified and predicted by evaluating the relevant resisting and driving forces that control vertical and lateral changes. Fundamental problems with the Rosgen classification and NCD have been presented by highly respected geomorphologists and engineers in academia and government in the scientific literature (Johnson and Heil, 1996; Miller and Ritter, 1996; Harmel et al., 1999; Kondolf et al., 2001; Juracek and Fitzpatrick, 2003; Smith and Prestegard, 2005; Simon et al. 2005; Kondolf, 2006; Simon et al. 2007; Roper et al., 2008).

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THE IMPORTANCE OF REACH SENSITIVITY AND CATCHMENT CONNECTIVITY IN RIVER REHABILITATION PLANNING

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ABSTRACT

This study documents catchment-wide river responses to human disturbance in the upper Hunter catchment, New South Wales, Australia in the period since European settlement. The spatial distribution and timing of ten forms of erosional and depositional river adjustment are used to assess river sensitivity to change and to detect geomorphic response gradients through time. Many reaches have been resilient to change, because of inherited controls such as bedrock-forcing or terraces which constrain the capacity for river adjustment. This has resulted in a patchy (localised) pattern of responses to human disturbance. A gradient of primary, secondary and tertiary responses to human disturbance is noted. An initial phase of adjustment was followed, after a considerable lag period, by a more extensive period of incision and channel expansion. A shift to dominantly depositional processes, in the period following the flood of record in 1955, characterised the tertiary (recovery) phase. The timing of disturbance and the lag times to response is explained by placing reach-based adjustments in context of catchment-scale (dis)connectivity of sediment flux. With this information in hand, strategic rehabilitation plans should enhance recovery while maintaining the relative disconnectivity of this system.

Key words: river sensitivity, landscape connectivity, river rehabilitation, reach scale, catchment scale

1. INTRODUCTION

It is now widely recognised that even though river management and rehabilitation is implemented at the reach-scale, these initiatives should build upon catchment-scale geomorphic insights (Downs and Gregory, 2004; Wohl et al., 2005). The character and behaviour of any given reach are influenced by biophysical fluxes, the operation of which reflect the inherent sensitivity of different river types to adjust and landscape connectivity at the catchment scale (Fryirs et al., 2007a). Hence, geomorphic concerns for river sensitivity, landscape position, landscape connectivity and the evolutionary history of river adjustments provide a coherent set of insights from which to frame management programs (Kondolf & Larson, 1995). Despite the primacy of these considerations, remarkably few investigations have analysed the history of geomorphic river adjustments at the catchment scale.

Perhaps inevitably, studies of river change tend to emphasise reaches which have experienced dramatic adjustments (i.e. metamorphosis; Schumm, 1969). However, not all rivers demonstrate the same form, rate and extent of adjustment in response to human disturbance. In performing these analyses, it is just as important to consider why other parts of the landscape are less prone to change. This requires an understanding of the inherent sensitivity of a river to adjust (e.g. Brunsden & Thornes, 1979). Much conceptual work has been conducted on the theme of 'river sensitivity' to adjustment/change. However, a closer scrutiny of the literature reveals that there is very little guidance on how to measure river sensitivity and assess how this changes over time. We contend that any analysis of river sensitivity is an innately time driven exercise, reflecting the 'condition' of the landscape at the time of disturbance events. In this light, analyses of river evolution and response to disturbance are key analytical tools with which to interpret river sensitivity to change. The inherent sensitivity of any given river type can be measured in terms of its 'capacity for adjustment', which describes the ability of a channel to adjust in vertical (aggradation/degradation), lateral (channel expansion/contraction; migration, translation, etc) and wholesale (thalweg shift, avulsion, channel abandonment, etc) dimensions. 'Capacity for adjustment' has been defined by Brierley & Fryirs (2005: 144) as "*morphological adjustments of a river … that do not bring about a change in wholesale river type, such that the system maintains a characteristic state (i.e. morphology remains relatively uniform in a reach-averaged sense)*". When phases of reach-scale geomorphic adjustment to human disturbance are tracked over time, a gradient of primary, secondary and tertiary responses can be detected, the forms of adjustment identified and the inherent sensitivity for adjustment measured.

When placed in a catchment context, the timeframes over which adjustment occurs and the lag time between disturbance and response are controlled by both the landscape setting and the connectivity of the system (Fryirs et al., 2007a, b). Connected (coupled) catchments readily convey geomorphic adjustments to off-site locations, thereby increasing the potential for change in downstream reaches. In contrast, disconnected catchments tend to suppress geomorphic adjustment, with minimal impact (or lagged) responses to disturbance in off-site locations. Therefore, while geomorphic response gradients can be detected for various river styles, the timeframe over which the river may adjust (or whether it will adjust at all) will vary in different landscape settings with different flow and sediment regimes and vegetation associations, and different disturbance impacts. These catchment-specific relationships determine the recovery potential of rivers and the pressures and limiting factors that may enhance or suppress recovery in the future (Brierley & Fryirs, 2005, 2008). These insights should be used to build scenarios of 'what is achievable' in river rehabilitation planning.

In this paper we examine catchment-scale geomorphic river responses to human disturbance across the upper Hunter catchment, New South Wales, in the period since first documented records are available (around 1880) as a means for examining how river sensitivity and connectivity can be measured and used in river rehabilitation planning.

2. REGIONAL SETTING AND METHODS

Parish maps from the 1880s are supplemented by five complete sets of aerial photographs (1938, 1953, 1955, 1972 and 1998) to analyse differing forms of river adjustment along thirteen river courses, covering a total river length of ~570 km in this 4295 km^2 catchment. Erosional and depositional variants of geomorphic adjustment are mapped systematically across the catchment for four time intervals, parish maps-1938, 1938-1955, 1955-1972 and 1972-1998. In addition to the comprehensive aerial photograph sets, partial coverage sets were analysed from 1941, 1942, 1946, 1958 and 1968, providing further insight into the types and continuity of river adjustment over time. Forms and timing of geomorphic adjustment are related to River Styles (a geomorphic river classification scheme; Brierley and Fryirs, 2005) and position within the catchment. River adjustments were classified into categories based on their form and extent (see Fryirs et al., subm.). Forms of adjustment were differentiated into erosional (in lateral, wholesale and vertical dimensions) and depositional types (in lateral and vertical dimensions) (Figs. 1 and 2).

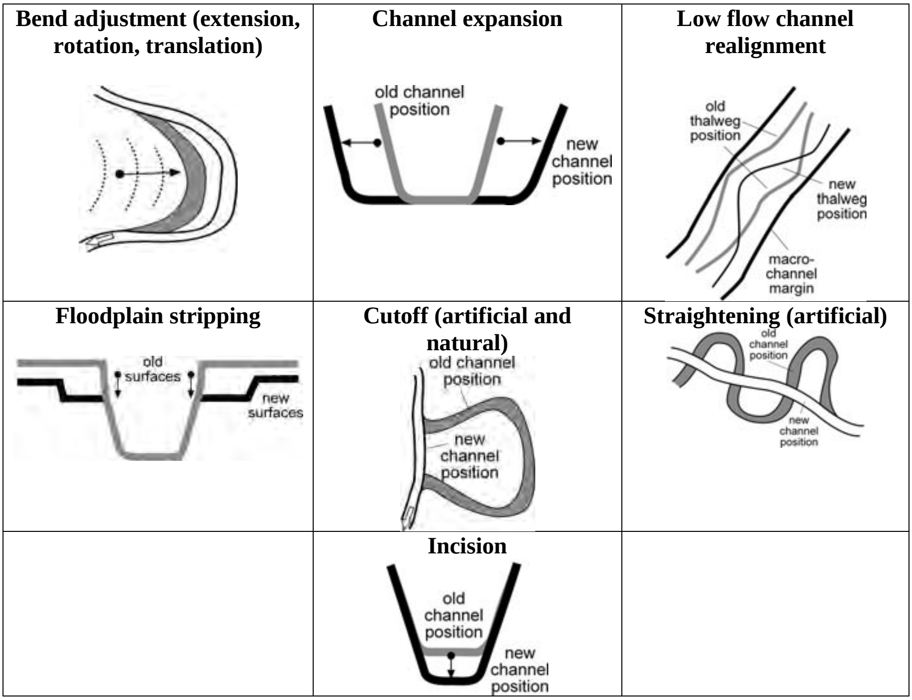

Figure 1 – Forms of erosional adjustment (from Fryirs et al., submitted).

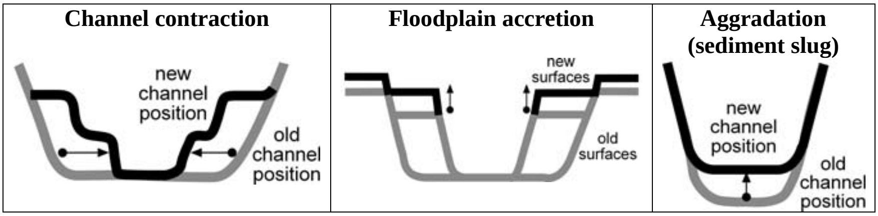

Figure 2 – Forms of depositional adjustment (from Fryirs et al., submitted).

The flood history of the upper Hunter catchment reflects El Nino-La Nina conditions with periods of drought interspersed with floods of varying magnitude. Drought conditions occurred between 1821-1856, 1901-1948, in the early 1980s and since the late-1990s. The flood of record occurred in 1955 with a discharge of 5685 m^3s^{-1} and a recurrence interval of 1:100 years (Hoyle et al., 2008).

3. RESULTS

3.1 Catchment wide capacity for river adjustment

Laterally-unconfined rivers (i.e. more alluvial river variants) experienced the most significant channel adjustments with all ten forms of adjustment occurring along 80-100 % of these rivers' length (Fig. 3). In most instances, these reaches have experienced multiple forms of river adjustment at the same locations over time. Incision progressively moved upstream since the early 20th Century. These reaches are considered to have significant capacity to adjust and are *sensitive* to change. Partly-confined and confined rivers are less prone to adjust. Partly-confined rivers experienced a more restricted range of adjustments along localised sections of channel (Fig. 3) with 43 % of the river length affected. Lateral adjustments dominate, with vertical adjustments limited by bedrock and terrace control. Given this pattern of adjustment, these rivers are considered *moderately resilient* to adjustment.

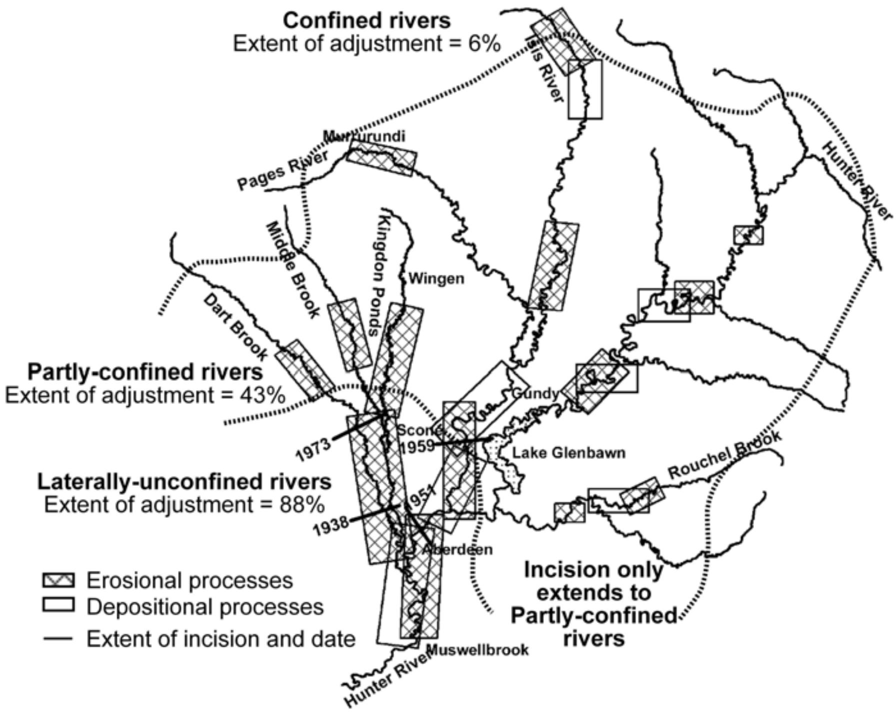

Figure 3 - The distribution of erosional and depositional adjustments to rivers across the upper Hunter catchment since European settlement.

Limited geomorphic adjustment has occurred along confined rivers. Only 6 % of river length is affected. These rivers are considered *resilient* to change as they have limited capacity to adjust. Although laterally-unconfined reaches experienced the most substantial adjustment, they only comprise a small proportion of total river length in the catchment (16 %) (Fig. 3). Partly-confined and confined reaches make up the remainder of the catchment. Hence, significant geomorphic adjustment has been restricted to a relatively small proportion of river length in the catchment. Indeed, the reach in the widest section of valley in the study area has experienced a patchy (localized) sequence of geomorphic adjustments in the period since European settlement, with relatively straight subreaches of this meandering reach experiencing negligible geomorphic responses to human disturbance (Hoyle et al., 2008).

3.2 Timeframe of river adjustment

Initial channel incision and expansion in response to human disturbance began between 1881-1938. The most active phase of geomorphic adjustment occurred between 1938-1955. This phase was characterised by significant channel expansion, floodplain stripping, incision and localised bend adjustment. While responses to human disturbance varied significantly across the catchment, the flood of 1955 marked the end of dominantly erosional processes and a transition towards dominantly depositional processes. This was reflected by significant bench formation, floodplain accretion and channel contraction in many reaches (Fryirs et al., subm.; Hoyle et al., 2008). The onset of this recovery phase was likely been aided by; firstly, the 'stabilisation' of channels via engineering works installed since the 1955 flood (see Spink et al., in press.); secondly, the lack of major (geomorphically effective) floods since 1955; thirdly, extensive landuse change has resulted an increased vegetation establishment along channels; finally, closure of Glenbawn Dam in 1957 which has reduced high flows and increased low flows (Erskine, 1985) and disconnected sediment supply (Erskine, 1985; Fryirs et al., 2007b).

3.3 Reach-scale geomorphic response gradients and catchment connectivity

Phases of reach-scale geomorphic adjustment to human disturbance are characterised as a gradient of primary, secondary and tertiary responses, the nature of which reflect the type/pattern of rivers and their variable capacity for adjustment (see Fryirs et al., subm.). For example, meandering rivers that experienced primary responses such as cutoffs then experienced secondary responses such as channel expansion, and tertiary responses such as channel contraction and bend adjustment. In contrast, low sinuosity rivers experienced a gradient of channel expansion, floodplain stripping, channel contraction, floodplain accretion and low flow channel realignment. Because of the disconnected nature of this catchment (see Fryirs et al., 2007b), secondary responses occurred between 50-70 years after initial disturbance.

A subsequent tertiary phase of river recovery, denoted as a transition from predominantly erosional to predominantly depositional geomorphic processes, occurred around 70-120 years after initial disturbance. The 1955 flood marked this transition. Such responses are ongoing across much of the upper Hunter catchment.

4. DISCUSSION: IMPLICATIONS FOR RIVER REHABILITATION PLANNING

Unless due consideration is given to analyses of river evolution, rehabilitation plans may target the symptoms, rather than the underlying causes, of river adjustment (Montgomery, 2008; Wohl, 2005). Evolutionary insights provide a critical basis with which to predict likely future adjustments, guiding the design of rehabilitation options and assessment of prospective treatment responses. Rehabilitation and management strategies which focus solely on river form, without examination and consideration of the adjustment processes which shape or maintain the form, are likely to be ineffective (Kondolf et al., 2001). Catchment-specific patterns of differing river types, their connectivity, and their adjustment in response to human disturbance, are key considerations in the development of place-based approaches to river management (Brierley et al., 2006). Catchment-scale analyses are required to identify potential off-site impacts, lag times and complex responses. This requires understanding of reach-scale sensitivity to adjustment, threshold responses, and the way in which these responses are mediated through catchments (and associated lag times).

Non-uniform responses to human disturbance have been reported across the upper Hunter catchment in this study (Fryirs et al., subm.). Geomorphic adjustment has been concentrated along laterally-unconfined rivers which have the capacity to adjust, but are localised elsewhere along rivers that have limited capacity for adjustment. Non-uniformity in the timing of adjustment has also been recorded, with significant lag times between disturbance and response. While the underlying *causes* of geomorphic adjustment have been relatively similar across the upper Hunter catchment, a range of *geomorphic response gradients* has been detected. These response gradients depict the series of geomorphic adjustments that are ‘set in train’ once disturbance occurs. The sequence and timing of adjustments along these gradients vary depending on the inherent sensitivity to adjustment of differing river types and reach position within the catchment. When placed in context of the (dis)connectivity of the catchment, practitioners can determine where ‘hotspots’ of adjustment are likely to occur and whether this adjustment will be manifest elsewhere in the catchment (i.e. determine off-site impacts). This provides a basis to effectively prioritise where rehabilitation actions should take place to enhance river recovery. However, caution is urged in extrapolating these findings elsewhere. Catchment-specific timing, patterns, and rates of geomorphic responses to differing forms of disturbance must be placed in context of the character and configuration of each river system.

If river management strategies are to effectively 'work with nature', focus must be placed on understanding past river adjustment (whether natural or human-induced) as this imprint influences contemporary processes. Trajectories of change can then be constructed and recovery potential investigated for different river types (Brierley & Fryirs, 2005). Given the catchment specific patterns of river types and their linkages, predictions of reach and catchment-scale responses to disturbance events, and the recovery potential of the system, must be considered in the context of river history and an understanding of spatial linkages of physical processes in the catchment of concern (Fryirs & Brierley, 2000, 2001). From this, strategic catchment-framed prioritisation and action plans can be applied to enhance prospects for the river system to recover naturally (Brierley et al., 2002; Fryirs & Brierley, 2000).

5. CONCLUSIONS

River sensitivity to adjustment, and the pattern of reaches within a catchment, are key determinants of river evolution and trajectories of change, and hence the potential for river recovery across catchments. The key river management lessons from this paper are:

a. plan effectively through proactive, catchment-scale applications.
b. address the underlying causes, rather than the symptoms, of river change through thorough analyses of river evolution and adjustment.
c. respect the inherent diversity and variability of river forms and adjustments in the adoption of ecosystem-based approaches to river management.

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THE RAPIDS OF MOUNTAIN STREAMS: THEIR IMPLICATIONS IN THE FLUVIAL RECONSTRUCTION CRITERIA

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ABSTRACT

Transversal works made of boulders which reproduce step-pool and cascade morphologies typical of mountain streams are one of the most applied morphological channel reconstruction techniques in steep channels. The step pool sequences are characterized by good stability due to their significative dissipation of the flow-associated energy, and their investigations can be useful for the correct design and construction of artificial boulder steps. Moreover, the typologies defined as rapids (or cascades) often provide a good channel bed stability, comparable to that characterizing the step-pool sequences, and could be a good alternative to the construction of artificial steps. The existence of some characteristic morphological relationships for natural rapids can help in the construction of artificial ramps in reaches with low bed stability, and where a reduction of stream velocity is necessary.

Several mountain streams of the Northeastern Italian Alps were selected for field surveys, to record the main morphological (mean reach slope and width) and sedimentological (bed surface D_{50} and D_{90}) parameters of step-pools and rapids. The aim of the work was to verify the invariance of geometric, morphometric and grain size relationships in natural rapids; in this way, artificial structures could be constructed according to morphological characteristics (channel width, length and slope) typical of the rapids observed in natural mountain streams.

Key words: channel reconstruction, step-pools, cascades, channel slope, channel width

1. INTRODUCTION

The rapids, also called cascades, are typical channel morphologies of steep mountain streams (channel slope higher than 3-4%), characterized by a chaotic distribution of boulders and cobbles, thus offering an effective defence for the river from the excess of flow kinetic energy. The energy dissipation is due to the formation of tumbling flows around the coarsest elements; such coarse elements form a superficial armour layer which, coupled to the energy dissipation along the flow path, provides a good level of stability to the rapids comparable to that characterizing the step-pool sequences.

Several investigations (Whittaker, 1987; Grant et al., 1990; Abrahams et al., 1995; D'Agostino & Lenzi, 1998; Chin, 1999) were conducetd both on the origin of step-pool typologies and on the relationships amongst the characteristic morphometric and geometric parameters. A certain invariance was observed if geometric parameters (step height *H*, step spacing *L*, channel bankfull width *W*), channel reach slope (*S*) and sediment grain size (*D*) of step-pools were inter-correlated (Vianello et al., 2006).

The present study had the goal to verify if the relationships between the geometry and morphometry of the rapids are common and invariant, despite the geographic location of the analyzed streams. In this paper the rapids are divided into glide and stepped cascades (D'Agostino & Vianello, 2004); the firsts are characterized by a regular profile, the seconds by the presence of irregular steps similar to those of step-pool sequences but not complete in the transversal direction.

As for the step-pool morphologies, whose geometric parameters and relationships are often chosen when planning the artificial boulder steps (Lenzi et al., 2000; D'Agostino et al., 2004; Vianello et al., 2006), the characteristic morphological relationships observed for the rapids can be used for the construction of boulder and cobble ramps in mountain stream reaches where it is necessary to reduce the flow energy to stabilize and equilibrate the channel. D'Agostino (2003) generalized Lane's (1955) relation expressing the natural tendency to equilibrium of an alluvial river as follows:

$$Q_l\, S = q_s\, D_{50}\, S_S\, S_F \qquad (1)$$

where Q_l is the liquid formative discharge (in m^3/s), S the channel slope (in m/m), q_s the specific sediment discharge (in m^2/m), D_{50} the median grain size of channel bed sediment (in m), S_S an adimensional factor of energetic dissipation related to channel sinuosity, and S_F is a factor of dissipation linked to the presence of sediment protrusions, thus defining the whole local dissipations due to the hydraulic jumps, also called 'spill resistance' (MacFarlane & Wohl, 2003). The eq. (1) is a mean-long period equilibrium law between flow energy ($Q_l\ S$, $m^3/s = W \cdot m^{-1} / N \cdot m^{-3}$) and the energy expended by the flowing water to transport sediments and model the channel ($E_M = q_s\ D_{50}\ S_S\ \ S_F$). According to the hydraulic geometry theory proposed by Leopold and Maddock (1953), the bankfull width (W, in m) can be expressed as function of the formative discharge; if the relation is inverted, we obtain:

$$Q_l = k_1 W^{\alpha} \quad (2)$$

where k_1 and α are coefficients calibrated in function of the analyzed basin. If we set eq. (2) in eq. (1), channel bankfull width can be expressed as:

$$W = \left(\frac{E_M}{S\, k_1} \right)^{1/\alpha} \quad (3)$$

2. DATA SET PRESENTATION, RESULTS AND DISCUSSION

With the aim to investigate the morphological characteristics of step-pool and rapids, about 400 step-pool and rapid typologies of six north-eastern alpine streams were selected for field surveys, and characterized by different basin drainage areas and by a different lithology (Tab. 1). The selected sites are the Pramper, Flizòn and Cordevole Streams (Dolomites, Veneto Region), the Sarca of Val Genova and Fersina Streams (Trentino Alto Adige), and the Brandet Stream (Val Camonica, Lombardia) (Fig. 1).

Field surveys provided measurements of morphological parameters such as mean channel reach slope, rapid and step-pool reach length, step height and spacing (for stepped cascades and step-pools), and mean bankfull channel width. Superficial grain size measures were taken along step-pool and rapid reaches using the method of grid by number proposed by Wolman (1954); the values of D_{50} and D_{90} of the sediment distributions were obtained accordingly for each analyzed streams. The morphological measurements, conducted along 85 step-pool sequences and 319 rapid typologies (glide and stepped cascades), gave a mean bankfull channel width (W) ranging between 5.0 and 8.5 meters, while the mean slope (S) of the different channel reaches ranged between 11% (glide cascades) and 13% (Tab. 2).

Table 1 - Analyzed streams of the Italian Alps; basin drainage area (A), mean channel slope (S_m), and dominant channel bed lithology.

Stream	A (km^2)	S_m (-)	dominant lithology
Pramper	15.3	0.10	dolomitic
Cordevole	7.1	0.14	volcanic tuff and dolomitic
Felizòn	31.3	0.17	dolomitic
Fersina	73.8	0.08	granitic
Sarca of Val Genova	138.4	0.08	granitic
Brandet	21.6	0.18	metamorphic

Figure 1 - Step-pool and rapid morphologies along reaches of the streams of the Italian Alps analyzed in this study (name of the stream on the top of the picture).

Table 2 - Mean reach slope (*S*) values, bankfull channel width (*W*) and characteristic grain sizes (D_{50} and D_{90}) relative to natural step-pool and rapid morphologies surveyed in the field (data extracted from the analyzed streams of Tab. 1).

Morphologies	N°	*S* (-)	*W* (m)	D_{50} (m)	D_{90} (m)
step-pools - StP	85	0.13	6.45	0.33	0.43
stepped cascades - SC	233	0.10	8.47	0.22	0.57
glide cascades - GC	86	0.11	4.85	0.11	0.29

2.1 Bankfull channel width (*W*)

A general but weak (R^2<0.3) decrease of *W* with the increasing channel slope (*S*) was observed for both step-pools and rapids (Fig. 2). An upper envelope curve was identified, defining that channel width values remain below the equation:

$$W_{max} \cong \frac{2.5}{S^{0.9}} \tag{4}$$

The bankfull width analysis was then conducted to compare step-pools to stepped and glide cascades (Fig. 3).

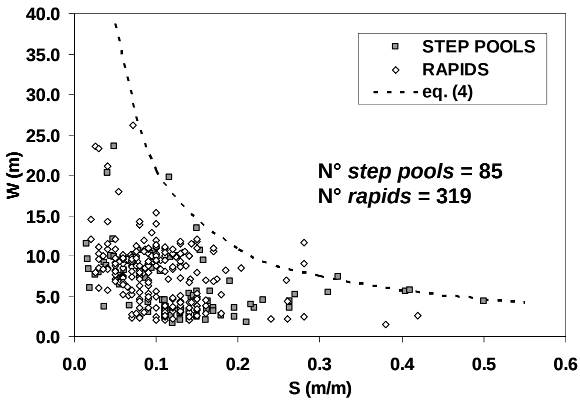

Figure 2 - Bankfull channel width (*W*, in m) variation versus channel reach slope (*S*, in m/m), relative to step-pool and rapid morphologies; the dash curve defines the upper envelope of eq. (4), interpolating the highest *W* values with the *S* variation.

The diagram of Fig. 3 show that a *W*-*S* relationship fits better for glide cascades (R^2=0.48) rather than for stepped cascades and step-pools. The presence of irregular steps in the stepped cascades represents an element of energy dissipation; it means that the morphological channel adjustment as response to channel slope prevails into the vertical direction too (step height and pool modeling). Fig. 3 shows that step-pools, at the same slope value, are affected by channel widths comparable to those typical of stepped cascades (SC). Furthermore, glide cascades (GC) show lower values of maximum width (Fig. 3). The equations expressing the upper envelopes for the morphological group of step-pool-stepped cascades (StP-SC) and for the glide cascades (GC) are the followings:

$$W_{max\,StP-SC} \cong \frac{3.0}{S^{0.7}} \tag{5}$$

$$W_{max\,GC} \cong \frac{1.6}{S^{0.7}} \tag{6}$$

Comparing eq. (5) and (6) with eq. (3), the resulting equations are the followings:

$$\left(\frac{E_M}{S\,k_1}\right)^{1/\alpha}_{max\,StP-SC} = \frac{3.0}{S^{0.7}} \cong \left(\frac{5}{S}\right)^{1/1.43} \tag{7}$$

$$\left(\frac{E_M}{S\,k_1}\right)^{1/\alpha}_{max\,GC} = \frac{1.6}{S^{0.7}} \cong \left(\frac{2}{S}\right)^{1/1.43} \tag{8}$$

The comparison between eq. (7) and (8) reveals that the E_M/k_1 ratio relative to step-pools and stepped cascades is double to that of glide cascades. Assuming a small k_1 variation in a restricted geographic area the energetic dissipation, in presence of hydraulic jumps, could result greater than that produced by a more regular bed profile (that is, by glide cascades). Furthermore, the E_M/k_1 reduction, moving from stepped morphologies to glide cascades, is close to that existing between mean D_{50} values relative to the different morphological typologies (mean D_{50}=0.27 m for StP/SC; mean D_{50}=0.11 m for GC; Tab. 2).

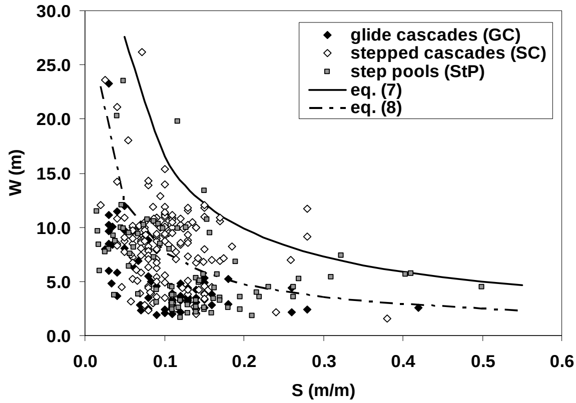

Figure 3 - Bankfull channel width (*W*, in m) versus channel slope (*S*, in m/m) for glide cascades (GC), stepped cascades (SC) and step-pools (StP).

2.2 Steps spacing

A further analysis focused on the comparison between step spacings (*L*) measured for step-pool sequences (step wavelengths) and for stepped cascades. As observed in previous flume and field investigations (Whittaker, 1987; Chin, 1999; Abrahams et al., 1995; Lenzi et al., 2000; Vianello et al., 2006), a step spacing decrease is evident with the growing slope (Fig. 4). Being the step height controlled by the coarsest grain size, whose dimensions remain more or less constant in the same stream, a slope increase is followed by a decrease of step spacing. Such behaviour was observed for the whole data set of the six analyzed streams (Fig. 4).

The experimental relation proposed by Whittaker (1987):

$$L = 0.31 S^{-1.19} \qquad (9)$$

gives a fairly good interpretation of the field measurements trend (Fig. 4); however, a high dispersion in the data is evident, moslty for slope values lower than 10%. We also assessed a relation with the form:

$$L_{max} \cong \frac{1}{S} \qquad (10)$$

Eq. (10) could represent a good support for the design of artificial rapids with high roughness according to fluvial-morphological criteria. If we substitute *S* of eq. (4) with the $1/L_{max}$ ratio of eq. (10), we obtain:

$$W_{max} \cong 2.5\ L_{max}^{0.9} \tag{11}$$

useful for the morphological design of dissipative structures made of boulder steps.

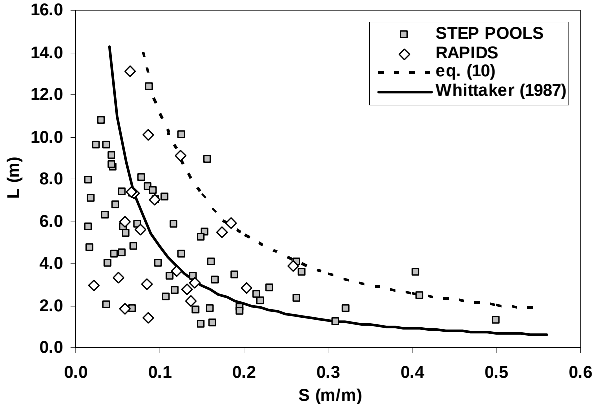

Figure 4 - Step spacing (*L*, in m) versus channel reach slope (*S*, in m/m); field data relative to step-pools (StP) and stepped cascades (SC). Comparison with he equation (9) proposed by Whittaker (1987).

2.3 Steps height

Abrahams et al. (1995), on the basis of flume and field experiences, verified that the longitudinal profile of step-pool sequences is the one which minimizes the flow velocity, i.e. the morphology giving the greatest bed stability. Such condition is satisfied when the ratio between step height (*H*) and spacing (*L*) results higher than channel slope (*S*); it means, when the pool profile has an adverse slope:

$$1 < \frac{(H/L)}{S} < 2 \tag{12}$$

The relationship is valid for natural step-pool morphologies, where the ratio *(H/L)/S*, also called steepness, often shows the mean value of 1.5 (D'Agostino & Lenzi, 1998; Vianello et al., 2006). The same analysis for our data set shows that, including the stepped cascades characterized by more irregular and incomplete steps, the steepness has mean values next to 1.5 (1.40 for step-pools and 1.35 for stepped cascades). A lower value of steepness for cascades reflects a profile geometry with the alternation of steps and pools less developed than those of step-pool sequences.

A small variation between the height (H) of step-pools and stepped cascades was found, with a mean H value of 0.93 m for step-pools and 0.79 m for stepped cascades. If we analyze the H/L variation as function of S, the majority of values lies above the $H/L=S$ line and below the following equation (Fig. 5):

$$\left(\frac{H}{L}\right)_{max} = 1.1\ S^{0.5} \qquad (13)$$

If we insert in eq. (13) the expression of mean L given by Whittaker (1987) relation (eq. (9)), a relationship for the direct H estimation as function of only the S parameter can be obtained; the expression is:

$$H_{max} = 0.34\ S^{-0.7} \qquad (14)$$

Field data are satisfactorily limited by eq. (14) and by the $H/L=S$ line (Fig. 5).

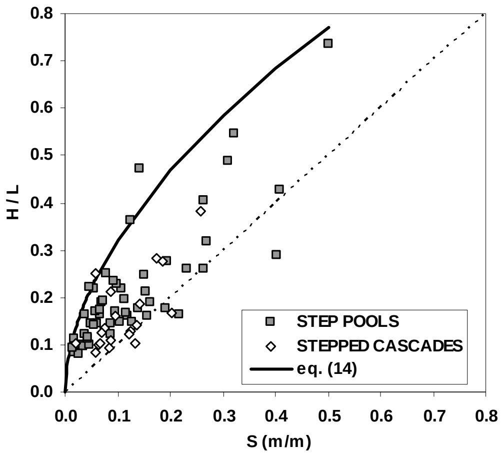

Figure 5 - *H/L* ratio versus channel reach slope (*S*, in m/m); field data relative to step-pools (StP) and stepped cascades (SC).

2.4 Pools with length of a rapid

The majority of rapids (glide and stepped cascades) are characterized by a well developed pool at the end of the ramp, here called final pool. For some of the analyzed Alpine streams, the rapids had pools with a longitudinal length (Lp) inversely correlated to the upstream rapid length (Lr) (Fig. 6). This self-adjustment of the channel morphology could be attributed to the fact that the rapids (the glide cascades in particular) determine a spatially-continuous pattern of flow energy dissipations.

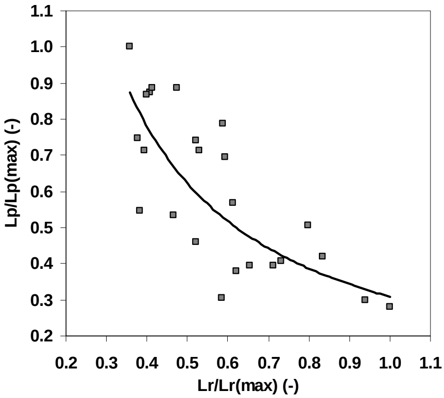

Figure 6 - Pool length (*Lp*) versus upstream rapid length (*Lr*); field data relative to glide and stepped cascades of the analyzed Alpine streams. *Lp* and *Lr* were converted into adimensional values being divided for the maximum rapid and pool lengths of the data set.

The obtained relationship between *Lr* and *Lp* has the following form:

$$L_p' \cong \frac{0.3}{L_r'} \tag{15}$$

with R^2=0.6, and with L_p' and L_r' the adimensional values of *Lp* and *Lr* ($L_p' = Lp/Lp_{(max)}$ and $L_r' = Lr/Lr_{(max)}$; $Lp_{(max)}$= 15.0 m, $Lr_{(max)}$= 37.7 m). Eq. (15) can be explained as a response of the channel to the energy expenditure along the rapid profile. The longer is the rapid, the lower is the energy level at the downstream end of the same rapid; this reflects in a lower capacity of pool depth and length (Lenzi et al., 2000; Vianello, 2001).

3. CONCLUSIVE REMARKS

The analyses of a good number of field surveys relative to step-pool and rapid morphologies suggest that:

- stepped cascades can be considered as transitional channel bed morphologies between classic rapids (it means, glide cascades) and step-pool sequences; they result similar, both for formative bankfull width and for energetic flow dissipation, to the step-pool typologies;
- stepped cascades seem to follow the flow velocity minimization theory proposed by Abrahams et al. (1995), thus reducing step spacing as response of the increasing channel slope, according to the relationship proposed by Whittaker (1987);
- in mountain streams restoration techniques, the realization of longitudinal structures similar to the natural ramps with high gradient could constitute an alternative to the hydraulic works made with

artificial steps. The upper envelope values for bankfull channel width, step spacing and step height estimation (W_{max}, L_{max} and H_{max}) can be derived from the mean slope (S) of the channel reach to be restored (eqs. 10, 11 and 14), and then used for its design.

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CHANNEL MOBILITY AND SEDIMENT MANAGEMENT: THE MAGRA RIVER PROJECT (CENTRAL-NORTHERN ITALY)

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ABSTRACT

A research project was carried out with the aim of defining strategies for management of sediment and channel mobility, based on the comprehension and analysis of geomorphic processes. The research included the following phases:

1. Geomorphological study of channel evolution, morphological forms, processes, and sedimentary features of the main alluvial channels of the Magra catchment.

The interpretation of present trends of channel adjustments was conducted by analysing geomorphological maps and by assessing the historical channel changes from the comparison of aerial photos, and by conducting intensive field surveys.

2. Identification of areas suitable for potential sediment recharge. Based on a series of main factors (lithology, landslides, physiography, and land-use), we defined an index of potential recharge by landslides and an index of potential direct recharge from the hydrographic network. We calculated such indices for all the sub-catchments, thus identifying the more suitable areas for possible coarse sediment supply.

3. Quantification of sediment transport and sediment budgets. Sediment transport was estimated by using hydraulic formulae..

4. Definition of strategies and guidelines for managing sediments and lateral channel mobility. The concept of 'erodible river corridor' or 'functional mobility corridor' has been applied to the Magra and Vara rivers, and obtained through a GIS analysis by overlapping the corridor of historical (last 50 years) channel shifts with zones of possible future erosion (next 50 years). A 'map of strategies for sediment management' was obtained, as a synthesis of all the aspects previously studied (morphological evolution, sediment budgets, areas of potential sediment recharge in the catchment).

Key words: Channel changes, Sediment management, Magra River

1. INTRODUCTION

The importance of geomorphological river dynamics for the creation, maintenance and evolution of physical habitats, aquatic and riparian ecosystems, is being increasingly recognised. Sediment transport and channel mobility represent two key processes, and their understanding is of crucial importance for defining river restoration and management strategies. In Italy, as in many other parts of Europe, many rivers have experienced severe incision and bedload deficit, mainly due to a series of human factors. This evolution has led to the need of sustainable management of sediment, and notably to promoting bedload supply and recharge, bank erosion preservation and restoration, but also measures for mitigating the ecological impacts of channel incision (Piegay et al., 2005; Habersack & Piegay, 2008).

Starting from this base, the Basin Authority of Magra River (Central - Northern Italy) has undertaken a river management policy based on the comprehension and analysis of geomorphic processes. A research project was carried out with the aim of defining strategies for the management of sediment and channel mobility. The objective of this paper is to summarise the main methods and approaches used in this project for addressing the problems of channel mobility and sediment management. For full details on the methods and results, we refer to the project reports (Rinaldi, 2005, 2007) and to Rinaldi et al. (in prep). In this project, we used a combination of geomorphological methodologies (GIS analysis of channel changes and of sediment sources, field stream surveys), and quantitative hydraulic estimations of sediment transport and sediment budget, in order to obtain a series of practical tools ('functional mobility corridor' and 'map of synthesis for sediment management') to be used for channel and sediment management.

2. GENERAL SETTING

The Magra River is located in Nothern Tuscany and Liguria (Central – Northwestern Italy). The catchment has an area of about 1698.5 km^2, and its morphology is characterised by aligned ridges with a NW-SE trend, created by Mesozoic and Tertiary units with folded structure, separated by two main basins with a similar trend: on the west, the valley of Vara River, the main tributary of Magra (catchment area of 572 km^2), and on the east the middle-upper Magra valley.

The area falls within a temperate climatic zone with a dry season. The mean annual precipitation is relatively high, being 1707 mm, with the highest values reaching up to 3000 mm in the upper part of the Magra basin. The Magra R. has a total length of about 69.5 km, while the Vara R., its main tributary, has a length of about 65 km. Mean daily discharge at a gauging station located along the middle – lower Magra (catchment area of

932 km^2) is 40.8 m^3s^{-1}, while the peak discharge with a 2 year return period (Q_2) is 622.7 m^3s^{-1}.

3. GEOMORPHIC ANALYSIS

The general structure of the research project is summarised in Fig. 1. The geomorphic analysis is divided in three main phases: (a) identification of historical and recent channel changes, and present trends of adjustments; (b) identification at the catchment scale of areas suitable for potential recharge of coarse sediment; (c) quantification of bedload and sediment budgets at reach scale by using hydraulic formulae.

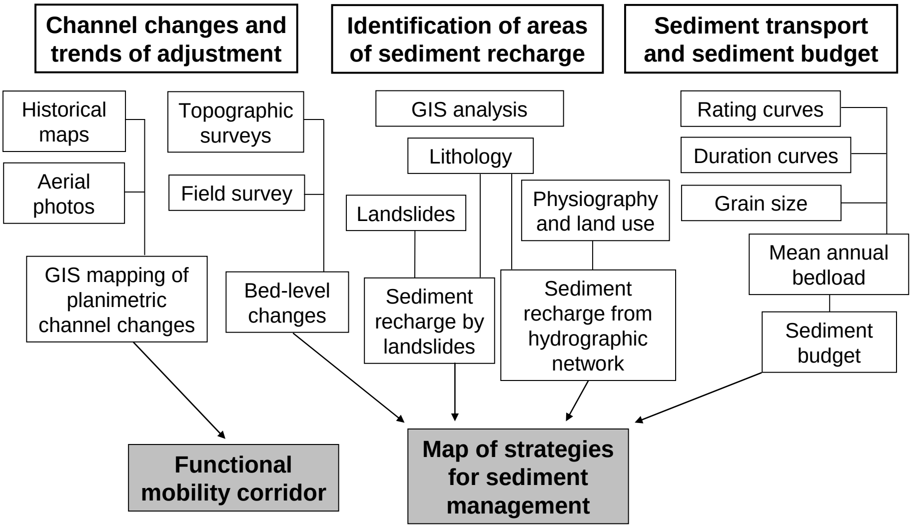


Figure 1 – General structure of the methodological framework.

3.1 Channel changes and trends of adjustment

A detailed GIS analysis of channel changes was carried out using a multi-temporal series of historical maps (1877, 1904-08) and aerial photos (1937, 1954, 1971, 1981, 1995, 1999, 2003, 2006). A map of planimetric changes (scale 1:10.0000) was obtained for the entire study rivers, and the temporal trends of variation in active channel width were reconstructed. A comparison of longitudinal profiles of different years of the channel bed (1914, 1958, 1971, 1989, 1999-2000, 2003, 2006) was possible for the lower reaches of Magra and Vara River, while for the upstream reaches field evidences were used to obtain a classification of past vertical changes and present trends of adjustment.

Present forms and processes were characterised by field surveys and aerial photo interpretation. A geomorphological mapping (scale 1:10.0000) of fluvial landforms along the channel and the river corridor was obtained for the entire rivers. An extensive sediment survey was carried out during the period 2004/05, in order to characterize the variability in sediment size and, subsequently, to estimate the sediment transport. During a first phase, pebble counts were conducted on channel bars for a total of 27 locations along Magra and Vara, and additional 8 locations along the main tributaries. During a second phase, a series of 13 volumetric samples of the sub-surface layer were collected, in order to have more precise information for the sediment transport calculations.

The GIS analysis showed a progressive reduction in channel width, particularly along the unconfined, downstream reaches, where this reduction was very significant. Similarly, channel incision was particularly important along the downstream reaches, where the bed-level lowering from 1914 to now exceeded 7 m in some points.

All the information and results of the geomorphic analysis were summarised in a channel evolution model. Three main phases of channel adjustments were distinguished: (1) a first phase of minor incision and channel narrowing occurred from about the end of 1800 and the half of 1900, as a result of land-use changes at basin scale, construction of weirs along tributaries, and construction of groynes along the downstream reaches of Magra and Vara; (2) a phase of major adjustments (incision – narrowing) occurred between the 50's and the beginning of the '90s, mainly as a result of sediment mining; (3) during the last 10-15 years, an inversion in the trend of channel width (widening phase), and in some case of bed elevation, was observed in some reaches, mainly as the effect of intense flow events occurred during 1999 and 2000. However, the last aerial photos (2006) have revealed a new slight decrease in channel width compared to 2003.

3.2 Identification of areas for potential sediment recharge

In order to consider possible strategies for sediment recovery at catchment scale, it is important to identify areas for potential sediment recharge, with particular regard to the coarse fractions more suitable for bedload transport. At this purpose, we considered recent experiences carried out in the catchment of the Drome River (France) (Liebault et al., 2001). Similarly, in this study we used a semi-quantitative approach, derived from the definition of some indexes, based on assigning a series of scores to the parameters which are considered as the most significant for the problem, proportionally to their relative importance. In fact, the scope of this phase was to obtain a classification of the areas of the basin with a relative degree of potential sediment recharge, rather than a quantification of the sediment supply. Full details of this methodology are reported in Rinaldi (2007).

Two types of sediment sources were considered: (A) *sediment recharge by landslides* (point sources); (B) *direct sediment recharge in the hydrographic network* (linear sources). As regard the first index, the parameters considered as the most important were: the landslide activity (active, dormant, or inactive), the connection of the landslide to the fluvial network, and the lithology, so that for each landslide the index was defined as the product P_1=*activity x connection x lithology*. Similarly, as regard the second index, some main physiographic and land-use classes were defined, so that for each river stem of the hydrographic network the index was defined as the product P_2=*lithology x physiography/land-use*. For each index, five classes of potential of recharge (from very low to very high potential) were defined.

Subsequently, for each sub-catchment, a weighted average of each of the two indexes (P_{1tot} and P_{2tot} respectively) was calculated. A GIS analysis was carried out allowing visualizing effectively the results, and identifying the basin sub-catchments with the highest potential of recharge for the two processes (landslides and direct recharge in the fluvial network).

The following step consisted in selecting the actual significant areas for potential sediment recharge. As regards the first type of sediment source, only the landslides falling in the first two classes of the index P_1 (high and very high potential) were selected. Then, suitable landslides were further selected on the base of the following additional factors: (a) distance of the source from the downstream incised reaches; (b) longitudinal connectivity of sediment to the incised reaches (i.e. the landslides upstream a dam located on the Vara River were excluded because the deriving sediment can not reach the incised reaches). Similarly, as regard direct sediment recharge in the hydrographic network, in a first phase the sub-catchments falling in the first two classes of the weighted average of the index P_{2tot} were selected. A further selection was based on the same parameters used for the potential recharge by landslides (distance and location, longitudinal connectivity).

3.3 Quantification of sediment transport and sediment budgets

Sediment transport was estimated by using hydraulic formulae. Four formulae were selected as the most suitable for the studied river and were tested: Schoklitsch, Shields, Meyer Peter & Muller, Parker (1990). Subsequently, a sediment budget was calculated for the Magra and Vara rivers. As first step, the two rivers were divided in 11 and 12 relatively homogeneous sub-reaches, respectively. For each sub-reach, the following steps were performed to calculate the mean annual bedload transport capacity using the procedure suggested by Biedenharn et al. (2001): (a) selection of a representative cross-section and median diameter of bed sediments; (b) calculation of the rating curve by 1-D hydraulic modelling (Hec-Ras 3.1.3); (c) definition of the discharge duration curve of the reach; (d) calculation of the mean annual bedload capacity, by using the selected bedload formulae for each interval of discharge, and integrating for the duration of each discharge. Based on the Exner sediment continuity equation, it was then possible to calculate the mean annual excess or deficit of bedload for each sub-reach. The nine main tributaries were included in the sediment budget. Based on the values of the mean annual sediment budget, the tendency of the sub-reach to be subject to aggradation or incision was evaluated.

4. STRATEGIES FOR SEDIMENT AND CHANNEL MANAGEMENT

4.1 The functional mobility corridor

Traditional policies for managing bank erosion are currently being reconsidered (Piegay et al., 2005) due to the increased awareness of managers regarding: (i) the unsustainable nature of some engineered bank protections; (ii) the economic costs of providing that protection; (iii) the key role of bank erosion in channel dynamics; and (iv) the recognition that bank erosion provides ecosystem services and other benefits that were not previously considered in the cost-benefit analyses used to plan bank protection works. Hence, river managers are increasingly adopting the idea of allowing rivers to migrate freely within a defined corridor, property rights within the corridor usually being obtained either by negotiation with land owners or by buying the land outright.

The ‘functional mobility corridor’ (Malavoi et al., 1998) (in Italian: ‘fascia di mobilità funzionale’) or Erodible Corridor Concept (ECC: Piegay et al., 2005) was extensively applied in the Magra project, and will be adopted as the base for future sustainable channel mobility management. The procedure was implemented by a detailed GIS analysis, and included the following three steps: (1) overlapping the river courses of the last 50 years (1954 – 2004), and obtaining the corridor of channel changes; (2) defining the zones of possible future erosion (next 50 years) by calculating the present mean rates of bank erosion for each sub-reach of the river; (3) overlapping and delineating the external limit of the two previous zones. The ‘actual functional mobility corridor’ is defined in a process of participatory management led by the Basin Authority of the Magra River, taking into account justified local constraints (e.g. main infrastructures, protection of drinking water wells, etc.). The definition of the ‘actual functional mobility corridor’, in which decision-makers have to develop a specific land-use policy to permit erosion to occur, is an on-going process.

Restriction of the historical analysis to the past 50 years, and the evaluation of the trends for the next 50 years, are motivated by the following reasons: (a) the river at the beginning of the 1900 showed abundant bedload, different channel patterns, wider beds and greater instability than they do today, implying that if pre-1950 data were also used, streamway evaluation would be overestimated because watershed and floodplain conditions prior to 1950 were much different than they are today; (b) such a wide streamway, often occupying the entire valley floor, would have doubtful practical application, given that part of the alluvial plain is today urbanised; (c) regarding the zones of possible future erosion, 50 years has been selected as a suitable interval because it coincides with the life span of the management project.

4.2 Map of strategies for sediment management

All the aspects previously analysed (morphological evolution, areas of potential sediment recharge in the catchment, sediment budgets) have been synthesised in a ‘map of strategies for sediment management’. This map (scale 1:60.000) includes three main components: (1) suitable areas for potential bedload recharge; (2) actions and/or measures at catchment scale; (3) river classification and associated sediment management recommendations.

(1) Suitable areas for potential bedload recharge. The landslides and the sub-catchments selected for potential sediment recharge, according to the criteria previously described, are reported on the map.

(2) Actions and/or measures at catchment scale. A series of management actions have been defined (Tab. 1). They are divided in two main categories: (a) actions to preserve natural sediment supply; (b) actions to promote sediment budget recovery. The first group includes six main actions consisting in prohibiting interventions, rather than promoting active actions, and are mainly referred to the hillslopes and tributaries. They are intended to be applied to all the landslides and sub-catchments defined as suitable for potential sediment recharge. The second group includes seven main actions consisting in undertaking some kind of intervention to promote the recovery of the sediment budget (i.e. moving sediments from sites where they are in excess to adjacent sites or downstream reaches where they are in deficit). These actions are mainly referred to the alluvial channels (Magra and Vara) and their main tributaries in their final mobile reach.

(3) River classification and associated sediment management recommendations. This classification represents the basis for the application of the actions to promote sediment budget recovery (b), and was based on four different aspects, in the attempt of considering at the same time past changes, present trends of adjustments, and hydraulic tendency towards conditions of aggradation/incision. For this scope, the following four classifications, derived from the geomorphic analysis, were initially used:

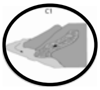
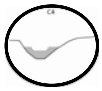
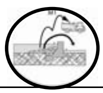
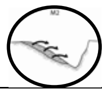
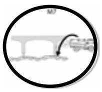
(a) bed-level changes at the scale of 100 years (from 1900 to 2004). Five classes of bed-level changes were defined: *S*) stable (changes ranging from 0.5 to -0.5 m); *Il*) limited incision (from -0.5 to -1 m); *Im*) moderate incision (from -1 to -2 m); *Ii*) intense incision (from -2 to -4 m); *Iii*) very intense incision (<-4 m). Situations of net aggradation (from 1900 to 2004) were never observed along the study rivers, therefore this case was not included in the classification.

(b) Present trend of bed-level adjustments. The following four classes were defined: *A*) aggrading; *E/A*) equilibrium/aggrading; *E*) equilibrium; *I*) incising.

(c) Bed-level recovery compared to the situation of 1950. This aspect was included because, in case of reaches where aggradation is the present trend of adjustment, it is also important to know how much bed-level recovery has occurred compared to the reference situation of 1950. Five classes were defined: *A*) recovery > 100 % (i.e. net aggradation compared to 1950); *B*) recovery from 80 to 100 %; *C*) recovery from 50 to 80 %; *D*) recovery from 0 to 50 %; *E*) recovery < 0 % (i.e. still incising).

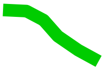
(d) Hydraulic sediment budget. Based on the unit volumes of sediment budget calculated for each reach, five classes were defined: *A*) aggrading; *E/A*) equilibrium/aggrading; *E*) equilibrium; *E/I*) equilibrium/incising; *I*) incising.

Table 1 – Map of strategies for sediment management: part of the legend reporting the actions for promoting sediment recovery.

Actions to preserve natural sediment supply			
	***C1***: do not stabilise landslides		***C2***: do not stabilise hillslopes in direct connection with the hydrographic network
	***C3***: do not stabilise eroding streambanks		***C4***: do not build new transversal hydraulic structures
	***C5***: do not build new longitudinal hydraulic structures		***C6***: avoid maintenance of existing hydraulic structures
Actions to promote sediment budget recovery			
	***M1***: mobilise sediments trapped upstream of weirs		***M2***: mobilise instream sediments
	***M3***: move sediments accumulated on the floodplain into the channel		***M4***: carry out a bedload release downstream of dams
	***M5***: mobilise sediments in situations of hydraulic risk (for aggradation)		***M6***: introduce sediments deriving from other reaches
	***M7***: introduce sediments in situations of risk (for local scour)		

From the combination of all the possible cases deriving from the previous four classifications, three main macro-classes were defined, and specific actions in terms of sediment management were assigned to each of these classes (Tab. 2).

Table 2 - Map of strategies for sediment management: part of the legend concerning the river classification and associated sediment management recommendations.

Symbol	Classes and associated channel bed conditions	Management actions
	***Class 1***: Reaches with tendency to aggradation and high bed recovery compared to 1950	**Promoting sediment shifting** within the same reach (action ***M2***) or to the closest downstream reach in class 3 (actions ***M1*** or ***M5***)
	Class 2: Reaches with variable tendencies and medium recovery	**Allowing sediment shifting** within the same reach (action ***M2***) or to the closest downstream reach in class 3 (actions ***M1*** or ***M5***)
	***Class 3***: Incised reaches with low bed recovery compared to 1950	**Not allowing any sediment shifting**, except in case of local aggradation upstream of weirs (action ***M5***), and **promoting introduction of sediments** deriving from upstream reaches in class 1 or 2 (actions ***M6*** or ***M7***)

A series of associated guidelines for sediment management were defined. For example, in case of sediment mobilization from an aggrading reach (with an excess in the annual sediment budget) to an incised downstream reach, the volumes of mobilised sediment must not exceed the values of the mean annual sediment budget.

5. CONCLUSIONS

The ‘map of strategies for sediment management’ and the application of the ECC represent a scientifically-sound base for future channel and sediment management. The map provides strategies for the future management of sediments and associated delivering processes, while the ‘functional mobility corridor’ defines the areas in the river corridor where free lateral movements can be allowed. In combination, these two maps represent the management tools to promote the recovery of the incised reaches and future sustainable sediment management.

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RIVER RESPONSE TO CHANNEL REGULATION, UPPER ODRA RIVER, POLAND

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ABSTRACT

The Upper Odra (4666 km^2, 41.5 m^3/s) is a submontane river with a groundwater-snowmelt-rainfall regime. Before the regulation it was a meandering river. As an effect of a series of training works developed during the 19th century, the natural processes of erosion and sedimentation were interrupted. The construction of groynes caused a channel narrowing and changed the natural sedimentation pattern, resulting in a decrease of the channel width from over 150 m to approximately 50 – 70 m after the rectification. Nowadays the channel sinuosity of the Upper Odra ranges from 1.3 to 2.3, while the valley floor slope is about 0.3 m/km. Furthermore, the construction of regular arrays of groynes along the Upper Odra channel created a new environment for sediment deposition.

Key words: regulated river, sediment budget, inter-groyne infill

1. INTRODUCTION

It is apparent that sediments in river channels are in a dynamic condition. However, human activities aimed to channel stabilization disturb the natural balance of fluvial processes, and result, for example, in changes of the typology and rate of overbank sedimentation and channel bed dynamics (Knox, 1999; Mandel & Bettis, 2000; Ciszewski, 2002). From the perspective of engineers, a river channel is stable when it maintains the same morphology. The complete channel stabilisation is in fact unattainable. An example is drawn from the Upper Odra course in southern Poland. This paper describes the rate of sediment transport and accumulation within the trained reach of the Upper Odra River, in the lee-side of a series of groynes. Newly constructed groynes intensify the within-channel sedimentation creating an additional significant sink for the suspended material transported in the river channel.

2. STUDY SITE AND METHODS

The Upper Odra River is a submontane river with a groundwater-snowmelt-rainfall regime. It flows in the temperate climatic zone. Before the regulation, the Upper Odra (drainage area of 4666 km^2, mean flow of 41.5 m^3/s) was a meandering, sand-bed river. As an effect of training works and of agricultural, urban and industry development, the natural processes of erosion and sedimentation were interrupted in the 19^{th} century (Klimek, 1999). The construction of groynes in 19^{th} century resulted in a decrease of channel width from over 150 m before the rectification to approximately 50 – 70 m after the training works. Nowadays, the Upper Odra channel sinuosity ranges from 1.3 to 2.3, whereas the valley floor slope reaches 0.3 m/km. The construction of regular arrays of groynes along the Upper Odra channel created a new environment for sediment deposition. In fact, groynes keep the main flow away from the river banks but also result in deposition of material adjacent to the groyne structures.

Three different age indicators were used to calculate rates of vertical accretion since approximately 1750: coal dust, plastic artefacts, and ^{137}Cs. Coal dust and plastic objects are very common in the youngest sediments. Coal dust can be used to estimate rates of sedimentation on the Odra River since about 1750, when the first coal mines within Upper Odra catchment started to operate. The artificial radioactive element ^{137}Cs was used as an age indicator for the sediments deposited after 1964 (detectable Caesium-137 began in 1954, the first peak appeared in 1958/1959, and the second peak occurred at 1962-1964).

By determining the depth of the strata containing artefacts, more detailed age estimates were obtained. Rates of sediment accumulation per year were defined in thickness (cm y^{-1}), and calculated dividing the thickness of sediments deposited above the stratum containing the dated artefact by the number of years since the artefact deposition. The rate of sedimentation can be expressed as:

$$\overline{R}_S = S_A / (Y_P - Y_{S_A})$$

where R_S = average rate of sedimentation (cm y^{-1}), S_A = depth of stratum containing artefact of known age (cm), Y_P = year of deposition of top layer of the unit and Y_{SA} = year of artefact deposition.

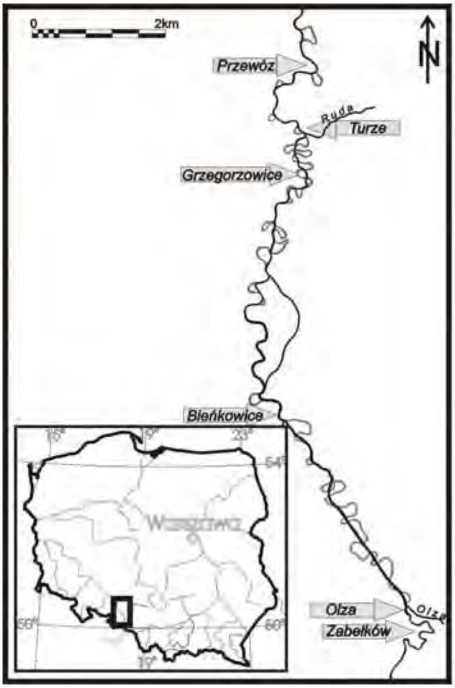

Figure 1 – Location of the study sites. The grey line indicates the channel course before the regulation. Present channel course is drawn in black.

3. SEDIMENT TRANSPORT AND DEPOSITION

During the years when no major high flow events occurred, the supply of material to the Odra reach did not usually exceed 100,000 tons, but up to 80% of the transported material was deposited within the Upper Odra reach. Between 1978 and 1990, in years with major high flow events as well as for certain years without those episodes, a strong increase in sedimentation of transported material, expressed as percentage of losses in the overall volume of transported material, was recorded. The percentage of losses in material transported by the Odra River within the investigated reach fluctuated widely until the mid-1980s. At the end of the 1980s, a sudden drop in the intensity of sedimentation material was recorded, conditioned by diminishing transport volumes (Fig. 2).

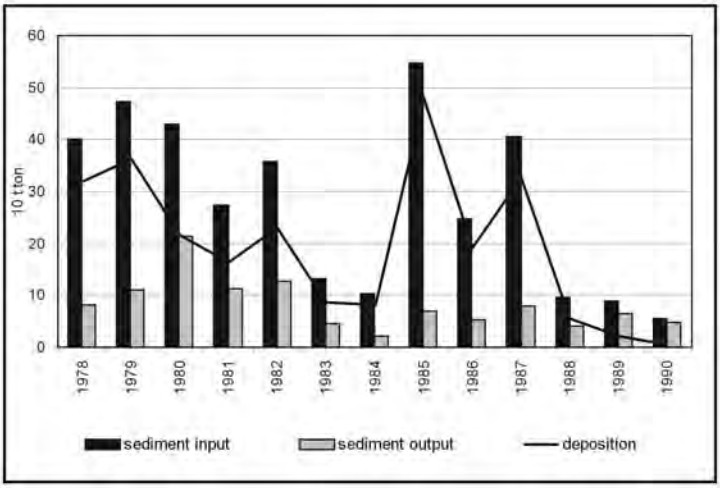

Figure 2 – Sediment budget within the studied reach of the Upper Odra River.

The period for which such calculations were conducted is too short to draw any conclusions concerning trends. It should be noted, however, that during the thirteen years included in the study the percentage of transport losses in the studied Odra reach dropped from 80% to 10%.

The average total supply of material transported to the studied reach by the Odra itself and by its tributaries in 1978-1990 was around 277,500 tons/year, of which on average 82,400 tons/year were transported beyond this reach. This means that within the studied Odra reach, around 195,000 tons of transported material were deposited each year as overbank sediment, which corresponds to the deposition of 5,500 tons of transported material for each km of river reach each year. Between 1978 and 1990, the peak supply was recorded in 1985, when a six-day flood occurred. The supply of material at that time amounted to around 548,000 tons, 87% of which was deposited within the inter-embankment area of the Odra reach under analysis.

The inter-groyne basins are a significant sink for material transported in the Upper Odra channel. Basins are in-filled with vertically accreted silt and sandy silt. Sediment accretion rates were derived using artefacts as an alluvia age indicator. In the last 40 years, the average rate of sediment accretion has been 5 cm per year, while shortly after channel stabilisation the rates ranged from 1.2 to 2.8 cm per year. During large floods, up to 30 cm per event have been deposited (Czajka, 2005).

The average calculated rate of sediments accretion is 1.7–6 cm/year (Tab. 1).

Synthetic artefacts in the alluvia provide evidence of increasing rates of vertical accretion during the last 50 years. These results correlate with data concerning the sediment budget within the investigated sectors of the Upper

Odra. On average, 195.000 tons of suspended material transported by the Upper Odra has been yearly trapped as overbank deposits within the investigated sections (Czajka, 2005).

Table 1. Average annual sediment accumulation rates in for dated periods.

Zabelkow		Olza		Bienkowice		Grzegorzowic		Przewoz	
years	cm/y	years	cm/y	years	cm/y	years	cm/y	years	cm/y
2001-1997	5	2000-1954	1,8	2001-1994	15,7	2001-1987	2,8	2001-1997	5
1997-1985	5	1954-1882	2,2	1994-1980	4,2	1987-1954	6,7	1997-1960	5,7
1985-1905	2,8			1980-1950	3	1954-1850	1,5	1960-1789	1,7

4. CONCLUSIONS

The human-influenced changes of channel geometry created a new environment for sediment deposition. Inter-groynes basins are continuously filled with sediments transported in river channel. This process results in another changes in river bed morphology, as channel width decreases dramatically.

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APPLICATION OF PROCESS-BASED NUMERICAL APPROACHES TO ANALYSIS OF BANK STABILITY AND RIVER RESTORATION

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ABSTRACT

Streambank erosion by mass-failure represents an important form of channel adjustment and a significant source of sediment in disturbed streams. Little if any quantitative information is available on the effectiveness of bank treatments on reducing erosion. To evaluate existing streambank-derived sediment loads and the potential to reduce sediment loadings from streambanks, the hydraulic and geotechnical processes responsible for mass failure were simulated under existing and remediated conditions using the Bank-Stability and Toe-Erosion Model (BSTEM). Two sites were selected from each of the three watersheds known to contribute the greatest amounts of streambank-derived fine sediment to Lake Tahoe The 1995 annual hydrographs supplemented by the rain-on-snow event of January 1-2, 1997 were discretized into individual events and input into the toe-erosion sub-model using an excess shear-stress approach. The updated geometry was then exported into the bank-stability sub-model to test for the relative stability of the bank under peak-flow and drawdown conditions. BSTEM was used iteratively for all flow events for both existing conditions and with riprap toe protection. Under existing conditions, total streambank erosion by hydraulic and geotechnical processes ranged from 472 m^3 to 5260 m^3. On average, 13.6% of the material was eroded by hydraulic shear, the remainder by mass failures. Iterative simulations with 1.0 m-high riprap toe protection showed a dramatic reduction in mean, total and fine-grained streambank erosion (87%). Failure frequency for the simulation period was reduced in most cases to a single episode. Thus, an almost 90% reduction in streambank loads was realized by virtually eliminating the erosion of only 14% of the material that was entrained by hydraulic forces. As a consequence, average load reductions were about an order of magnitude. Results stress the critical importance of protecting the bank toe-region from steepening by hydraulic forces. Iterative simulations using bank-top vegetation showed about a 50% reduction in loads.

Key words: Bank-stability model, Lake Tahoe, sediment loads

1. INTRODUCTION

Humans have interacted with and exploited the Lake Tahoe Basin since the 1850s. Activities such as logging, road construction, mining, overgrazing and urbanization threaten to do irreparable damage to the lake. Over the past 35 years, a trend of decreasing water clarity has been documented (Goldman, 1988). This trend has been partly attributed to the delivery of fine-grained sediment emanating from upland, urban and channel sources. A recent study by Simon (2008) estimated that about 25% of the median annual fine-grained loading of sediment to the lake was derived from streambank erosion, making this an important source. In fact, about 20% of all fine sediment delivered to Lake Tahoe was found to come from the banks of the Upper Truckee River and Blackwood Creek. To improve lake clarity it is essential to quantify the magnitude of the load reductions that could be expected after implementing potential mitigation strategies.

To evaluate the potential reduction in fine-sediment loads emanating from streambanks, it is necessary to analyze the discrete processes that control streambank erosion under existing and mitigated conditions. These processes include hydraulic erosion of bank-toe sediments, mass failure of upper-bank materials and the reinforcing effects of vegetation, if present. All of these processes can be modeled using the Bank-Stability and Toe-Erosion Model (BSTEM) (Simon et al., 2000). The model has been used successfully in the Tahoe Basin to predict the influence of riparian vegetation on streambank stability (Simon et al., 2006).

2. OBJECTIVES AND STUDY APPROACH

The primary objective was to quantify potential reductions in fine-sediment loads from streambank erosion by: (1) Selecting critical erosion sites within watersheds known to produce substantial quantities of fine sediment from streambank-erosion processes; (2) Quantifying annual loads from streambank erosion for existing conditions at these sites by simulating toe-erosion and bank-stability processes with BSTEM over the course of an annual hydrograph; (3) Repeating the simulations for mitigated conditions; and (4) Comparing load reductions for the modeled sites and by extrapolating results to the remainder of the main stem channel.

2.1 Bank Stability and Toe Erosion Model

The original BSTEM model (Simon et al., 2000) allowed for five unique layers, accounted for pore-water pressures on both the saturated and unsaturated parts of the failure plane, and the confining pressure from streamflow. The enhanced BSTEM (Version 4.1) includes a sub-model to predict bank-toe erosion by hydraulic shear. This is based on an excess shear-stress approach that is linked to the geotechnical algorithms. Complex geometries resulting from bank-toe erosion are used as the new input geometry for the bank-stability sub-model. If a failure is simulated, that new bank geometry can be exported back into either sub-model to simulate conditions over time by running the sub-models iteratively with different flow and water-table conditions. Version 4.1 allows the user to select between cantilever and planar-failure modes and allows for inclusion of the mechanical, reinforcing effects of riparian vegetation (Simon and Collison, 2002; Micheli and Kirchner, 2002; Pollen and Simon 2005).

2.1.1 Bank-Toe Erosion Sub-Model.

The bank-toe erosion sub-model can be used to estimate erosion of bank and bank-toe materials by hydraulic shear stress. The effects of toe protection can also be incorporated. The model calculates an average boundary shear stress operating on individual bank nodes from channel geometry and flow parameters using a rectangular-shaped hydrograph. The hydrograph is defined by flow depth and flow duration. The bed elevation is fixed because the model does not incorporate, in any way, the simulation of sediment transport.

2.1.2 Bank Stability Sub-Model.

The bank stability sub-model combines three limit equilibrium-methods to calculate a Factor of Safety (F_s) for multi-layered streambanks. The methods simulated are horizontal layers (Simon et al., 2000), vertical slices for failures with a tension crack (Morgenstern and Price, 1965) and cantilever failures (Thorne and Tovey, 1981). This version (4.1) of the model assumes hydrostatic conditions below the water table, and a linear interpolation of matric suction above. The reinforcing effect of riparian vegetation was accounted for where applicable. This was achieved by adding cohesion to certain bank layers to simulate the effect of root-reinforcement on streambank stability. Root-reinforcement estimates were obtained using the RipRoot model (Pollen and Simon, 2005), which takes into account a distribution of different diameter roots, with corresponding tensile strengths determined for each species, acting over a failure plane. RipRoot estimates the reinforcement provided by roots crossing the shear plane, based on an algorithm that allows progressive loading of the streambank, breaking of roots and associated redistribution of stresses as root breakage or pullout occurs.

2.2 Site Selection

Critical erosion sites were selected (Tab. 1) from the three watersheds known to contribute the greatest amounts of fine sediment by streambank processes (Simon, 2008). Blackwood and Ward Creeks represent steep (0.008-0.03 m/m), coarse-bedded systems where 10-15 m-high terrace slopes sporadically abut the channel. The Upper Truckee River study reaches represent flatter (0.002 m/m) sections that meander through grassed meadows.

Table 1 - General site characteristics for modeled streambanks.

Stream	Location (km)	Bank height (m)	Special characteristics
Blackwood Creek	1.94	3.0	No top-bank vegetation
	2.39	2.4	Lemmon's willow (moderate)
Upper Truckee River	4.51	2.6	Meadow vegetation
	8.45	1.9	Mixed meadow and woody vegetation
	13.1	2.7	Golf course with Lodgepole pine
Ward Creek	2.48	14.9	14.9 m steep, terrace slope adjacent to channel; coarse material at toe; Mature conifers
	3.60	1.3	Meadow vegetation

2.3 Input Data

BSTEM requires (1) data that quantify the driving and resisting forces for erosion by hydraulic shear and, (2) geotechnical data that define the gravitational forces that control mass failure. Geotechnical and hydraulic-resistance data for the Upper Truckee River and Ward Creek collected as part of an earlier study in 2002 were supplemented with additional data collected along these streams and along Blackwood Creek in 2006. Apparent cohesion (c_a) and friction angle (ϕ') of *in situ* bank sediments were obtained using a borehole shear test device (BST). Bulk unit weight (γ_s) was obtained from core samples of known volume. Pore-water pressure at the time of geotechnical testing was obtained with miniature, digital tensiometers and used to calculate effective cohesion (c'). For cohesionless materials (sands and gravels), critical shear stress (τ_c) was obtained using a Shields-type approach. For cohesive sediments, a submerged jet-test device was employed and provided data on τ_c and the erodibility coefficient (*k*).

2.3.1 Derivation of Hydraulic Data.

To provide for the driving, hydraulic forces, a typical, high-flow annual hydrograph that contained a series of high flow events and a long duration snowmelt period was used. Calendar year 1995 was selected with the addition of the rain-on snow event of January 1, 1997. The recurrence interval of this event was about 35 years for Blackwood and Ward Creeks, and about 56 years for the Upper Truckee River. Stage data from four USGS gauging stations were discretized into individual events to be used as input into the toe-erosion sub-model.

3. ITERATIVE OPERATION OF BSTEM MODEL

The BSTEM model was run in a series of iterative steps until all of the flow events were simulated. For each flow event, the iterative approach entailed:

1. Using the toe-erosion sub model to determine the amount (if any) of hydraulic erosion and the change in geometry in the bank-toe region for the first flow event.
2. Exporting the updated geometry into the bank-stability sub-model to test the relative stability of the bank. Water-table elevation was set to the elevation of the flow in the channel.

If the factor of safety (F_s) was greater than 1.0, geometry was not updated and the next flow event was simulated. If F_s was less than 1.0, failure was simulated and the resulting failure plane became the new bank geometry for simulation of toe erosion for the next flow event. In addition, if the next flow event had an elevation lower than the previous one, the bank-stability sub-model was run again using the new flow elevation while maintaining the higher groundwater level to test for stability under drawdown conditions. A F_s less than 1.0 would simulate failure and the new bank geometry was exported into the toe-erosion sub-model for the next flow event.

The number of mass failures and volumes of sediment erosion by hydraulic and geotechnical processes were noted for each flow event. Values were summed for all events to obtain the amount of erosion under the prevailing conditions. This process was then repeated to simulate the effects of bank-toe protection and vegetation as stabilizing factors. To simulate the effects of bank-toe protection, it was assumed that 0.256 m boulders had been placed from the channel bed to a height of 1.0-1.5 m up the bank toe. Bank-top vegetation was simulated by adding 3.0-23 kPa of cohesion to the upper 0.5 to 1.0 m of the bank. Comparison of the volumes of erosion and the number of mass failures under the different scenarios provided a means of calculating the potential reduction in streambank loads.

4. RESULTS OF BANK-MODEL SIMULATIONS

Model simulations were carried out for the sites listed in Tab. 1 and for the flow events shown in Fig. 1. Example results for the Upper Truckee River at km 13.1 are provided in Tab. 2, showing hydraulic erosion and geotechnical stability for the series of flow events. Under existing conditions at this site, a total of 1288 m3 of material was eroded during 12 periods of hydraulic erosion and 4 mass failure episodes. Toe erosion represented just 7% of the total bank erosion in the reach. Note that where failure was predicted to occur at the peak of a flow event, F_s was commonly higher at the worst-case drawdown scenario as the geometry was more stable. The addition of toe protection virtually eliminated bank steepening by hydraulic erosion at the bank toe and total bank erosion was reduced by about 89% to

137 m^3 over the same period (Tab. 3). This result is further manifest in the reduced frequency of mass failures for each site under the toe-protection scenario (Fig. 1) where failure frequency was either completely eliminated or reduced to a single failure event. In each case this failure event corresponded to the January 1-2, 1997 event. Similar results were obtained for all other paired simulations (Tab. 3). Results from the Ward Creek site at rkm 2.48 are somewhat unique in that they represent a large (14.9 m) terrace where under existing conditions only one failure was simulated. The finding that load reductions of 87% can be realized with added toe protection highlights the important relation between hydraulic erosion at the toe that steepens bank slopes, and subsequent bank instability. Under existing conditions, toe erosion accounted for an average of 13.6% of the total streambank erosion, yet control of that process resulted in a total sediment-load reduction from bank erosion of almost 90%.

Additional load-reduction scenarios were simulated for the Upper Truckee River and Blackwood Creek. On the Upper Truckee River, these included the addition of 16.5 kPa in cohesion from top-bank vegetation for the site at rkm 4.51, and bed-slope reduction of 43% (by channel relocation) for the site at rkm 13.1. A planned slope reduction of about 20% in the vicinity of rkm 1.94 on Blackwood Creek was similarly evaluated. Load reductions of about 53% were simulated for the case on the Upper Truckee River where root reinforcement was provided to the top 1.0 m of the bank. For locations with higher banks, load reductions would probably not be as significant because of the reduced affect of roots on bank strength. Load reductions from the flattening of bed slope and the consequent decrease in boundary shear stresses were 54% and 42% for the Upper Truckee River and Blackwood Creek, respectively.

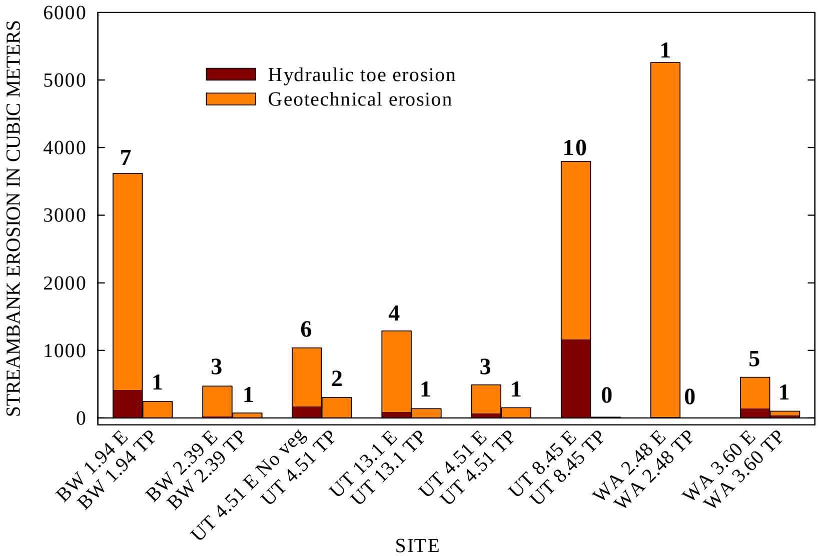

Figure 1 - Simulated volumes of streambank erosion by hydraulic and geotechnical processes assuming a 100 m-long reach under existing conditions (E), and with toe protection (TP). Numbers in bold refer to the frequency of bank failures.

Table 2 - Iterative modeling results for the Upper Truckee River (rkm 13.1) for existing conditions and with toe protection.

A. Existing Conditions (assuming 100m reach)

Event #	Shear stress (Pa)	Toe erosion	Volume (m^3)	FS SW=GW	Failure	Volume (m^3)	FS Drawdown	Failure	Volume (m^3)	Shear emergence (m)	Failure Angle (°)	Total Volume (m^3)	Total fines (m^3)
1	6.57	**Yes**	0.70	1.22	No	0.00	1.21	No	0.00	1912.03	40	0.70	0.13
2	6.32	**Yes**	8.50	0.95	**Yes**	362	-	-	0.00	1911.88	40	371	67.4
3	8.12	**Yes**	1.40	1.56	No	0.00	1.49	No	0.00	1911.91	34	1.40	0.25
4	5.34	**Yes**	0.30	1.47	No	0.00	1.45	No	0.00	1911.88	34	0.30	0.05
5	2.53	**Yes**	0.20	1.29	No	0.00	-	No	0.00	1911.88	34	0.20	0.04
6	7.08	**Yes**	3.50	0.99	**Yes**	194	1.37	No	0.00	1911.88	44/32	198	35.9
7	6.55	**Yes**	0.50	1.48	No	0.00	-	-	0.00	1911.98	32	0.50	0.09
8a	7.89	**Yes**	64.0	0.91	**Yes**	194	-	-	0.00	1911.88	46	258	47.0
8b	7.89	**Yes**	8.70	0.97	**Yes**	185	1.29	No	0.00	1911.88	44.5/32	194	35.3
9	6.46	**Yes**	1.10	1.41	No	0.00	1.35	No	0.00	1911.94	34.5	1.00	0.20
10	3.04	No	0.00	1.51	No	0.00	1.49	No	0.00	1911.94	34.5	0.00	0.00
11	3.13	No	0.00	1.50	No	0.00	1.47	No	0.00	1911.94	34.5	0.00	0.00
12	5.18	**Yes**	0.00	1.35	No	0.00	1.28	No	0.00	1911.91	34.5	0.00	0.00
1/1/1997	13.8	**Yes**	1.60	1.03	No	0.00	0.35	**Yes**	262	1911.88	34.5	264	48.0
TOTALS		**12**	**90.5**		**3**	**935**		**1**	**262**			**1288**	**234**

B. Toe Protection (assuming 100 m reach)

Event #	Shear stress (Pa)	Toe erosion	Volume (m^3)	FS SW=GW	Failure	Volume (m^3)	FS Drawdown	Failure	Volume (m^3)	Shear emergence (m)	Failure Angle (°)	Total Volume (m^3)	Total fines (m^3)
1	6.57	No	0.00	1.41	No	0.00	1.40	No	0.00	1912.10	40	0.00	0.00
2	6.32	No	0.00	1.44	No	0.00	-	-	0.00	1912.10	40	0.00	0.00
3	8.12	No	0.00	1.31	No	0.00	1.25	No	0.00	1912.10	40	0.00	0.00
4	5.34	No	0.00	1.36	No	0.00	1.34	No	0.00	1912.10	40	0.00	0.00
5	2.53	No	0.00	1.38	No	0.00	-	-	0.00	1912.10	40	0.00	0.00
6	7.08	No	0.00	1.27	No	0.00	1.19	No	0.00	1912.10	40	0.00	0.00
7	6.55	No	0.00	1.33	No	0.00	-	-	0.00	1912.10	40	0.00	0.00
8	7.89	No	0.00	1.26	No	0.00	1.13	No	0.00	1912.10	40	0.00	0.00
9	6.46	No	0.00	1.34	No	0.00	1.30	No	0.00	1912.10	40	0.00	0.00
10	3.04	No	0.00	1.45	No	0.00	-	-	0.00	1912.10	40	0.00	0.00
11	3.13	No	0.00	1.44	No	0.00	1.43	No	0.00	1912.10	40	0.00	0.00
12	5.18	No	0.00	1.36	No	0.00	1.32	No	0.00	1912.10	40	0.00	0.00
1/1/1997	13.8	**Yes**	0.10	1.19	No	0.00	0.28	**Yes**	137	1912.10	40	137	25.0
TOTALS		**1**	**0.1**		**0**	**0.0**		**1**	**137**			**137**	**25.0**

Table 3 – Summary of iterative modelling results for existing conditions and with protection.

River	Rkm	Condition	Toe Erosion	Failure Erosion	Toe Erosion	Failure events	Total Erosion	Load reduction	
			m^3	m^3	%	#	m^3	m^3	%
Blackwood	1.94	Existing	418	3199	11.6	7	3617	3373	93.3
Blackwood	1.94	Toe Protection	0	244	0.0	1	244		
Blackwood	2.39	Existing	26.7	445	5.7	3	472	398	84.3
Blackwood	2.39	Toe Protection	0	74.0	0.0	1	74.0		
Upper Truckee	4.51	Existing, No Vegetation	171	866	16.5	6	1037	733	70.7
Upper Truckee	4.51	Toe Protection	0.01	304	0.0	2	304		
Upper Truckee	13.1	Existing	90.5	1197	7.0	4	1288	1151	89.4
Upper Truckee	13.1	Toe Protection	0.10	137	0.07	1	137		
Upper Truckee	4.51	Existing-Veg	66	424	13.5	3	490	336	68.6
Upper Truckee	4.51	Toe Protection-Veg	0	154	0.0	1	154		
Upper Truckee	8.45	Existing	1161	2633	30.6	10	3794	3792	99.9
Upper Truckee	8.45	Toe Protection	2.2	0	100	0	2.2		
Ward	2.48	Existing-No Toe Slope	14.2	5242	0.3	1	5256	5256	100.0
Ward	2.48	Toe Protection-No Toe Slope	0	0	0.0	0	0		
Ward	3.6	Exisitng	143	461	23.7	5	604	502	83.1
Ward	3.6	Toe Protection	36	66	35.3	1	102		

5. APPLICATION AND EXTRAPOLATION OF RESULTS

To obtain an estimate of the total load reduction that could be anticipated for each stream, modelled results were combined with observations of the longitudinal extent of recent bank failures along the main-stem lengths of each stream. The longitudinal fraction of banks experiencing recent failures was noted for each bank in a reach and expressed as one of five percentage ranges (0-10%, 11-25%, 26-50%, 51-75%, 76-100%) (Tab. 4). The midpoint of the range for each bank (left and right) was used to determine a local mean failure extent. This was then classified as low, moderate or high to apply different unit loadings along each stream. Unit loads associated with each class were selected by comparing bank-derived sediment volumes estimated by the numerical simulations with the observed failure extents. For reaches classified as low, a load an order of magnitude lower than the moderate value was used. Unit loads for each reach were multiplied by a weighting factor representing the total length of banks (left and right) that had recently failed and summed for all reaches to obtain total streambank-derived loads for the stream. Fine-grained loadings for each reach were calculated using the measured percentage of fines (<0.063mm) for the site. Tab. 4 shows a worked example for Blackwood Creek.

5.1 Amount and Cost of Load Reduction

To address potential management scenarios for fine-grained load reduction by toe protection, three options were considered which included treating all reaches (All), treating only those reaches eroding at high rates (H), and treating only those reaches eroding at high and moderate rates (H+M) (Tab. 5). A cost for rock placement of $984 per meter was used as the cost basis (obtained from local sources) that was then multiplied by the length of reach represented by each treatment option. A median load reduction of 86.8% was used to determine the cost per metric tonne of load reduction. Total load reductions ranged from 33% to 87% depending on the treatment option (length treated). The unit cost (in \$/T) of performing this type of rehabilitation similarly varied from \$267/T to almost \$2,500/T (Tab. 5).

Table 4 – Example calculation of total streambank loads for Blackwood Creek. Results of RGAs (columns 2 to 3) permitted a mean percentage of each reach experiencing bank failures to be estimated. The mean of consecutive failure was multiplied by the reach length to estimate the weighting factor. Fine-grained loads were determined by multiplying the fraction of fines in each reach by the estimated total load. Colour coding refers to high (36.170 m^3/km), moderate (4.720 m^3/km), and low (427 m^3/km) streambank derived unit loads calculated from data in Tab. 3.

Distance (km)	Extent of failures (%)			Reach length (km)	Reach failing (%)	Weighting factor	Total volume (m^3)	Fraction <0.063 mm (%)	Fines volume (m^3)
	Left	Right	Mean	1	2	(1)*(2)/100			
8.29	0-10	0-10	5.0	-	-	-	-	-	-
8.19	0-10	26-50	21.5	0.10	13.25	0.0133	62.5	5.8	3.6
7.69	11-25	11-25	18.0	0.50	19.75	0.0987	46.6	0.00	0.00
7.18	11-25	11-25	18.0	0.51	18	0.0918	43.3	26.0	11.3
7.17	11-25	76-100	53.0	0.01	35.5	0.0035	128	26.0	33.4
6.84	0-10	11-25	11.5	0.33	32.25	0.1064	50.2	26.6	13.4
6.51	0-10	51-75	34.0	0.33	22.75	0.0751	354	22.1	78.3
6.03	0-10	26-50	21.5	0.48	27.75	0.1332	629	20.0	125.7
5.55	0-10	26-50	21.5	0.48	21.5	0.1032	487	7.9	38.5
5.08	0-10	51-75	34.0	0.47	27.75	0.1304	616	23.5	144.7
4.15	26-50	11-25	25.5	0.93	29.75	0.2767	1306	3.6	47.0
3.95	0-10	76-100	46.5	0.20	36	0.0720	2604	21.4	557.3
2.80	51-75	0-10	34.0	1.15	40.25	0.4629	2185	12.3	268.7
1.97	26-50	11-25	25.5	0.83	29.75	0.2469	1165	24.8	289
1.77	11-25	51-75	40.5	0.20	33	0.0660	2387	16.6	396.3
0.32	51-75	0-10	34.0	1.45	37.25	0.5401	2549	16.3	415.6
0.00	26-50	26-50	38.0	0.32	36	0.1152	544	16.3	88.6

Table 5 – Loads and costs for performing bank-toe protection assuming a unit cost of \$984/m for placement of stone at the bank toe. H+M refers to reaches designated as high and moderate.

Stream	Loads (T)				Total Cost (\$)			Unit Cost ($/T of Load Reduction)		
	Existing	Toe Protection			Toe Protection					
		All	H + M	H	All	H + M	H	All	H + M	H
Blackwood Creek	4432	585	623	2920	8,159,449	6,840,551	403,543	2,121	1,796	267
Load reduction (%)		**86.8**	**85.9**	**34.1**						
Upper Truckee River	5691	751	914	3789	20,911,417	10,735,138	2,601,378	4,233	2,247	1,368
Load reduction (%)		**86.8**	**83.9**	**33.4**						
Ward Creek	2956	390	451	910	6,358,661	3,120,669	1,731,594	2,478	1,246	846
Load reduction (%)		**86.8**	**84.7**	**69.2**						
Totals	**13079**				**35,429,527**	**20,696,358**	**4,736,515**			

6. SUMMARY AND CONCLUSIONS

Under existing conditions, total streambank erosion by hydraulic and geotechnical processes ranged from 472 m^3 to 5260 m^3. On average, 13.6 % of the material was eroded by hydraulic shear, the remainder by mass failures, which occurred about 5 times over the simulation period. The iterative simulations with 1.0 m-high rock-toe protection showed a dramatic reduction in mean, total and fine-grained streambank erosion (87 %). Failure frequency for the simulation period was reduced in most cases to a single episode. Thus, an almost 90 % reduction in streambank loads was realized by virtually eliminating the erosion of only 14 % of the material that was entrained by hydraulic forces. As a consequence, simulations show mean load reductions of about an order of magnitude. Results stress the critical importance of protecting the bank toe from steepening by hydraulic forces that would otherwise entrain previously-failed and in situ bank materials, thereby allowing the upper bank to flatten (by failure) to a stable slope.

The use of an iterative method for modelling bank stability through a series of storm events has been shown here to be a practical way of assessing volumes of toe erosion and bank erosion through hydraulic scour and mass failure events. This application provides an upper bound of the volume of sediment delivered to the channel by bank-erosion processes but will not provide downstream loading values because sediment delivered from the banks to the channel is not routed by the model.

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CHANNEL ADJUSTMENTS AND SEDIMENT FLUXES IN GRAVEL-BED RIVERS OF NORTH-EASTERN ITALY: IMPLICATIONS FOR RIVER RESTORATION

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ABSTRACT

The aim of this paper is to explore possibilities and limitations of restoring physical processes in gravel-bed rivers in north-eastern Italy. After presenting the current knowledge about channel adjustments and sediment fluxes in such rivers, it is discussed how the understanding of physical processes can be used in restoration.

Rivers in north-eastern Italy, as many other Italian rivers, have undergone remarkable channel adjustments in the last century, and particularly in the last 50-60 years. Narrowing and incision have been the dominant processes during the 20th century, until the 1980s-1990s. Channel width has been reducted of 50-70 % and bed-level has been lowered of 2-3 m on average, but locally up to 8.5 m. A different evolutionary trend has commonly occurred in the last 15-20 years, since channel widening has been the dominant process and aggradation has occurred in several reaches. The gravel mining and channelization works have been the main causes of channel changes, in particular of the main phase of adjustment that took place from the 1950s to the 1980s/1990s, whereas the dams, torrent control works, and reforestation likely had a smaller effect on channel dynamics. Such human interventions have dramatically altered the sediment regime, whereas a significant change of channel-forming discharges has been documented in just one case.

In terms of restoring physical processes, the evolutionary trends show that natural channel recovery is on-going in several reaches over the last 15-20 years. This suggests that allowing and promoting bank erosion could be an effective option to restore sediment fluxes in the study reaches. On the other hand this strategy could not be effective in the medium-long term, implying that sediment management should consider also upstream sediment sources and connectivity along the fluvial system.

Key words: Channel incision, human impact, sediment management

1. INTRODUCTION

Rivers in north-eastern Italy, as many other Italian rivers, have experienced widespread channel adjustments in the last decades, in particular incision and narrowing (Surian, 2006; Surian et al., 2008). These adjustments have been mainly induced by a range of human interventions which have altered fluvial processes, in particular sediment fluxes. Since channel adjustments had several effects on hydraulic, ecological and environmental aspects, restoration is needed to mitigate such effects and to improve the overall functionality of these rivers.

The aim of this paper is to explore possibilities and limitations of restoring physical processes in gravel-bed rivers in north-eastern Italy. The selected rivers were analysed through a range of techniques, specifically analysis of historical maps and aerial photographs with GIS, comparison of topographic surveys (longitudinal profiles and cross-sections), and geomorphological surveys. After presenting the present knowledge about channel adjustments and sediment fluxes in the selected rivers, it is discussed how the understanding of physical processes can be used in restoration. The paper focuses on evolutionary trends of river channels and their causes, which are crucial issues for a sustainable management and restoration of streams that are largely affected by human impact (Downs & Gregory, 2004; Habersack & Piegay, 2008). Moreover, the paper discusses sediment management, specifically the various options that are available to restore sediment fluxes.

2. GENERAL SETTING

The selected streams (Brenta, Piave, Cellina, Tagliamento, and Torre Rivers) are located in north-eastern Italy and drain from the Alps (Fig. 1). Some physiographic and hydrological characteristics of these streams are reported in Tab. 1. The drainage basin areas range from 446 to 3899 km^2 and the river length from 58 to 222 km. As for the discharge regime, there is a significant difference between low and high flows for all streams. This difference has been enhanced by stream regulation which has significantly decreased low flows, but has not altered, in most of the cases, the high flows. The floods are relatively flashy and of high magnitude.

Table 1 – Hydrological and physiographic characteristics of the selected streams. Note: (-) data not available

River	Drainage basin area (km^2)	Length (km)	Basin relief (m)	Precipitation (mm yr^{-1})	Mean annual discharge (m^3 s^{-1})	Largest flood (m^3 s^{-1})
Brenta	1567	174	3079	1390	71	2400
Piave	3899	222	3162	1330	132	5300
Cellina	446	58	2401	1770	-	950
Tagliamento	2580	178	2696	2150	109	4650
Torre	1105	69	1679	2280	-	-

The study reaches, which range in length from 10 km (Cellina) to 49 km (Tagliamento), are those where major channel adjustments occurred over the last 100 years and in most of the cases are located in the piedmont plain. In such reaches, the river channels are generally very wide (some hundred metres) and not confined, or slightly confined. Presently, there is a range of channel morphology, since several reaches exhibit a downstream transition from braided to single thread, but originally the braided configuration was dominant in the study reaches. Channel slope is generally in the range 0.002-0.006, except in the Cellina River where it is about 0.01. River beds are composed of gravels and banks are non-cohesive or composite.

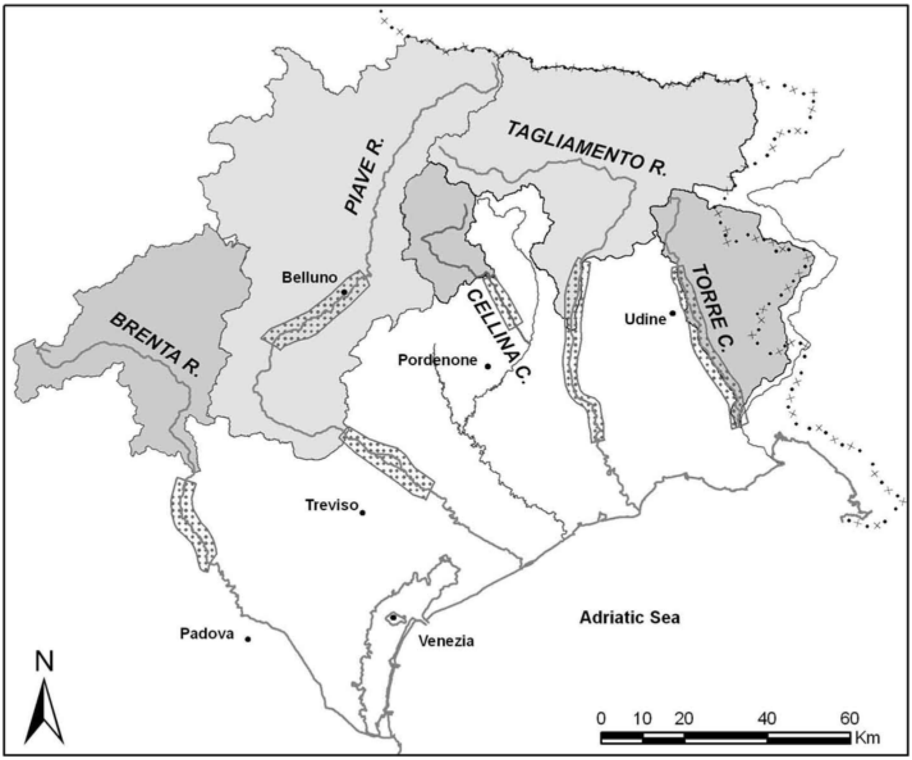

Figure 1 – General location of the selected rivers, showing the study reaches.

3. HUMAN IMPACT ON FLUVIAL SYSTEMS

A range of human impacts (channelization, sediment mining, dams, reforestation) has taken place in the selected streams during the past centuries, and particularly during the last 100 years. These interventions have both direct (e.g. levees and groynes) and indirect (e.g. reforestation) effects on channel dynamics. The chronology of human interventions is quite similar in the selected rivers, although some small differences exist. In most cases channelization started during the 19th century, initially with the construction of levees, then, during the 20th century, also with the construction of groynes and other bank protection structures. Reforestation and torrent control works are not well-documented, but the available data suggest that both interventions generally started in the 1920s-1930s. Reforestation occurred after several centuries of intense logging and it is still on-going. Dams were constructed in 4 out of the 5 streams selected: some were built in the 1930s, but most of the dams during the 1950s. Since then, several millions of cubic metres have been trapped in reservoirs, especially in those river systems with a large impounded drainage area (i.e. Brenta, Piave, and Cellina). Gravel mining was very intense between the 1950s and the 1980s. During relatively short periods of time (20-30 years) large volumes of sediments were removed from the channels, e.g. 8.6 x 10^6 m^3 in the Brenta from 1953 to 1977, 24 x 10^6 m^3 in the Tagliamento from 1970 to 1991, 15 x 10^6 m^3 in the Torre from the 1950s to the 1970s (such values are underestimates, because they come from official data, which do not commonly correspond to the real volumes extracted).

Such interventions altered dramatically the sediment regime, although by different magnitude and timing. A major effect has been produced by gravel mining, which has significantly decreased or ceased in the last 20 years or so. Although several difficulties exist for obtaining reliable bed-load transport calculations, as well as the volume of the sediment extracted, we estimated that when mining was most intense the extraction rates exceeded replenishment rates by ten or more times (e.g. Surian and Cisotto, 2007). The other interventions (e.g. dams, reforestation) likely have a lower, but more extended, effect on sediment regime.

Dams and diversions have markedly reduced low flows, but no reductions have occurred in channel-forming discharges (Surian, 2006; Surian and Cisotto, 2007). Historical trends of maximum annual discharges show that no significant changes occurred in the Brenta, Piave, and Tagliamento, whereas some changes occurred in the case of the Cellina after the construction of a dam in 1954.

4. CHANNEL ADJUSTMENTS AND SEDIMENT FLUXES

The use of historical maps and aerial photographs allowed a detailed analysis of channel width change during the last 200 years (Fig. 2). Since the study reaches are relatively long and not homogeneous in channel morphology, most of the reaches were divided in 2 or 3 sub-reaches. Data from the various sub-reaches clearly show that channel narrowing was the dominant process, but also that changes occurred at similar times (Fig. 2). Four phase of channel width changes were identified: i) a first phase (about the 19th century) characterised by relatively small changes and by the absence of a dominant process (i.e. channel widening or narrowing); ii) a second phase (first half of the 20th century) with dominant channel narrowing, which varied from 9 % (lower reach of the Tagliamento) to 42 % (upper reach of the Piave); iii) a major phase of channel narrowing, from the 1950s to the 1980s/1990s, with width reduction varying from 25 % to 59 %; iv) a recent phase, last 15-20 years, with dominant channel widening. It is worth noting that the total width reduction at the end of the narrowing phase, in the 1980s/1990s, varied from 49 % (middle reach of the Tagliamento) to 73 % (lower reach of the Piave and Torre), whereas the following widening ranged from 1% to 20 %.

In terms of bed-level changes, the available topographic data and geomorphological surveys allowed to identify two phases in most of the selected reaches: a first phase of incision followed by a phase with rivers exhibiting equilibrium or sedimentation. Incision, which was likely associated with the major phase of channel narrowing, was commonly from 2 m to 4 m, but up to 8.5 m in the lower reach of the Brenta. During the last 15-20 years most reaches have shown equilibrium or sedimentation, but most of the channels are still incised since recent sedimentation has seldom exceeded previous incision in magnitude.

The channel adjustments that occurred over the last 100 years have produced significant changes in the channel configuration of the selected reaches. Some reaches have retained a braiding morphology, even if with much lower braiding intensity, whereas in other reaches a change from braiding to wandering or single thread has taken place.

As mentioned before, alteration of sediment fluxes has been the main effect of human interventions and can be considered the main factor that has driven channel adjustments. In all the selected reaches an alteration of sediment fluxes occurred, due to in-channel mining, and, in some reaches, to dams or other upstream factors (e.g. torrent control works in the drainage basin). A quantitative analysis of sediment transport and sources was carried out only for the Brenta River (Surian & Cisotto, 2007). In this case it was estimated that local erosion, in particular bank erosion, was the main source of sediments for bedload transport in the period 1984-1997. The amount of gravels coming from the banks was estimated as 110000 $m^3\ yr^{-1}$, being from 9 up to 20 times higher than upstream contribution. This analysis suggests that the major phase of incision along the Brenta, from the 1950s to 1980s, was due to sediment mining within the study reach and to a low sediment supply from upstream, whereas the recent phase of sedimentation is strictly connected with channel widening, bank erosion being the main source of bedload transport.

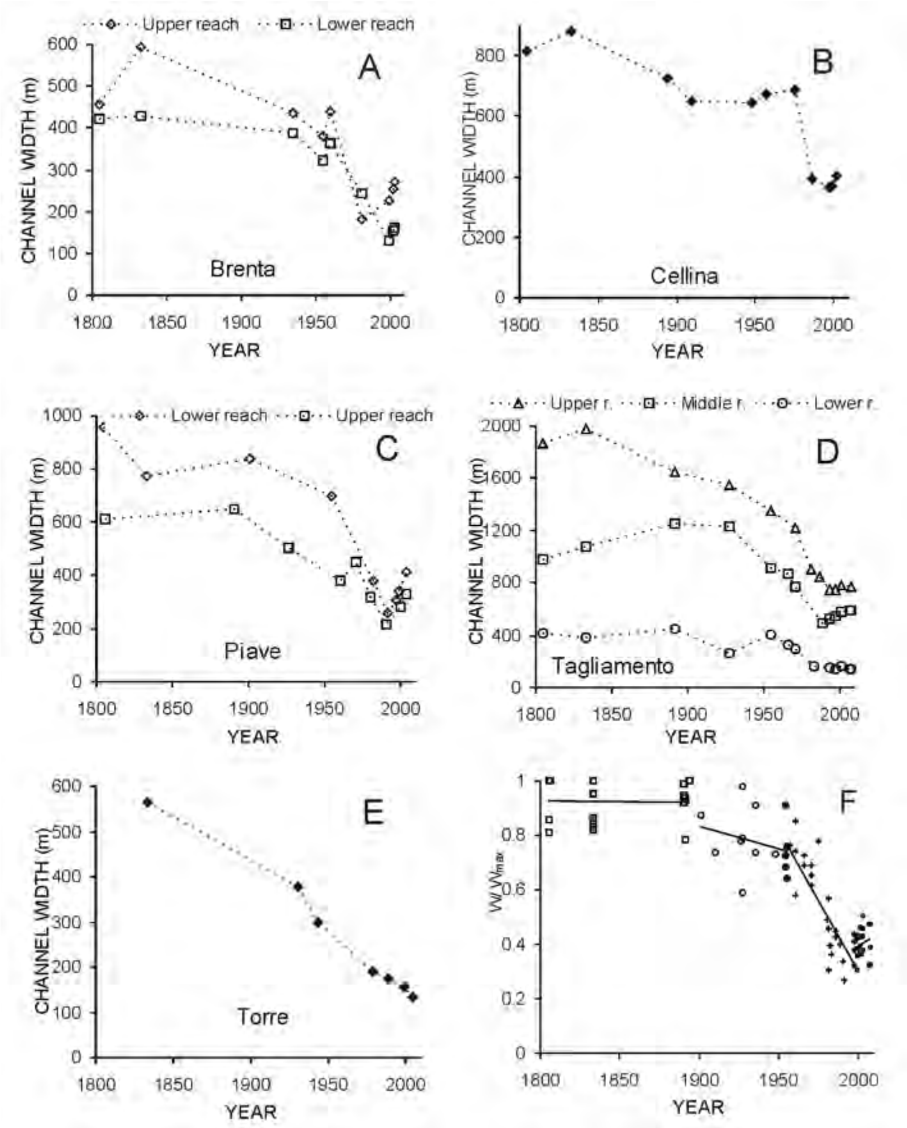

Figure 2 – Changes in channel width over the last 200 years in the selected rivers (A-E); an overall analysis is shown in the last graph (F), where the width is represented by the ratio "W/W_{max}", W is the width measured in the different years and W_{max} the maximum width in the study period, for each sub-reach.

5. IMPLICATION FOR RIVER RESTORATION AND MANAGEMENT OF SEDIMENT FLUXES

The channel adjustments described in this study had several effects on structures, environment and floods. As regards structures, for instance, two bridges failed along the Brenta during the 1970s and several bridges were severely undermined along the Torre. As regards environment, two aspects that are affected by channel adjustments are groundwater resources and aquatic and riparian ecology. Finally, channel adjustments have a significant effect on floods, since channel narrowing and incision cause a faster flood conveyance and, therefore, an increase of flood hazard in the downstream reaches where river channels are narrower and less steep than in the braided reaches. There is therefore a need to mitigate these negative effects in the selected rivers using a range of management/restoration approaches.

For setting restoration goals it is worth avoiding the identification of a reference state (Kondolf et al., 2007), that corresponds to pristine condition which hardly can be defined in fluvial systems with a long history of human impact. Instead, it would be useful to restore geomorphic processes having in mind mitigation of the different effects induced by channel adjustments, which does not imply restoring the channel morphology and processes of the beginning of the 20th century, i.e. before major adjustments. For instance, two goals could be: i) stopping channel incision if it is still on-going in some reaches, and ii) promoting channel widening, especially where a notable change of configuration took place.

Considering that channel adjustment is driven by the imbalance between driving (stream power) and resisting forces (sediment supply and material size), sediment management will be the key issue to reach equilibrium conditions. Besides, removing some bank protections could be another option to facilitate channel recovery.

Though the selected rivers underwent similar channel changes some differences do exist, especially for the most recent changes. Three reach typologies may be defined: the reaches where sedimentation is on-going (e.g. the lower reach of the Brenta, the upper reach of the Piave), those in equilibrium (middle and lower reach of the Tagliamento) and incising reaches. No intervention, corresponding to a natural recovery, could be the strategy adopted for those reaches that are aggrading at present. This strategy could be worth in the short-term but it could result not effective in the medium-long term since imbalance could take place once bank erosion could not keep going. In these cases, as for the Brenta, it is likely that interventions at basin scale will be required. In those reaches close to equilibrium it could be considered the option of removing some bank protection if sedimentation will improve the state of the channel and related environment. Finally, more efforts would be required to restore the incising reaches (likely some reaches of the Cellina and Torre), with intervention at reach and basin scale. In any case, the analysis of sediment sources and connectivity for all the selected rivers will be crucial. In the medium-long term it will be important to increase the upstream sediment supply and connectivity, since supply from banks could not last for a long period.

6. CONCLUSIONS

Gravel-bed rivers in north-eastern Italy underwent notable channel adjustments in the last 100 years, specifically narrowing, up to 73 %, and incision, up to 8.5 m. The evolutionary trends show that natural channel recovery is on-going, since widening and aggradation have occurred in several reaches over the last 15-20 years. This suggests that allowing and promoting (e.g. removing some protections) bank erosion could be an effective option to restore the physical processes, specifically sediment fluxes, in the study reaches. On the other hand this strategy could not be effective in the medium-long term, implying that sediment management should consider also upstream sediment sources and connectivity along the fluvial system.

ACKNOWLEDGEMENTS

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RESTORING GEOMORPHOLOGICAL AND ECOLOGICAL PROCESSES IN INCISED RIVERS IN THE NORTHERN APENNINE (ITALY): PROBLEMS, CRITERIA AND APPROACHES

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ABSTRACT

Incised and degraded rivers pose a series of problems and challenges for their restoration and management. It is increasingly recognised that the geomorphic aspects assume a key role, particularly in projects with the main objective of restoring or promoting a more natural form and dynamic of the river.
In this paper, we present a brief overview of a series of research projects (Ombrone and Pesa Streams in the Arno River catchment; Vara, Magra and Panaro Rivers) aimed to propose strategies conciliating flood risk and restoration objectives.

All case studies are affected by similar problems, related for many aspects to a common morphological evolution of the channel. A strong human impact, due to a period of very intensive sediment mining and to many other disturbances and interventions (land use changes, dams, weirs, bank protections, etc.), is responsible for: (a) channel bed incision of variable intensity, but always very significant, and persistent conditions of sediment deficit; (b) progressive channel narrowing, related to the reduction in sediment transport and to bed lowering, and in some cases directly associated with artificial interventions. The physical degradation of these rivers has many negative consequences on habitats and ecosystems.

The proposed strategies of management and restoration take into account the past channel evolution, and are compatible with the present trends of channel adjustments. In particular, the option of promoting channel recovery rather than morphological reconstruction is identified as the best strategy, being sediment load and stream power of these rivers sufficiently high.

Key words: incised channels, geomorphic processes, geomorphic recovery

1. INTRODUCTION

River restoration requires an interdisciplinary approach that can involve a series of expertises and disciplines, whose relative importance varies according to the objectives of the project. It is increasingly recognised that in projects with the main objective of restoring or promoting a more natural form and dynamics of the river, the geomorphic aspects assume a key role. In fact, the comprehension of the physical and biological processes represents the basis of any restoration intervention attempting to act on the causes, rather than on the symptoms of the problem. The importance of the interaction among geomorphic and ecological aspects is confirmed by the Water Framework Directive, where the hydro-geomorphological aspects assume a relevant role.

In this paper, we present a brief overview of methodologies for assessing geomorphic problems, and approaches for restoring geomorphic processes in a context, the Northern Apennine (Italy), where most of the rivers are seriously impacted and physically degraded. This overview is based on a series of case studies (Ombrone and Pesa Rivers in the Arno River catchment; Vara, Magra and Panaro Rivers) associated to research projects carried out during the last years and aimed to propose strategies conciliating flood risk and restoration objectives. The overview has also the scope to highlight the typical problems which arise when attempting to restore heavily impacted and degraded rivers, in an extremely urbanised context such as Italy, and to discuss possible strategies used in other countries having similar problems (i.e. Habersack & Piégay, 2008).

2. CASE STUDIES AND PROBLEMS

A series of research projects, aimed to propose strategies for recovering the geomorphic and ecological functioning, are shortly presented (Tab. 1). These projects concern rivers located within the northern Apennine, in areas with relatively similar physical and hydro-climatic conditions.

Although all the projects are characterised by similar aims (recovery or improvement of morphological and ecological functioning), they differ in the specific objectives, as well as in the length of the study reaches and therefore the different level of detail. Two projects (Ombrone R. and Pesa R.) were directly related to the design of retention basins; therefore the main objective was to propose solutions which would conciliate hydraulic safety and river restoration. Other two projects (Vara R. and Panaro R.) were aimed to propose interventions for river restoration, independently from flood risk objectives. Lastly, the Magra – Vara R. project was aimed to the definition of strategies for sediment management, rather than to river restoration interventions.

From a geomorphological perspective, all the case studies, although with some difference, are characterised by common problems, related to a similar channel evolution. The strong human impact, related mainly to the past intense in-channel gravel mining, resulted in: (a) channel incision and deficit of sediment transport; (b) progressive channel narrowing, related to the bed-level lowering and to previous and recent interventions of channelization and bank stabilization.

Table 1 – Summary of case studies aimed to the recovery of geomorphological and ecological functioning. N: number of project; L: length of study reach (km); A: catchment drainage area (km^2).

N	River	L	A	Aims and objectives of the project
1	Vara R.	6	570	Definition of strategies of river management and intervention compatible with trends of channel adjustments
2	Magra R. – Vara R.	50-45	1698	Definition of guidelines for management of sediments and river corridor
3	Panaro R.	34	1780	Restoration of the physical and ecological processes in the river channel and its corridor
4	Pesa R.	25	399	Identification of options and solutions achieving a defined level of flood risk reduction by a system of off-stream retention basins, and in the same time promoting river restoration
5	Ombrone R.	7	489	Evaluation of compatibility of retention basins for flood risk reduction with geomorphological and ecological functioning of the river

3. METHODS AND MAIN RESULTS

A similar methodology was applied to all the case studies, although the some details were different, depending on the specific problems of each case study and the objectives of the project. The general approach used the knowledge of past channel evolution, and the assessment of present trends of adjustments, as basis for the definition of strategies and interventions acting towards the recovery of physical processes. The methodology included the following phases:

(1) Assessment of the general setting of the watershed (geological, hydrological, and climatic conditions, land-use) and classification of the river in relatively homogeneous reaches and sub-reaches reflecting the major structural controls (direction and confinement of the alluvial valley floor), and the different channel morphologies.

(2) Analysis of channel changes. Most of the available maps and aerial photos were acquired and analysed in GIS, with the aim to allow for comparisons and measurements of the planimetric parameters (channel

width, sinuosity, braiding index). Then, the bed-level changes were reconstructed through comparison of topographic surveys of different years..
(3) Field surveys. A series of sheet forms for geomorphological field survey were developed and applied to the case studies with particular focus on the interpretation and classification of channel adjustments.
(4) Quantification of bedload and sediment budgets. An evaluation of sediment transport was carried out for some of the rivers (Ombrone, Vara, Magra), particularly for those projects aimed to sediment management (Magra project: see Rinaldi et al., this volume).

Combined with the geomorphological analysis, the ecological aspects were subsequently studied in detail, including the analysis of riparian vegetation, macroinvertebrates, aquatic and riparian habitats and diversity, fish fauna, water quality. This integrated approach allowed to assess the stream conditions, to identify problems and assets, and to better understand the interactions between geomorphic and ecological problems.

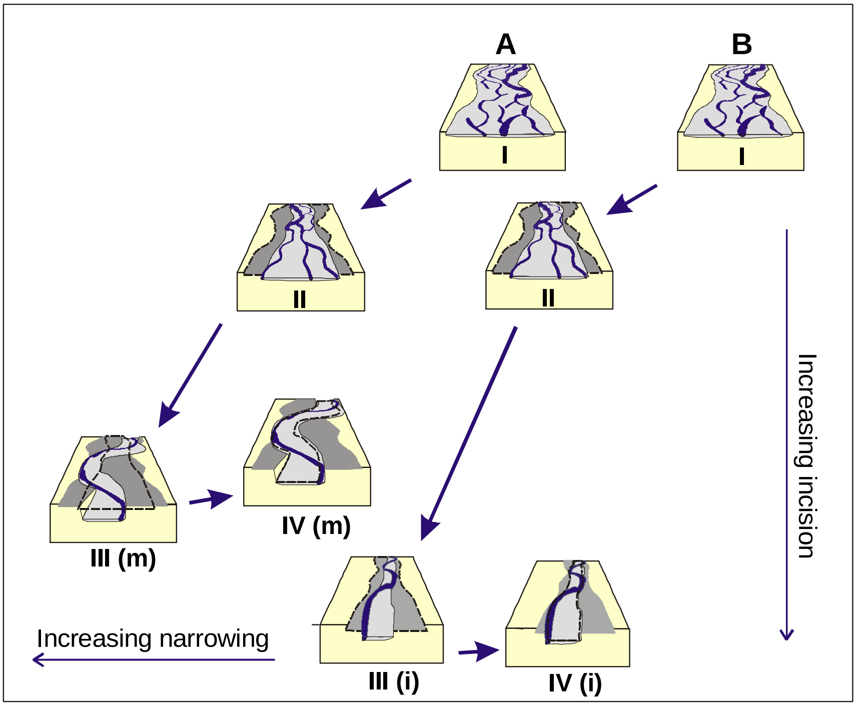

Figure 1 – Model of channel evolution summarizing the types of channel adjustment for the investigated rivers (modified from Rinaldi et al., 2008). A) Cases of moderate (m) channel incision and narrowing (Vara and upper-medium Magra); B) cases of intense (i) incision and narrowing (Panaro and lower Magra).

The results of the geomorphological analysis highlighted similar problems for all the case studies, summarized as follows: (1) all investigated rivers have been affected by channel bed incision, with the highest bed-level lowering (up to 7-10 m) recorded along the Panaro River and the lower part of the Magra River; (2) similarly, all investigated rivers have been affected by channel narrowing, as recently observed in most of the Italian alluvial rivers (Rinaldi, 2003; Surian & Rinaldi, 2003); (3) two phases of channel adjustment (incision – narrowing) can be distinguished, with the phase of major changes occurring between the 50's and the beginning of the '90s; (4) such changes appear strongly connected to human factors, with quite evident causes-effects relationships, and with the highest changes occurred along the rivers with strong human impact; (5) an inversion of trend of channel width is observed in some case during the last 10-15 years, (widening phase), coupled with local aggradation (Surian & Rinaldi, 2004; Rinaldi et al., 2005). The channel evolution model derived from the main investigated rivers (Magra, Vara, and Panaro Rivers) and reported in Fig. 1 is useful to summarise the main phases of channel adjustments (Rinaldi et al., 2008).

These geomorphic adjustments, combined with the heavy human control, produced various negative consequences, such as the impoverishment and loss of physical habitats, loss of groundwater resources and the resulting effects on riparian vegetation, etc.

4. PROPOSED STRATEGIES FOR RIVER RESTORATION

The definition of restoration strategies was driven by a series of basic principles, including the following:

(1) discard the idea of a "natural" reference state. The concepts of 'vision' and 'reference state' are extremely difficult to be applied when we deal with restoring geomorphic processes. In particular, the concept of restoring 'pristine' conditions is actually inapplicable in countries such as Italy (as well as other European countries), where the human impacts on the fluvial systems begun already in the Roman Period.

(2) Dynamic equilibrium as a possible 'guiding image'. As an alternative to 'natural reference state', a 'guiding image' can be developed based on historical data and theoretical models (Palmer et al., 2005). Definition of such a 'guiding image' is important to define clear restoration objectives and select appropriate restoration measures. The guiding image' of an 'ecologically dynamic state' (Palmer et al., 2005) corresponds to the concept of 'dynamic equilibrium' in geomorphology.

(3) The knowledge of past channel adjustments and present trends is essential. In those cases where the river is in 'dynamic equilibrium', it is anyhow important to know the historical changes in order to understand the previous channel morphology, the responses to human alterations, and the present trends of adjustment.

Knowledge of the past channel evolution and present trends of adjustment were used as a base for defining management and restoration criteria. In Tab. 2 a classification of geomorphic functioning associated to the different stages of the channel evolution model (Fig. 1) is reported, with the suggested strategies for restoring geomorphic processes and recovering channel forms.

Table 2 – Stages of channel evolution, associated classification of geomorphic functioning, and suggested strategies for restoring geomorphic processes.

Stage of evolution	Geomorphic features	Geomorphic functioning	Restoration priorities and strategies
Stage I	No significant changes; dynamic equilibrium	A. Good level (lateral connectivity, continuity in longitudinal sediment flux)	Preservation of natural processes (possible 'Guiding image')
Stage II	Limited changes; close to dynamic equilibrium	B. Good level (lateral connectivity, continuity in longitudinal sediment flux)	Preserving and/or promoting natural processes (possible 'Guiding image')
Stage III (m)	Moderate changes, still incising and narrowing; disconnected terraces	D. Poor level (lateral disconnection; deficit of sediment; etc.)	Promoting increase in sediment supply
Stage III (i)	Dramatic changes, still incising and narrowing; very disconnected terraces	F. Worst level (dramatic lateral disconnection; persistent deficit of sediment; lack of gravel; bank failures; etc.)	Increasing sediment supply; artificial sediment recharge; in some cases morphological reconstruction
Stage IV (m)	Partial recovery after moderate changes; portions of incipient floodplain	C. Intermediate level (initial recovery; decreasing lateral disconnection and sediment deficit)	Supporting natural recovery (allowing lateral mobility, bed recovery, and floodplain recreation)
Stage IV (i)	Initial recovery after intense changes; local portions of incipient floodplain	E. Very poor level (dramatic lateral disconnection; deficit of sediment but beginning of an inversion of trend)	Promoting natural recovery, in some cases by partial morphological reconstruction

In Tab. 3 a summary of the management and restoration strategies and interventions proposed for the case studies is reported. In most cases, promoting natural channel recovery is suggested as a better strategy, being the sediment load and stream power of the investigated rivers sufficiently high. In the cases of heavily incised rivers (Panaro and lower Magra rivers), the biggest issue is to promote an increased supply of sediments to the incised reaches. In the case of the Magra project (see Rinaldi et al., this volume), an identification of areas suitable for potential sediment recharge was carried out by using a similar methodology to that proposed by Liebault et al. (2001) for the Drome R. in France.

Another important source of sediment is created by bank erosion due to natural channel mobility. To promote natural sediment supply by this process, the 'erodible corridor concept' (Malavoi et al., 1998; Piegay et al., 2005) was widely used (in particular in the Magra – Vara project: Fig. 2). In the case of Ombrone R., lateral mobility is prevented by a series of walls functioning as artificial levees at some distance from the river, and the common maintenance practice is to carry out a periodical clearing and dredging of the channel and to maintain the channel in a fixed position (Fig. 3A). We proposed to apply the 'streamway' concept, leaving a space where channel mobility is allowed, and to protect the walls by bank protection interventions, rather than to fix the channel position.

Table 3 – Summary of main management strategies and proposed restoration interventions aimed to the morphological recovery.

River	Main management strategies and/or proposed restoration interventions
Ombrone R.	Management of bank erosion by creating a mobility corridor within the external embankments. Sediment management: mobilization of sediment from points of local aggradation to local scour. Diversify maintenance procedures for reaches with vegetation and wood. Creation of in-channel structures for habitat improvement.
Vara R.	Management of bank erosion by defining an erodible river corridor. Creation of portions of active floodplain and/or secondary channels.
Pesa R.	Proposal of retention basins with functions different from traditional typologies, such as: (a) delimitation of natural areas devoted to periodical inundation; (b) creation of constructed wetlands (e.g. free flow systems).
Magra R. – Vara R.	Delimitation of an erodible river corridor. Definition of an overall plan of strategies for sediment management.
Panaro R.	Increasing sediment transport by various strategies such as: mobilisation of sediments upstream of weirs; local recreation of floodplain and secondary channels and reintroduction of coarse sediments; allowing and/or promoting bank erosion.

Among the investigated rivers, the Panaro R. was the worst case in terms of physical and ecological degradation. The extremely high bed incision (up to 10 m) caused the loss of the entire thickness of alluvial deposits in some reaches and the incision of the bed into the underlying clay substratum (Fig. 4B). Sediment recovery of the channel bed is extremely complex, due to a persistent deficit of sediments, discontinuous bedload flow, scarcity of sediment sources, ongoing gravel mining, and existence of several weirs. Many ecological problems are strictly related to physical degradation, such as loss of habitats, particularly along the reaches incised into the clay substrate, interruption of lateral continuity of ecosystems, lowering of the water table with consequences on riparian vegetation. For such conditions, a series of interventions for morphological reconstruction are proposed, I addition to the strategies promoting upstream sediment supply. These interventions are concentrated in the extremely incised reach, and include: (a) channel widening, (b) recreation of an active floodplain by lowering the terrace surface and/or secondary (side) channels. Sediment obtained by the lowering of the terrace and by the excavation of secondary channels are planned to be artificially reintroduced into the river channel to promote sediment recovery.

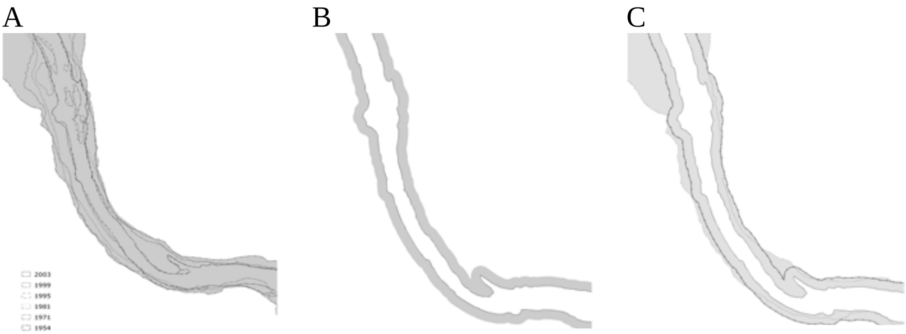

Figure 2 – Application of the Erodible Corridor Concept to the Magra R. A) Corridor of historical channel mobility: for the Magra R. defined as the extent of the channel mobility during the last 50 years; B) Erodible corridor in the next 50 years: possible extent of erosion in the next 50 years based on present mean rates of bank erosion; C) Erodible corridor or 'functional mobility' zone: external limit of the two previous areas.

As regard the Pesa R., the main objective of the project was the proposal of alternative options of off-stream retention basins aimed to a reduction of flood risk and, at the same time, enhancing the environmental conditions of the river corridor. Different typologies of retention basins have been defined, ranging from 'traditional' artificial type only aimed to flood risk reduction, to delimitation of natural areas devoted to be periodically inundated, to more environmental solutions, including the creation of constructed wetlands (e.g. free-flow systems).

A B

Figure 3 – Examples of degraded river conditions in Northern Apennine (Italy). A) Ombrone R.: common practice of channel maintenance by periodic clearing and dredging. B) Panaro R.: channel bed incised into the clay substratum.

5. CONCLUSIONS

A series of research projects (Ombrone and Pesa in the Arno River catchment; Vara, Magra and Panaro R.) were carried out in the last years aimed to assess problems and propose possible strategies for river restoration. Although restoration interventions have not yet been implemented, these projects are useful to provide a general background of possible approaches for restoring geomorphic processes, forms, and associated habitats, of an extremely degraded environment due to serious channel incision and heavy human impacts.

All case studies are affected by similar geomorphic problems, such as channel incision and consequent disconnection of the river from adjacent alluvial plain, channel narrowing, persistent sediment deficit, combined with a heavy human impact. These geomorphic alterations have several negative consequences, such as impoverishment and loss of physical habitats, loss of groundwater resources and consequent effects on riparian vegetation. Restoring geomorphic processes, forms, and associated habitats is extremely difficult in such a context. The research projects identified a series of possible strategies, based on recent experiences in other European countries dealing with incised rivers (Habersack & Piégay, 2008), such as: strategies for increasing sediment supply from hillslopes and tributaries, application of the Erodible Corridor Concept to promote channel mobility and sediment input by bank erosion. In the cases of extremely incised reaches, some intervention of morphological reconstruction were also proposed to accelerate the geomorphic recovery, such as channel widening, recreation of an active floodplain by lowering the terrace surface and/or secondary channels.

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MODELLING SEDIMENT DYNAMICS DUE TO NATURAL REFORESTATION IN THE DRAGONJA CATCHMENT, SW SLOVENIA

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ABSTRACT

Under the influence of socio-economic changes in many regions in Europe, a trend of decreasing agricultural activity has been observed since the Second World War. The resulting reforestation profoundly changed water and sediment supply to river channels, deposition rates on the floodplains and erosion rates on the hillslopes. We studied these changes in the 91 km^2 Dragonja catchment in southwestern Slovenia.

With the spatially distributed erosion and sediment delivery model WATEM/SEDEM, the hillslope sediment delivery to the river channel was calculated on the basis of parameters (soil and precipitation parameters, a DEM and land use) measured in the field and laboratory in 2002 and land-use maps based on aerial photographs from 1954, 1975, 1985 and 1994. For two independent calibrations, WATEM/SEDEM modeled a sharp decline of 69 % in total hillslope sediment delivery from 1954 to 2002.

As the sub-catchments Rokava and Upper-Dragonja were not reforested in the same way, the sediment yield response was different as well. Separate calculations showed the same reduction (45 %) in sediment yield from 1954 to 1975. After 1975 the sediment yield was stable in the Rokava sub-catchment. In the Upper- Dragonja the trend continued, to a total reduction of 76 % of sediment outflow since 1954.
The sources of fine sediment were determined by analyzing the suspended sediment texture. The analysis suggested that during a discharge wave the suspended sediment originates predominantly from the hillslopes. During low stage the sparse sediment in the water column largely originates from large bedrock banks.

Key words: Dragonja, Slovenia, hillslope erosion, land-use change, natural reforestation, WATEM/SEDEM

1. INTRODUCTION

The effects of deforestation and intensification of agriculture on erosion (e.g. Singh, 1999), slope stability (Vanacker et al., 2003) and soil properties (e.g. Varela et al., 2001) have been studied widely. However, the effects of reforestation have received much less attention. Under the influence of socio-economic changes in many regions of Europe, a trend of decreasing agricultural activity exists. This trend induces in catchments either planned reforestation or nature development, or unplanned land abandonment and natural reforestation. This reforestation profoundly changes water and sediment supply to the rivers, the deposition rate on the floodplains and the erosion rate on the valley slopes. As a result, fluvial dynamics and fluvial morphology have changed (e.g. Piégay et al, 2004;

Figure 1 – Location of the Dragonja catchment, southwestern Slovenia.

Keesstra, 2007). Most of these studies qualitatively link the observed changes in land use with the observed changes in fluvial morphology. However, quantitative estimates of changes in water and sediment fluxes are not readily available. The primary aim of this study is to reconstruct the change in sediment dynamics due to the reforestation of the Dragonja catchment based on measurements. Secondly, we aimed to model the sediment dynamics for the period 1954 to 2002 and calibrate the model outcomes with field measurements.

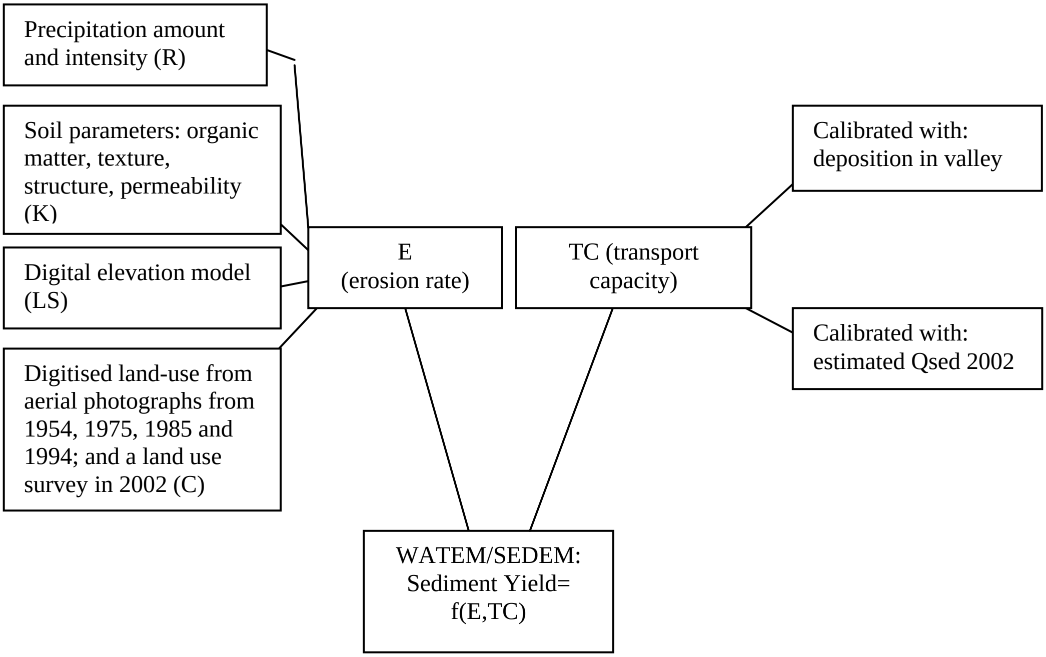

Figure 2 - Schematic diagram of the procedure used in the model.

2. GENERAL SETTING

The Dragonja catchment is situated in the southwestern part of Slovenia. The river is 30 km long and the catchment is approximately 91 km^2 (Fig. 1). The elevation of the drainage basin ranges from 400 m at the headwaters to sea level at the river mouth. The Dragonja flows into the Adriatic Sea. The upstream part of the Dragonja River consists of two sub-catchments, the Dragonja (32 km^2) and the Rokava (20 km^2) sub-catchments.

Over the last 55 years, important changes in land-use have occurred. After the Second World War, socio-economic changes in the region caused depopulation. The population dropped from 6000 inhabitants in 1940 to 3000 in 2000, resulting in large-scale abandonment of agricultural fields, which slowly changed into a mature forest (Globevnik, 2001; Keesstra, 2006). After abandonment, these fields gradually reverted to mixed deciduous forest dominated by oak (*Quercus pubescens*), hornbeam (*Carpinus orientalis croaticus*) and ash trees (*Fraxinus ornus*) (Keesstra, 2006). Due to natural reforestation occurred from 1950 until 1975, the river has narrowed and incised into its former bed creating a terrace, which now stands 1.5 m above the current river. The process of narrowing and incision intensified after 1975 due to an increase of mature forest extension, forming a second terrace that stands 0.5 to 1.0 m above the current river (Keesstra et al., 2005).

3. METHODOLOGY

A schematic diagram of the methodological framework is shown in Fig.2.

3.1 Hydrology and sediment analyis

To obtain the current hydrological and sediment dynamics settings, we intensively monitored the discharge and suspended sediment concentration on the field from October 2000 to September 2004. At the outlets of the two main tributaries, the Rokava and the Upper-Dragonja River (Fig. 1) the water stages were measured every 10 minutes. Suspended sediment samples were taken during 13 flood events, resulting in a total of 178 and 167 processed samples for the Rokava and Upper-Dragonja branches, respectively. At the outlet of the study area (Pod Kaštel, Fig.1) daily discharge was measured by the Slovene Hydrological Survey from 1960 till 2002 (HZM, 2003). Suspended sediment concentrations were derived from 18 samples, which were manually taken during 3 peak events.

The texture of the collected suspended sediment samples was measured. Suspended sediment transport was computed by combining the information on sediment concentrations and discharge. To estimate the annual suspended sediment discharge over the period 1960-2002, the current suspended sediment concentrations were used, together with the daily discharge data measured at the outlet. The land-use was derived from aerial photographs taken in 1954, 1975, 1985 and 1994. The situation for 2002 was mapped during a field survey.

3.2 Model procedure

Changes in erosion and hillslope sediment delivery as a result of land-use changes occurred in the catchment was simulated with the model WATEM/SEDEM (Van Oost et al., 2000; Van Rompaey et al, 2001). The WATEM/SEDEM model requires a transport capacity coefficient (ktc), which varies between different land-use categories (eq. 2). However, this value needs to be calibrated first.

Two independent calibrations were performed: the first calibration was done by comparing the results obtained with model runs conducted using the land-use map of 2002 with the estimated total sediment outflow from the catchment in 2002 (Qsed). A second calibration was performed with the sedimentation rates on the lowest terrace (0.5 m above the current river). Floodplains and low terraces act as a sink of sediment which is (temporary) stored there (cf. Walling, 1996). Many researchers have estimated conveyance losses, i.e. the percentage of sediment that reaches the river channel, but is deposited on a floodplain or terrace. Trimble (1981; 1999) states that 20 to 30% of hillslope sediment delivery is stored in the valleys of the upstream tributaries with catchment areas similar to that of the Dragonja sub-catchments. Also Walling and Quine (1993; 23%), Fryirs and Brierley (2001; 32%), Lambert and Walling (1987; 28%) Verstraeten et al. (subm., 38%) and Walling et al. (1999; 40%) have found percentages of the same order of magnitude.

The amount of sediment deposited in the valleys was derived from coring and geomorphological mapping. The area of the terraces was estimated with the geomorphological mapping. The age of the terraces was known from previous research (Keesstra, 2007).

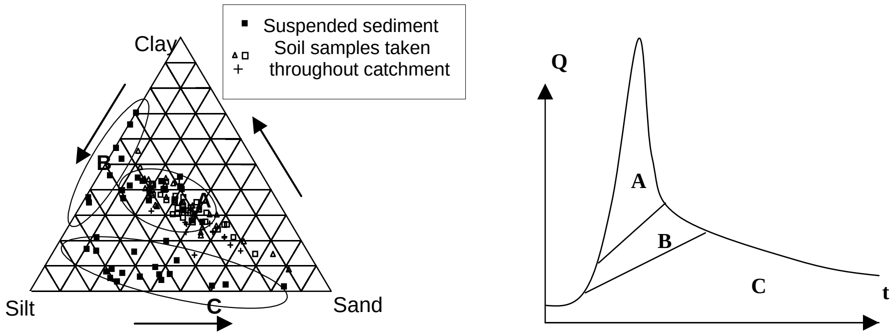

Figure 3 - left -Triplot of the texture of suspended sediment samples superimposed on soil samples taken throughout the catchment. Circles roughly indicate groups of the same texture. Group A represents samples taken during high flow, group B during low flow and group C during falling stage and intermediate flow. Right - Idealised discharge wave with sediment groups indicated by A: undiluted sediment from the hill slopes, with high concentrations of suspended sediment load (SSL). B: sorted (finer) sediment from the hill slopes due to insufficient transport, with intermediate concentrations of SSL. C: Sediment from bedrock banks, with very low concentrations of SSL.

4 RESULTS

4.1 Suspended sediment yield and hydrological parameters

The sediment that leaves the catchment originates from three sources, the hillslopes, the erosional cliffs and the channel (incision and bank erosion).

Analysis of the suspended sediment texture is used to determine the importance of these sources during the discharge wave. The suspended sediment texture was compared with the texture of the soil samples taken throughout the catchment (Fig. 3). When the texture results of the suspended sediment samples are compared to the discharge height during sampling (Fig. 3), the low stage samples predominantly show a fine-grained texture (group B), the high stage samples have a texture similar to the texture of the slopes (group A) and the middle stage samples predominantly have a relative coarse texture (group C) (Fig. 3).

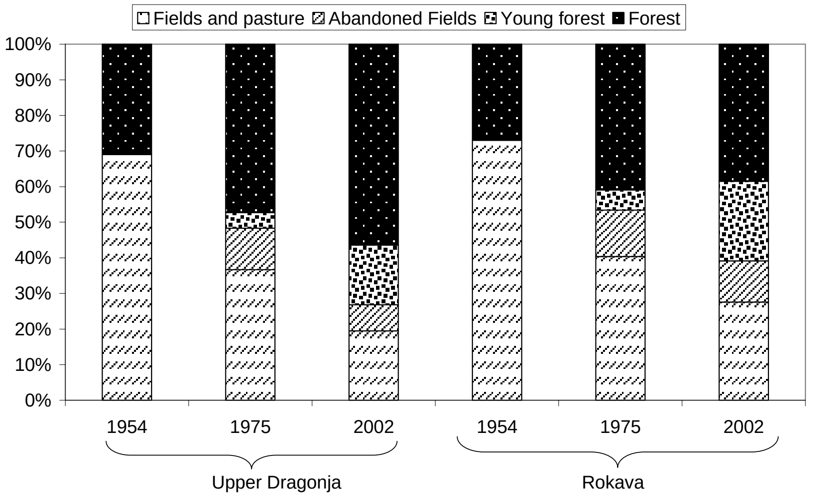

Figure 4 - Land use distributions for the Upper-Dragonja sub-catchment and the Rokava sub-catchment for the years 1954, 1975 and 2002. The catchment area is divided in slope classes as derived from aerial photographs.

The suspended sediment samples were also used to calculate the sediment delivery from the catchment.The estimation of the total sediment discharge at the outlet in 2002 equals 3.3 ton $ha^{-1}y^{-1}$.

4.2 Model results

In 1954 the majority of the two sub-catchments, Upper-Dragonja and Rokava catchment, was used for agriculture. In the Upper-Dragonja catchment only 29% of the area was forested, a large part of which was located on the steepest slopes. In general, the largest change in land use occurred between 1954 and 1975. However, also from 1975 to 1985 a clear decrease of agricultural land occurred. After 1985, land-use did not change much (Fig. 4). Furthermore, important differences exist between the Upper-Dragonja and the Rokava catchment. A large part of the Rokava catchment is still used for agriculture. The reason for this difference is a more favourable geographical position of the Rokava catchment relatively to the coastal cities and a gentler slope.

Table 1 - Results of the WaTEM/SEDEM model runs with several calibrations and for the separate sub-catchments.

Year	1954	1975	1985	1994	2002	Reduction in sediment outflow from 1954 to 2002
Literature conveyance losses: 20% (ton $ha^{-1}y^{-1}$)	32.5	17.6	13.5	14.0	11.2	66 %
Literature conveyance losses: 30% % (ton $ha^{-1}y^{-1}$)	21.2	7.7	6.1	7.0	5.8	72 %
Calibrated with sediment discharge (Qsed) (ton $ha^{-1}y^{-1}$)	10.2	4.3	3.5	4.0	3.3	67 %
Rokava (calibrated with Qsed) (ton $ha^{-1}y^{-1}$)	9.2	5.1	4.7	5.2	4.3	53 %
Dragonja (calibrated with Qsed) (ton $ha^{-1}y^{-1}$)	10.7	3.8	2.7	3.2	2.6	76 %

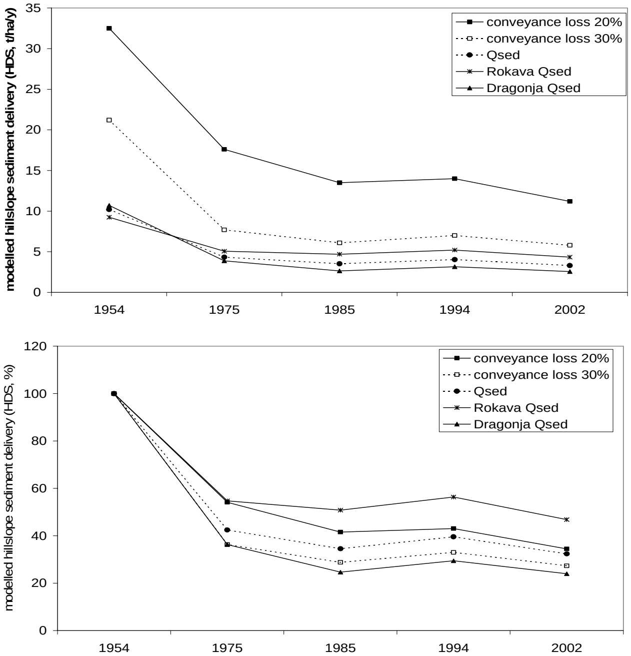

Figure 5 - Absolute (above) and relative (below) decrease in modeled hillslope sediment delivery (HDS) for the different calibration methods: with 20 or 30% of the sediment outflow deposited in the river plain or with estimated sediment discharge at the river outlet (Qsed)) and for the separate sub-catchments Rokava and Upper-Dragonja.

The two independent calibrations were used to estimate the change in hillslope sediment delivery from the catchment over the period 1954-2002 in five time steps: 1954, 1975, 1985, 1994 and 2002. With the conveyance loss calibration (30% of the sediment is deposited in the valley), the hillslope sediment delivery in the Dragonja catchment in 2002 equals 5.8 ton $ha^{-1}y^{-1}$. With the same input parameters hillslope sediment delivery modeled for 1954 is 21.2 ton $ha^{-1}y^{-1}$, which means a reduction of 72 % in hillslope sediment delivery over the period 1954 and 2002. When the calibration is done with the calculated annual sediment discharge in 2002, i.e. 3.3 ton $ha^{-1}y^{-1}$, the hillslope sediment delivery modeled for 1954 is 13.9 ton $ha^{-1}y^{-1}$, representing 76 % reduction, when the yields of 1954 is compared to 2002 (Tab. 1, Fig. 5).

As a result of the used calibrations, the range in hillslope sediment delivery is large. Nevertheless, the relative hillslope sediment delivery reduction is consistent to be around 70 % for all calibrations. Separate calculations for the sub-catchments Rokava and Upper-Dragonja show a reduction of 45 % in the hillslope sediment delivery in the period 1954 to 1975 for the Rokava catchment (Tab. 3). After 1975, the hillslope sediment delivery remained more or less stable. In the Upper-Dragonja the largest change occurred also in 1954-1975. But in this catchment the decrease in sediment outflow continued, with a total reduction of 76 % of the sediment outflow in 1954 (Fig. 5).

5. DISCUSSION AND CONCLUSIONS

In some other catchments in the Mediterranean area the source of the hillslope sediment delivery is predominantly point erosion such as gullies and rills (cf. Poesen and Hooke, 1997; Vandenkerkhove et al., 2001; Ries and Marzolff, 2003). However, in the Dragonja catchment this is not the case. The texture of the suspended sediment depends on the flow stage (Fig. 3). We attribute this dependency to the following process. During a flood wave, large amounts of sediment are detached by rainfall from the slopes. At the beginning of the flow wave, slightly sorted and finer sediment is discharged together with the accumulated sediment at the base of the erosional cliffs (group B, Fig. 3). At peak discharge, the hillslope sediments enter the river without sorting (group A). When rainfall stops and discharge starts to drop, the sediment flow retards and larger particles deposit in the channels.

Sediment discharged during this part of the discharge wave will therefore be relatively fine (group B, Fig. 3). During low stage all the available fine material has already flushed through system. The sediment still available to the river is the one from the erosional cliffs, which consist of sand, silt and claystone. The sediment delivered by the cliffs has therefore a wide range in texture. This sediment is transported in very low concentrations during baseflow and also during the beginning of the next flood wave (group C, Fig.

3). These results suggest that the largest sediment contributors are the hillslopes, which provide sediment due to rainfall-induced erosion.

Based on the conclusion that the majority of the hillslope sediment delivery originates from the hillslopes, we argue that the use of the WATEM/SEDEM model is acceptable for the Dragonja catchment, as it only models sediment delivery from hillslopes.

For a Mediterranean environment the model was tested in Italy (Van Rompaey et al., 2005), but the information on the catchments studied in that research is much coarser than the detailed information available for the Dragonja drainage basin. With the detailed data we could estimate a range for the absolute value of the hillslope sediment delivery. It ranged from 32.5 to 10.2 ton ha-1y-1 in 1954 to 11.2 to 3.3 ton ha-1y-1 in the year 2002 (Table 3). However, when we look at the relative changes in hillslope sediment delivery due to land use change, we can state that they can be predicted well. For several calibration runs WATEM/SEDEM modeled a decline of approximately 70% in sediment delivery to the river over the period 1954 - 2002.

Separate calculations for hillslope sediment delivery reductions were done for both the Rokava and Upper-Dragonja sub-catchments. The Rokava sub-catchment showed a reduction of 45 % in the hillslope sediment delivery in 1954-1975. After 1975, the hillslope sediment delivery stayed more or less stable. For the Upper-Dragonja sub-catchment, the largest change occurred in 1954-1975 as well. However, in this sub-catchment the decrease in sediment outflow continued, making the total reduction 76 % of the sediment outflow in 1954 (Fig. 5).

The differences in reforestation in these two sub-catchments are due to differences in the geology (Rokava sub-catchment has less relief) and the more favorable topographical setting of the Rokava makes it more accessible from the nearby city of Koper.

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ODER BORDER MEANDERS: A CONCEPT OF THE ERODIBLE RIVER CORRIDOR AND ITS IMPLEMENTATION

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ABSTRACT

Most of border river reaches in Europe have been straightened and stabilized by means of channelization structures to prevent shifts in the location of a state border. A meandering reach of the Oder at the Czech-Polish border is an exception to the rule and, at the same time, one of two meandering reaches preserved along this 854 km long river. Facing the plans of water authorities to stabilize the course of the border meanders, in 2000 the World Wildlife Fund formulated a concept of erodible river corridor in the reach, which led to elaboration of the plan for the corridor by 2005. Taking into account the historical extent of channel migration, the limits of floodplain area and the location of infrastructure, the plan defines boundaries within which free migration of the Oder channel would be allowed. The active channel migration is intended: (i) to increase retention of flood water in the reach through the continual formation of low-lying floodplain areas; (ii) to increase morphological and hydraulic complexity of the river, necessary to maintain a high diversity of riverine habitats; (iii) to enable the formation of early successional stages of riparian vegetation; and (iv) to reduce the cost of maintenance of bank-protection structures, readily destroyed by the river in the meandering reach. Notably, since the river has not been incised in the reach, channel migration will not increase the delivery of bed material to the downstream reach because the height of deposition of gravel material on bars equals its vertical extent in eroded banks.

Due to the efforts of the ecological organization and scientists, the river in the border reach and the areas on both sides are now protected within the European network of Natura 2000. Based on the forecast of erosion of the floodplain areas within the corridor in the near future, WWF-Poland started to purchase the threatened parcels of land from private landowners. Implementation of the concept of the erodible river corridor is actively promoted by local authorities who consider the protection of the Oder meanders and the preservation of natural processes in the reach to be the means of enhancement of the area attractiveness for tourists.

Key words: Erodible river corridor, Oder border meanders, bank erosion

1. INTRODUCTION

Stabilization of the course of rivers by bank-protection structures prevents erosion of valuable land on the valley floors but it also has several adverse hydrological, ecological and economic effects. Accumulation of overbank sediments on convex banks is not accompanied by the erosion of concave ones. As a consequence, highly elevated areas adjacent to the channels become overgrown with mature riparian forest, whereas a complete succession of riparian plant communities comprising pioneer plants on bars, willow shrubs and finally riparian forest, diverse in terms of age and composition, does not occur here as it normally does along actively migrating channels. Moreover, the potential for water retention on the valley floors is reduced, with the resultant increase of peak flood discharges in the downstream reaches. Bank stabilization involves considerable costs for the construction and maintenance of bank-protection structures, especially in sinuous and meandering river reaches where the structures are easily destroyed during floods (Piégay et al., 1997).

Channelization structures are undoubtedly necessary in the river sections adjacent to intensely developed valley floor areas but their occurrence in the undeveloped parts of valleys is questionable. The high environmental and economic costs of construction and maintenance of regulated channels in such reaches led to the formulation of the concept of an area with freely migrating river channel, described as ‘espace de liberté’, ‘streamway’ or ‘erodible river corridor’ (Piégay et al., 1996; 2005). Bojarski et al. (2005) introduced this concept in Poland, indicating that in valley sections with limited development, free channel migration should be allowed within a corridor, which is defined by the extent of floodplain and the location of buildings and infrastructure under protection from erosion. Allowing free channel migration within a so delimited corridor would spare the costs of flood defence for the land along the river, particularly when total expenditure for flood protection of the area exceeds its value (Piégay et al., 1997; Bojarski et al., 2005). At the same time, the existing bank-protection structures could be substituted with anti-erosion revetments constructed along the boundaries of the corridor.

This paper reports on the formulation of the concept of erodible river corridor in a meandering reach of the Oder at the Czech-Polish border and an early stage of its implementation.

2. ODER BORDER MEANDERS

Most of border river reaches in Europe have been straightened and stabilized by means of channelization structures to prevent shifts in the location of a state border. A meandering reach of the Oder at the Czech-

Polish border, between the localities of Chałupki and Bohumín and the confluence with the Olza, is an exception to the rule and, at the same time, one of two meandering reaches preserved along this 854 km long river. Relatively natural channel-forming processes, including floods, in this unique reach enhance self-purification of the Oder and shaped a mosaic of riverine and riparian habitats (pools, oxbow-lakes, side and mid-channel bars, steep channel banks, etc.) (Fig. 1), providing refuge for numerous rare and endangered animal species (Obrdlik, 2004). As a result of detailed environmental study on the transboundary reach of the Oder and its valley, performed in the years 2001-2003 by the initiative of an international ecological organization (World Wildlife Found), this area on both Polish and Czech side of the border was incorporated into, and protected under the NATURA 2000 network.

Figure 1 – Erosion of unprotected channel banks and recruitment of large woody debris to the river in its meandering border reach result in formation of habitats which are lacking in the regulated channel along most length of the Oder course.

The Oder in its meandering reach is characterized by relatively dynamic channel changes. Cartographic analysis of the changes accomplished over the last 260 years documented meander shifts within a belt about 1.5 km wide (Obrdlik, 2004). One of the elements of the channel dynamics was cutting off meanders, resulting in a rapid change of channel position in a short river reach. In 1966 a cutoff at Šunychl was created in an area of the inner, Polish part of the meander on the left side of the river, while in 1997 a reverse situation occurred due to the formation of a meander cutoff at Starý Bohumín. After the flood of 1997, the Polish and Czech Water Authorities responsible for maintenance of the channel planned to re-establish its previous course and infill the newly formed channel section in order to maintain the hitherto existing course of the state border. This concept was opposed by the WWF, which suggested working out a compromise reconciling the need for nature protection with that for maintaining the course of the state border. Shortly after the meander cutoff at Starý Bohumín was formed, the abandoned channel rapidly started to fill with fine sediment (Kasperek & Parzonka, 2005) and until now it has been largely silted up (Fig. 2), so that further discussion on the re-establishment of the previous channel course has become groundless. Following the study commissioned by the WWF, an erodible river corridor has been recommended as an optimal solution for the functioning of the meandering, border reach of the Oder.

Figure 2 – Cut-off meander of the Oder River at Starý Bohumín in 2004. Note that the abandoned channel is considerably silted up.

3. ERODIBLE CORRIDOR IN THE BORDER REACH OF THE ODER

While delimiting the erodible corridor of the Oder in its border reach, two alternatives were considered (Obrdlik, 2004). The first one, with an area of 90 ha, would encompass the zone of easily erodible sandy alluvium in the vicinity of the river. The second would correspond to the extent of migration of the Oder channel over the last 260 years and would comprise an area of about 290 ha. The final concept of the corridor (Wyżga & Bohač, 2005) was based on the latter variant, encompassing the area between the contemporary channel of the Oder and the channel active in 1742, which still conveys water during flood events. However, the extent of the corridor is restricted by flood embankments, bridges, roads and other infrastructures as well as a gravel pit located close to the channel (Fig. 3), which all must be protected from erosion. The total area of the planned corridor covers 270 ha, with 40% on the Czech and 60% on the Polish territory.

The final plan for the corridor (Wyżga & Bohač, 2005) included recommendations for the protection of channel-forming processes as well as high landscape values of the border reach of the Oder together with the maximal reduction of the cost of channel maintenance works and property loss on the valley floor. It was decided that at locations which do not require bank protection, the existing structures would not be removed but left until they are eroded by the river. Removal of the bank lining would involve the use of heavy machinery leading to significant destruction of riparian vegetation and bed armouring in the channel.

The active channel migration is intended (cf. Bojarski et al., 2005; Wyżga et al., 2005):

- to increase retention of flood water in the reach through the continual formation of low-lying floodplain areas;
- to increase morphological and hydraulic complexity of the river, necessary to maintain a high diversity of riverine habitats; and
- to enable the formation of early successional stages of riparian vegetation, which does no occur if the channel is artificially stabilized.

One of the aims of bank protection in the meandering reach of the Oder, indicated by water authorities, was the reduction of bed material delivery to the downstream river reaches. However, flooding of the river banks in the reach at a discharge of 2-year recurrence interval (Obrdlik, 2004) indicates that the river here is not incised. In this case, free channel migration will not increase bed material supply to the downstream reach because the height of deposition of gravel material on bars equals its vertical extent in eroded banks.

Presently, active erosion of concave banks and the accompanying formation of gravel bars on the opposite banks are recorded in several sites along the border reach of the Oder. The plan for the corridor (Wyżga & Bohač, 2005) included the forecast of retreat of river banks in the following years if the banks are not protected from erosion by artificial structures. Basing on the forecast, the WWF started to purchase land parcels adjacent to the Oder channel from private landowners to minimize future property loss. To date, about 20 ha of the land most threatened by erosion on both Polish and Czech sides of the river have been purchased. The land so acquired is transferred to the local authorities on condition that it will constitute a zone

Figure 3 – Aerial photo of the Oder meanders between the bridge at Chałupki (lower left corner) and the river confluence with the Olza. Light dashed line indicates boundaries of the proposed erodible corridor of the Oder. Note that lateral channel migration must be prevented where a gravel pit is located very close to the river (bottom).

of free channel migration and if eroded, no compensation claims will be lodged against the water authorities. This should eliminate pressure on water authorities to construct and maintain bank-protection structures which prevent the natural course of erosional and depositional processes in the river, thus reducing the biodiversity of riverine and riparian ecosystems.

4. DEVELOPING SOCIAL ACCEPTANCE FOR THE ERODIBLE RIVER CORRIDOR

The purchase of parcels adjacent to the river was accompanied by several initiatives aimed at gaining the acceptance of local communities for the appropriate use of the exceptional landscape and environmental values of the meandering reach of the Oder. Over a few year period, leaflets informing about the project and its aims were sent five times to every household located in the vicinity of the river corridor. By the initiative of the WWF, an educational trail was established along the river and field lesson plans were prepared. Environmental values of the meandering reach of the Oder are the basis for planned, permanent international transboundary co-operation intended to promote environmental education and tourism development in the border areas. The meandering reach is now the most significant tourist attraction of the border towns and villages and one of the most important attractions of the entire region. During a few years of its activity in this area, the WWF gained widespread acceptance among the local communities for implementation of the concept of the erodible river corridor and conservation of this dynamically changing river reach.

5. FINAL REMARKS

Presently, Czech water authorities declare they would refrain from any technical interventions that might deteriorate the ecological status of the Oder in its meandering, border reach. The Polish authorities, however, are concerned with possible effects of “leaving the river on its own devices” and continue to formulate concepts of engineering works to be undertaken in this river reach.

The described situation in which ecological organization indicates a possibility and expediency of the change in water management practices along a river reach and undertakes logistic, financial and educational actions to effect the change should be considered exceptional. The actions carried out by the international ecological organization WWF within the border meanders of the Oder are highly informative for Polish and Czech governments, and show the suitability and procedures for implementing and functioning of an erodible river corridor. However, it is the owner of the watercourses who is responsible for their maintenance and restoration of good ecological status according to the regulations of the Water Framework Directive of the EU. Hence, in the future, such actions ought to be undertaken, at a considerably larger scale, by water authorities of both countries.

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RIVER RESTORATION OF THE RIVER MUR ALONG THE BORDER BETWEEN AUSTRIA AND SLOVENIA

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ABSTRACT

The river Mur forms the national border between Austria and Slovenia for a length of about 35 km. At the end of the 19th century, the river bed consisted of widely ramified waterways with lateral branches. Between 1875 and 1894, the formerly braided system of the river was unified into a single straight river bed.

The main problem today is the deepened river bed which has become approximately 1.3 m lower in the last 30 years. Bed deepening leads to the destabilisation of existing river bank protection structures in built-up areas, the separation of old river branches as well as the lowering of the adjacent groundwater level. The main causes for the deepening of the river bed are the river regulation occurred at the end of the 19th century, and the chain of run-of-river power plants upstream of the border section.

A combination of measures consisting of an improved sediment regime and a widening of the river needed to be defined as concrete solutions to the problem of riverbed deepening of the “Grenzmur“. Results of the model calculation (MORMO) suggested that the most favourable approach would have been to allow the river to develop morphologically in width by lateral erosion and to exploit, at the same time, the potential sediment from the zones of widening to improve the sediment regime. In autumn 2006, construction measures began for the widening of the river bed in the Gosdorf area. This was the first of a total of six major river bed widening projects on the Austrian and Slovenian side.

The success of these measures is being checked via a monitoring programme. With the help of tracer rocks (simulated bed-load material), the route taken by the introduced material is followed via satellite navigation and documented. The morphological changes are observed via a webcam and documented as well.

Attention should be paid to the fact that this section of the River Mur, together with its alluvial forests on Austrian territory, is designated as an European Conservation Area (NATURA 2000).

Key words: River restoration, Mur River, riverbed deepening

1. INTRODUCTION

The main problem for the “Grenzmur“ today is the deepened river bed which has become approximately 1.3 m lower in the last 30 years. Between 1970 and 2000, the net material output from the river bed amounted to about 0.9 million m^3. This led to the destabilisation of existing river bank protection structures in built-up areas, the separation of old river branches in the hinterland and of their alluvial forests as well as the lowering of the adjacent groundwater level. The consequence is a significantly disturbed water balance.

2. GENERAL SETTING

In the European river network the River Mur belongs to the catchment area of the Danube. The river has its source in the Province of Salzburg at an altitude of about 1,900 m a.s.l. With a length of approximately 300 km, the Mur is the most important river of the Province of Styria. After about 260 km, the River Mur is the state border between Austria and Slovenia over a length of about 34 km. After a total length of 445 km, it enters the River Drava near Legrad (130 m a. s. l.) at the Croatian-Hungarian border. The River Mur drains a catchment area of 13,800 km^2. As the river breaks its bank at recurrent intervals, systematic training measures were begun along its Austrian-Slovenian border section at the end of the 19th century. Between 1875 and 1894, the formerly braided system of the River Mur was unified into a single straight river bed („Hohenburger-Regulierung“).

What is noteworthy is the longitudinal continuum. Starting from the River Mur, which forms the national border between Austria and Slovenia in this section, to the River Drava and further on to the Danube, the longitudinal flow remains uninterrupted for about 1,000 km. A section which is particularly remarkable for its natural landscape is the border stretch with its alluvial forests. On Austrian territory this section of the River Mur, together with its alluvial forests, is designated as a European Conservation Area (Natura 2000).

3. THE RIVER MUR AND ITS CHANGES IN THE COURSE OF HISTORY

In today’s border region between the Republics of Slovenia and Austria, the River Mur occupied large parts of the valley until the end of the 19th century. After the Middle Ages, the river had already shifted its course towards the north. At that time, the river bed of the “Grenzmur“ consisted of widely ramified waterways with numerous lateral branches and extraordinary structural diversity. The entire river system including its branches and islands was up to 1.2 km wide in this region. From 1875 to

1891, the River Mur underwent training from Graz to the Hungarian border. While the aim of these measures was to discharge the average flow within a defined main bed about 76 m wide, they did not provide protection against floods.

The frequency at which the "Grenzmur" changed its riverbed in the 19th century is evidence of the sediment surplus which existed at that time. The river was either in a state of dynamic equilibrium or in a state of latent aggradation. Today, the section of the River Mur at the border between Austria and Slovenia is suffering from an acute sediment deficit.

4. BASIC WATER MANAGEMENT CONCEPT FOR THE "GRENZMUR"

Based on these background problems, the Permanent Austrian-Slovenian Commission for the River Mur in 1998 commissioned a conceptual model which would have supported the decisions to be taken to halt the trend of bed erosion.

Figure 1 – Project area.

4.1 Results of the study

The collection and evaluation of data on changes of the bed morphology of the River Mur showed the river bed in the section of the "Grenzmur" to be unstable with a significant trend towards bed erosion. Signs of erosion are evident all along the section, varying in magnitude along the water course and reaching values of up to 130 cm since 1970. In some sections the thickness of the gravel layer (above the tertiary layer) does not exceed 0.5 m. Using the sediment transport model MORMO, the likely future development of the bed of the "Grenzmur" was demonstrated (Nachtnebel et al., 2000). From the predictions obtained by the sediment transport model it can be inferred that bed erosion of the “Grenzmur“ will continue unabatedly, unless countermeasures are taken (“business-as-usual”). Results of the model calculation suggest that the most favourable approach would be to allow the river to develop morphologically in width by lateral erosion and to exploit, at the same time, the sediment potential from the zones of widening to improve the sediment regime. The idea is to increase the sediment-effective width to approximately twice the existing width of the river.

4.2 Measures

The aim of “creating a dynamic stability of the river bed” or “preventing further bed erosion” should be attained as cost-efficiently as possible.

From among the several options, (e.g. transverse structures, groyne fields, weirs), these requirements are met best – from a water-management and ecological point of view - by increasing the width of the river bed to approx. 200 to 250 m.

It became apparent that a further deepening of the river bed of the “Grenzmur“ can be prevented for a period of about 60 years, if a dynamic widening of the bed width by lateral erosion can be maintained continuously over an extended period of time.

4.3 Pilot Measures

To verify the results for practical implementation, a number of pilot measures were carried out. These were to provide information on how quickly lateral erosion would occur on unprotected embankments and if the effects of sediment supply would become noticeable

5. PROJECT GOSDORF

In autumn 2006, construction measures began for the widening the river bed in the Gosdorf area. This was the first of a total of six major river bed widening projects on the Austrian and Slovenian sides, which were planned in accordance with the conceptual model.

Figure 2 – Widening of the river bed in the Gosdorf area.

It is planned to widen the River Mur from about 85 m to twice this width over a length of about 1.1 km (Plattner, 2005). This was achieved by machine-digging a lateral branch and transferring the material into the River Mur. The remaining bed load will be mobilised by the river itself during times of higher flow rates. From the approximately 900,000 m^3 of sediment which are available and which have been deposited by the river along its sides in the alluvial forests in the course of centuries, about 150,000 m^3 have been reintroduced into the River Mur.

The embankment stabilisation structures were used partly to fill up scours and partly for the construction of covered groynes in the hinterland. The success of these measures is checked by a monitoring programme.

The construction measures are intended to serve as a triggering process. Later on, the river itself should mobilise the gravel deposits, which have accumulated along its course, at times of higher discharge or during floods, distribute them further downstream in its bed and thus contribute towards stabilising and partly even raising the bed. 50% of the total costs of about 500,000 € are funded as an Interreg IIIA Project; the remaining part is financed by the Republic of Austria, the Province of Styria and the Municipalities.

5.1 Monitoring

To ensure that the morphological changes initiated by these measures are monitored as closely as possible, spatially detailed surveys are complemented by information obtained via webcam images. The survey includes taking pictures of areas at the bottom of the river bed (echo-sound measurements), scanning the river embankments by reflector-less surveying and surveying of surroundings via GPS. With the help of these data, terrain models are generated. Based on these terrain models produced from different surveyis, differential maps showing deposition and erosion can be drawn, from which mass balances can be calculated.

Figure 3 – Observation of riverbank erosion (www.wasserwirtschaft.steiermark.at).

For a more detailed observation of the morphology, two webcams providing higher resolution were installed. They allow to observe riverbank erosions during a discharge event and thus to gain an insight into the mechanism of erosion processes.

Bed-load transport is measured via telemetry, using artificial rocks which were equipped with radio-transmitters.

To facilitate ecological monitoring, the biotypes were mapped prior to starting with the measures implementation. In its original state, the areas of the project lying at rather higher altitudes were covered with alluvial forests in which oak, elm and ash prevailed; a smaller part of it used to be grassland or fallow grassland and shrubs. The lower part consisted of a willow forest as well as of a black alder and ash alluvial forest and grassland and fallow grassland. Lateral channels were absent.

Even before the construction work to widen the river at Gosdorf began, it was clear (Revital 2004) that the originally mapped area of relevant habitats according to Annex I of the FFH Directive would be reduced massively in size. However, this was a deliberate trade-off for the sake of achieving the management target of widening the River Mur in its course.

The excavation of bedload material supported the development of open zones in the form of gravel and sand bars and of gravel or sand escarpments as well as of gravel bars, mud banks and land/water edges of unconsolidated material along the newly formed or opened-up embankments. By the time the work was completed, the bank line in the project area was approximately tripled in length compared to the initial state. However, the recolonization of the newly created or initiated structures is by no means completed. On the contrary, the process has only been started.

With 51 species, which formerly existed, the fish fauna of the “Grenzmur“ is extraordinarily rich in the diversity of species compared to other similar bodies of flowing water (Zauner & Ratschan 2004). This is chiefly due to the presence of species with highly diverse ecological needs. For a sustained existence of all these species with intact populations it is therefore necessary to provide the appropriate habitats and thus great biotope diversity as well as unobstructed continuity with river sections further downstream.

Figure 3 - Biotope boundary “widening Aufweitung Gosdorf” (Wilfling et al 2008).

5.2 Ecological strategies

Creating retention space and widening river beds as well as connecting side channels as measures of protective flood management, provide the appropriate conditions to ensure a sustainable dynamic development of water structures and habitat in line with the mission statement for this section of the river. Proof of the positive effect of these measures as regards the creation of habitats has been furnished repeatedly. The River Mur bed-widening measures are thus part of the intensive efforts of revitalising this section of the river.

It is intended, by widening further sections and by networking water bodies, taking into account the experiences gained from monitoring, to promote the self-development of the River Mur in sections which are thought to be appropriate. Adopting an approach similar to Gosdorf, existing embankment protection structures are to be removed, and gravel is to be introduced actively into the river along with the creation of side channels.

The implementation of the measures at spread out interval not only prolongs the existence of typical pioneer site but also the transport of bed load by the River Mur itself.

6. CONCLUSIONS

It has been demonstrated already by the first monitoring results that the measures have had a positive impact: on one hand the deficit in bed load has been reduced by the input of material and on the other a contribution has been made towards improving the ecological status by the river's new morphodynamics.

Apart from the one-time supply of bed load material from the lateral channel, the bed load deficit should be compensated by dynamic lateral erosion. The resulting widening of the river bed with a reduction of the shear stress will continue to counteract the trend towards bed deepening. The experiences gathered through the "Gosdorf" project will be used for planning the details of the next measures to be implemented along the "Grenzmur".

The widening of the main channel of the River Mur has triggered profound changes in the biotope landscape. Apart from achieving the main goals of activating retention space and halting the progressive deepening the River Mur, valuable water-related habitats have developed already after a few months.

Encouraged by the positive experiences and results of the pilot projects and the measures in Gosdorf so far, further river bed widening projects are planned both on the Austrian and the Slovenian side for the coming years. All measures will be accompanied by comprehensive water-management and ecological monitoring. The projects which have been realised so far have been widely accepted by the population. The river and its surroundings have been re-discovered as a space to be lived in, and a space to be experienced, attracting local residents and tourists alike at weekends for their leisure-time activities. A visitors' channelling concept has been elaborated and integrated in the management scheme for the Natura2000 area.

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SEDIMENT DYNAMICS, CHANNEL MORPHOLOGY AND ECOLOGICAL RESTORATION DOWNSTREAM A DAM: THE CASE OF THE AIN RIVER

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ABSTRACT

The lower Ain valley is a free meandering river that has undergone significant morphological change in response to 20th century management and land use practices. The magnitude and the spatial extent of morphological adjustments were determined from aerial photography to map channel change, and from the construction of a sediment budget which estimates contemporary bedload yield. This first approach showed a sediment deficit of 10-1,500 $m^3 year^{-1}$ along a 25 km reach downstream of the Allement dam. The sediment deficit results in the loss of gravel bars and a consequent reduction in lateral mobility and habitat diversity, as demonstrated by ecological surveys of fish populations and aquatic vegetation.

These results were used as a basis to outline a sustainable management plan for the sedimentary dynamics of the Ain River. The objectives of this management plan are both preventive, i.e. they actively seek to preserve free-meandering reaches, and curative, i.e. they suggest ways to restore lateral channel mobility and associated ecological diversity in reaches that have already been affected by sediment deficit and channel incision. Taking this context into account, we selected some actions for channel restoration both in technical and economical terms. Preliminary operations were led as experiments, linking former channel restoration (mainly channel deepening and reconnection), and bedload reintroduction into the European framework Life Natura 2000. The morphological and ecological consequences of the restoration were monitored.

Key words: river restoration, dam, river ecology

1. INTRODUCTION

During the 20th century, a wide range of human activities (dam construction, gravel mining, land-use change) affected a majority of European rivers, limiting both water and sediment supply. Amongst these activities, damming was broadly studied (Williams & Wolman, 1984; Kondolf, 1997; Gurnell & Petts, 2005). Most of the dammed rivers studied in western countries currently show a sediment deficit causing channel adjustments with negative environmental and economical consequences (Kondolf, 1997). Although these consequences are now well-acknowledged, only a few studies (Kondolf & Matthews, 1993; Bunte, 2004; Reckendorfer et al., 2005) present sustainable sediment management or restoration plans to mitigate the effects of sediment deficit.

During the 20th century, the Ain River has undergone significant morphological adjustment in response to anthropogenic activities (land-use changes, dams construction), resulting in active channel narrowing, bed degradation and coarsening of bedload (Piégay *et al.*, 2000). Over the past 20 years, detailed observation of channel geometry has indicated that sedimentary dynamics continues to be affected by the upstream dams. As in many similar cases (Williams and Wolman, 1984; Gurnell and Petts, 2002), the dams installed along the Ain have reduced gravel bar surface area and caused the development of well-formed pavement. This reduces the lateral mobility of affected reaches (Rollet, 2007) and both aquatic and riparian habitat diversity (Dufour, 2005). Rollet (2007) demonstrated a sediment deficit from 10.000 to 15.000 $m^3 year^{-1}$ affecting a reach 25 km downstream of the Allement dam. In addition, downstream lateral sediment inputs are not sufficient to prevent the downstream propagation of this sediment deficit, threatening to impact the more dynamic downstream channel.The aim of this study was to define a management strategy that is both preventive, i.e. practices would actively seek to preserve meandering reaches, and curative, by suggesting ways to restore lateral channel dynamics and associated ecological diversity in reaches that have already been affected.

2. GENERAL SETTING

The Ain River is one of the most important tributaries of the Rhône River in Eastern France, draining a watershed of 3630 Km^2 (Fig. 1). The lower valley flows through an agricultural floodplain bordered with a large riparian forest. The mean active channel width of the 40 km study reach ranges between 80 and 100 meters. The annual flood approximates 780 $m^3 s^1$. Within a European context, the Ain is an unusually natural and freely meandering river. However, the upper valley is impacted by 5 hydroelectricity dams, built between 1931 and 1968, which act as sediment traps and regulate peak flows. In addition, the lower valley is regulated by 3 weirs which temporarily store the remnant sediment load delivered by local tributaries and from channel banks.

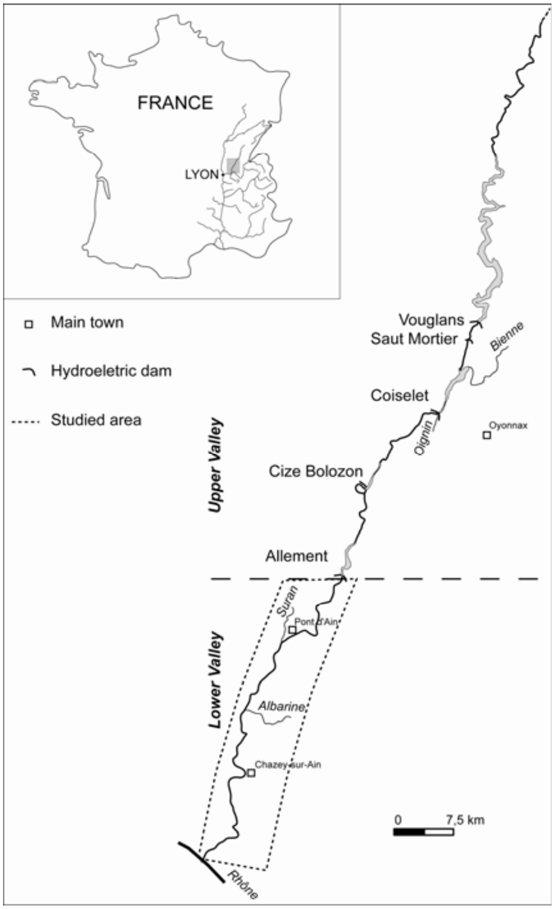

Figure 1 – The Ain River catchment.

3. RIVER RESTORATION STRATEGIES

If nothing is done to counteract downstream channel degradation, the most interesting and diverse, free-meandering reaches which support valuable riparian ecosystems will disappear in the next 20 years. In such a context, artificial reintroduction of sediment has been considered as a possible option for restoration. The establishment of a suitable strategy for sediment management relies on two fundamental questions: (1) what is the most appropriate sediment source to use in terms of quality (size, percent of fine sediment) and economy (distance from the main channel, cost of sediment treatment), and (2) what is the best way to introduce gravel into the channel, in order to minimize adverse environmental impacts on instream and riparian ecology. A survey of the current ecological status was conducted to determine both fish populations and riparian vegetation communities.

3.1 Determination of appropriate sediment sources

The aim of restoring sedimentary dynamics along the reach is to increase the volume of bedload in the active channel. The sediment used for this operation should have the same characteristics as channel bedload in the reach unaffected by the dam, and a low percentage of fine sediment. Excess fine sediment could result in clogging the bed or create anixyc conditions which in turn would asphyxiate the fish population, at the same time without contributing to bedload transport or the restoration of channel morphology. To limit the cost of acquisition, treatment (collection, sorting, and washing) and transport, we chose to use sediment stored in the floodplain because of the close proximity to the active channel, the similarity to the active channel sediment and the opportunity to combine channel and floodplain restoration by lowering these surfaces and improving the connection of riparian plants with groundwater.

The volume of sediment stored in the forested floodplain was quantified using aerial photos, drilling and measuring bank height. The floodplain contains enough sediment to sustain gravel reloading between 40 and 130 years

The cost of extracting this sediment (deforestation, removal of fine sediment) was estimated between 4 and 5 euros per cubic meter of bedload sediment.

3.2 General strategy for sediment remobilisation

Two general strategies could be employed for remobilizing the newly acquired sediment: artificial gravel introduction and artificial re-activation of lateral erosion. Along the Ain River the two approaches were combined.

Because the disappearance of gravel bars has diverted flow towards channel boundaries, and caused generalized bed degradation, the reach affected by sediment deficit were no longer mobile. Groynes construction was not kept as a suitable option to initiate the self-restoration processes (reactivating bank erosion and sediment introduction) because of the costs and environmental impacts involved. In addition this would be only a short term, unsustainable measure of restoration. Instead, artificially reintroducing sediment by lowering the floodplain was preferred for restoration. To test the behavioral response of the channel to such reintroduction, while at the same time taking advantage of the available sediment in these former channel areas, two pilot sites were monitored.

4. PRESENTATION OF PRELIMINARY OPERATIONS

Between 2003 and 2006, the European LIFE Nature programme was carried out along the lower Ain valley to restore riverine ecosystems, notably former channels disconnected because of main channel degradation. The ecological objectives of this restoration were two-fold; first, to recreate a former channel water body by deepening and increasing the connection with the water table, and second, to increase ecological diversity by lowering the upstream and downstream channel infills and increasing the frequency of flood scouring. These operations produced a huge volume of coarse sediment which was directly re-introduced into the active channel.

4.1 Design of former channel restoration

Three criteria were used to select three former channels to be restored (Fig. 2A); (1) an ecological assessment, using a typology of ecosystem functioning, (2) the location of the former channel in relation to the reach of sediment deficit, and (3) the amount of coarse sediment generated by restoration. This last criterion was estimated by drilling and using topographic measurements. It was estimated that the three channels chosen for restoration can generate 70.000 m^3 of gravels (Fig. 2B).

To avoid fine sediment clogging the channel bed, the layers of fines previously deposited within former channels were not used to reload the channel. Instead, these fine sediments were spread in the floodplain bordering the restored former channels. Restoration operations started in November 2005.

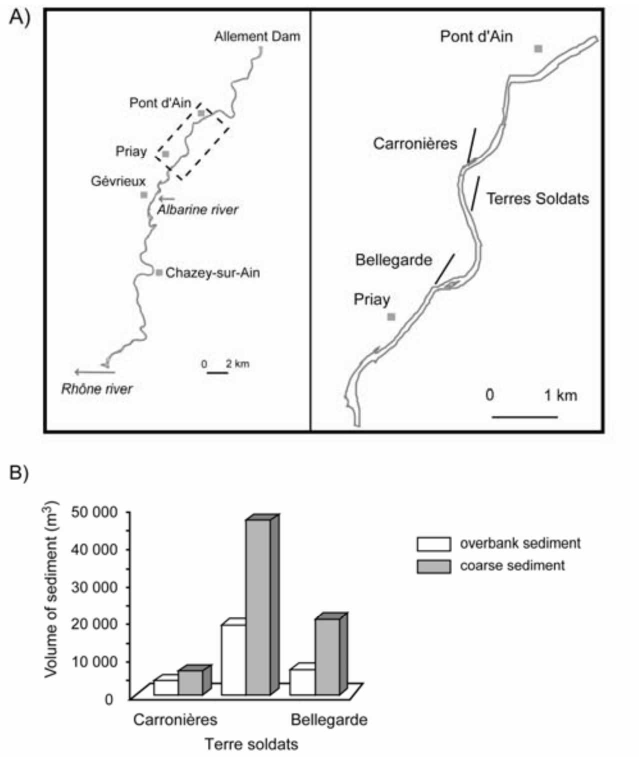

Figure 2 - Location (A) and sediment production (B) of each former channel restoration.

4.2 Restoration and survey

Since November 2005, two out of the three selected former channels were restored. A total sediment volume of 20.000 m^3 was extracted and introduced into the channel by one of two different methods, the choice of which depended on the specific site: (1) indirect layering of sediment on a highly eroded former gravel bar (Fig. 3A); and (2) introduction of the sediment directly into the channel, in a high velocity section, to promote a faster natural redistribution of the gravels downstream (Fig. 3B). The uppermost layer of sediment previously deposited in the floodplain was used to reshape channel geometry and banks of the former channel.

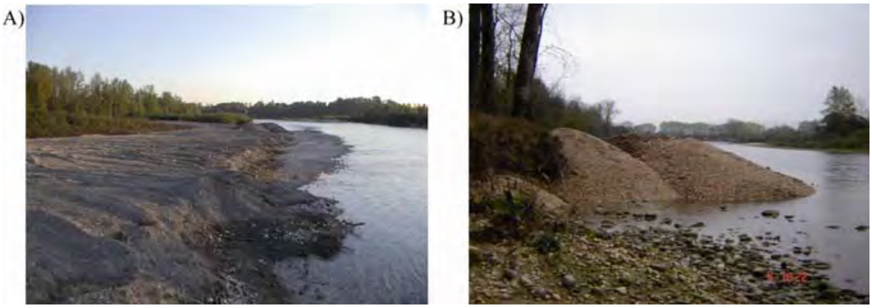

Figure 3 – Indirect (A) and direct (B) artificial gravel introduction in the river channel.

These first experiments were surveyed to analyse whether they had allowed progressive morphological adjustment, to observe the efficacy of the sediment restoration strategy, and to study the environmental effects of this process. The impact of these operations on river channel geometry was assessed using high resolution images and bathymetric measurements. It appears that the volume of introduced sediment was insufficient to modify channel geometry or instream habitats. However, these results confirm channel capacity to transport 15.000 to 20.000 m^3 in the reach of sediment deficit, without generating any negative environmental impact.

5. CONCLUSIONS

The experimental investigation of bedload restoration presented in this study is the first step of a more ambitious restoration plan. These preliminary experiments will be completed this summer by a new test coupling the deepening of a third former channel with the reintroduction of gravel. The second step of the restoration project that aims to use floodplain lowering is still in discussion, but is likely to remain the only option to really maintain long term sediment transport through the impacted reach.

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SEDIMENT INPUT AND SELF-INITIATED RIVERBANK EROSION TO MITIGATE CHANNEL INCISION: METHODS FOR MONITORING THE EFFECTIVENESS OF A NEW MANAGEMENT TECHNIQUE

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ABSTRACT

At the Mur River in Austria, hydroelectric power production, a lack of riverbank erosion, increase of channel slope and decrease of width have led to significant channel incision. At the beginning of a reach suffering from severe bed degradation, a river section of 1 km length has been restored. Bank protection structures have been removed and new side arms have been built. The dredged material has been moved into the main channel, from where it is transported downstream. Together with eroded riverbank material, the total amount of gravel input is anticipated to stop mid-term bed degradation.

An adapted combination of several monitoring methods is used to control the effectiveness of these measures. Particle tracking by radio telemetry is used to measure the distances of inserted tracers during several flow events. Detailed geodetic surveys are combined with surveying techniques based on webcam pictures to gain higher temporal resolution in monitoring morphologic processes. In order to obtain data for testing and calibrating riverbank erosion models, a monitoring of riverbank hydrology is performed.

So far the Mur River showed the intended response to the measures with respect to self-initiated bank erosion and distribution of the inserted gravel. The introduced monitoring program proved to be suitable for the assessment of the measures.

Key words: channel incision, Mur River, sediment input, riverbank erosion, monitoring methodology, radio telemetry, surveying techniques

1. INTRODUCTION

Lack of bedload due to intensive hydroelectric power production, missing riverbank erosion, increase of channel slope and decrease of river bed width have led to substantial degradation of the bed level of the Mur River at the border segment between Austria and Slovenia. In addition to ecological problems such as the disconnection of side-branches and floodplain forests, bank protection structures have been destabilised and the lowering of the groundwater table has led to problems in water supply.

In order to propose general principles for mitigation of the problems, a Basic Water Management Concept (BMLFUW, 2001) for the 34 km border reach of the Mur River was compiled. One of the proposed measures was realised in 2006/2007 in a river section characterised by the largest channel incision (1.2 m): a reach of 1 km in length was restored with the intention to stop bed degradation and its negative consequences. Bank protection structures were removed and new side arms were initiated. The dredged material was introduced into the main channel, from where it is transported downstream (Fig. 1). In combination with eroded riverbank material, the total amount of gravel input is intended to stop mid-term bed degradation.

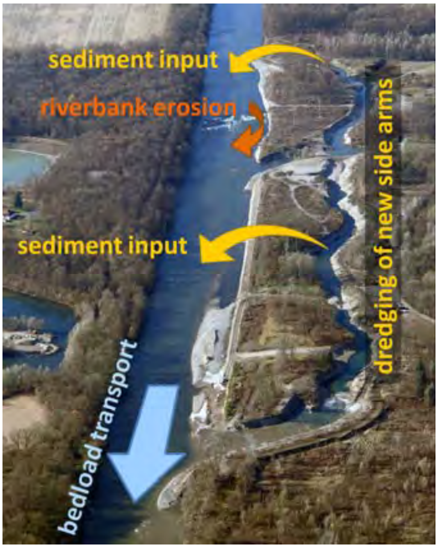

Figure 1 – Schematic drawing of the functionality of the measures.

2. GENERAL SETTING

The Mur River is a tributary of the Drava River and has a total length of approximately 450 km. It drains a catchment basin of 13824 km². At the end of the border segment between Austria and Slovenia the Mur River has a length of about 355 km and drains 10340 km². This reach is characterised by a mean discharge of about 150 m³/s.

3. MONITORING

The effectiveness of the measures in mitigating channel incision is evaluated by means of an intensive monitoring program. The effectiveness of the measures depends on:

1. Distribution of the inserted gravel;
2. Morphological change of the restored section;
3. Additional sediment input due to bank erosion.

Monitoring is conducted at small timescales to be able to link processes to individual flow events or even to individual conditions of flow dynamics. This is necessary in order to provide a good database for morphological modelling. The monitoring program is a combination of: (a) echo-sounder measurements of riverbed geometry, (b) tachymetric survey of riverbanks and hinterland, (c) survey of “control profiles” in the downstream section, (d) terrestrial photogrammetry at selected riverbanks, (e) stone tracking using telemetry, (f) basket sampler bedload measurements, (g) grain size analysis of bed material, (h) webcam picture survey, (i) monitoring of riverbank stability. The results will be considered in further planning of restoration measures at the degraded section of the Mur River.

3.1 Monitoring of morphology

Geometry monitoring combines methods of high spatial resolution with methods of high temporal resolution. High spatial resolution of the riverbed geometry is obtained from dense echo sounder measurements (distance of measured profiles less than 3 m). The hinterland is surveyed tachymetrically, while the geometries of the riverbanks are surveyed using reflectorless measurements. The resulting digital elevation models (Fig. 2) allow to plot maps displaying change in elevation (Fig. 3) and to calculate mass balances (Formann et al., 2007). Downstream of the restored section “control profiles” are surveyed to measure changes in bed elevation.

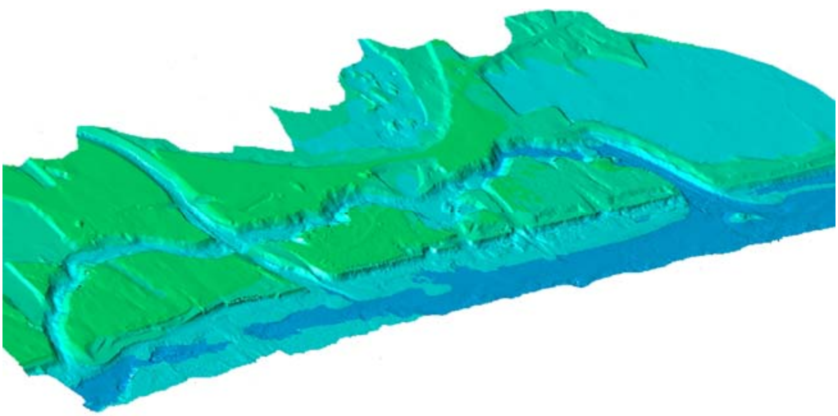

Figure 2 – Digital elevation model of the restored river section.

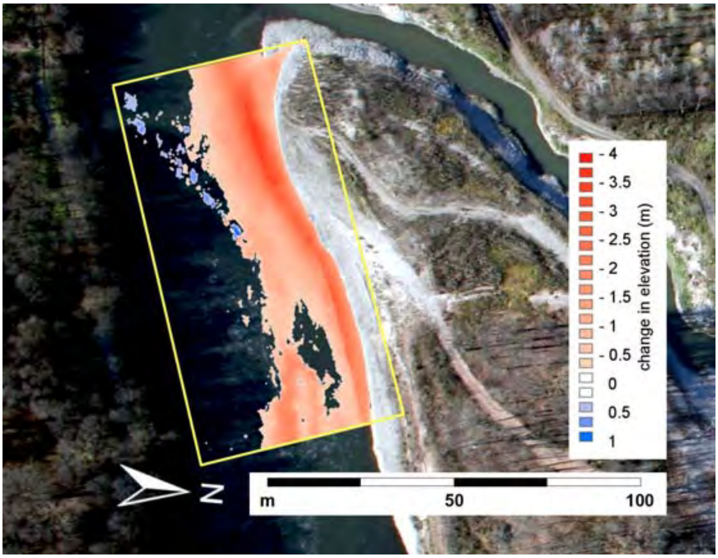

Figure 3 – Erosion of added sediment in time interval between May 2007 (initial geometry) and December 2007.

The previously outlined survey is repeated 1 to 2 times per year. Several methods are added to obtain a higher temporal resolution in the monitoring of the geometry: (a) 4 webcams, originally installed mainly for public information, are used to survey bank edge geometries (Fig. 4); (b) selected riverbanks are surveyed after every flood event using terrestrial photogrammetry; (c) in the side arm cross sections are surveyed after every flood event. In the same cross sections erosion pins are installed (Fig. 5) that are – if not submerged and personnel on-site available – monitored during flow events.

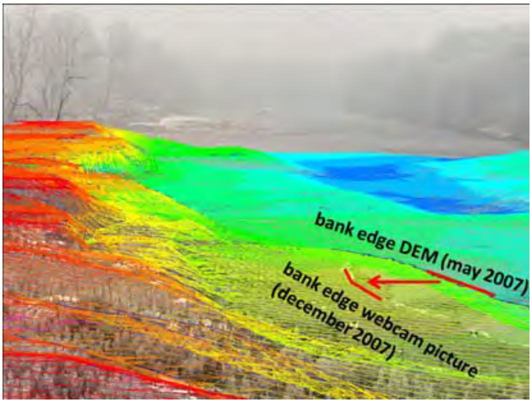

Figure 4 – Use of webcam pictures to obtain higher temporal resolution in the monitoring of riverbank geometry.

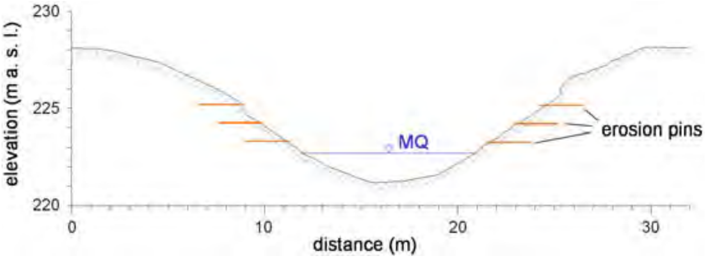

Figure 5 – Left: cross section of a side arm with erosion pins for obtaining additional geometry data in higher temporal resolution; right: erosion pin.

3.2 Monitoring of bedload transport

The use of particle tracking via radio telemetry allow to obtain the transport paths of artificial stones (Fig. 6) representing coarse gravel (Habersack, 2001; Habersack & Kloesch, 2008). Additional measurements with a basket sampler are conducted to measure cross-sectional bedload transport. Fig. 8 displays the positions of inserted telemetry stones (tracers) at different points of time; Fig. 7 shows the corresponding hydrograph. In Fig. 9 a cross section is depicted where six tracers were inserted at the bank toe.

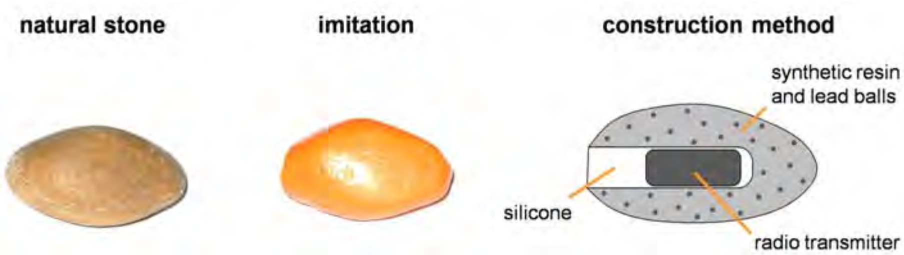

Figure 6 – Natural stone and its imitation with inserted transmitter.

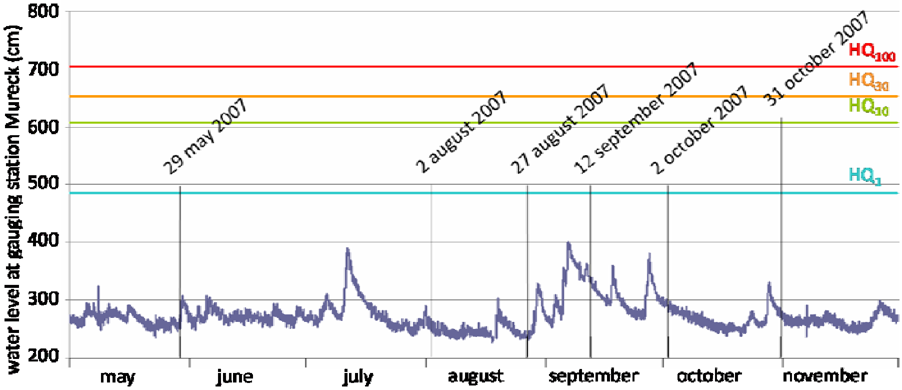

Figure 7 – Hydrograph at gauging station Mureck with dates of tracer positioning.

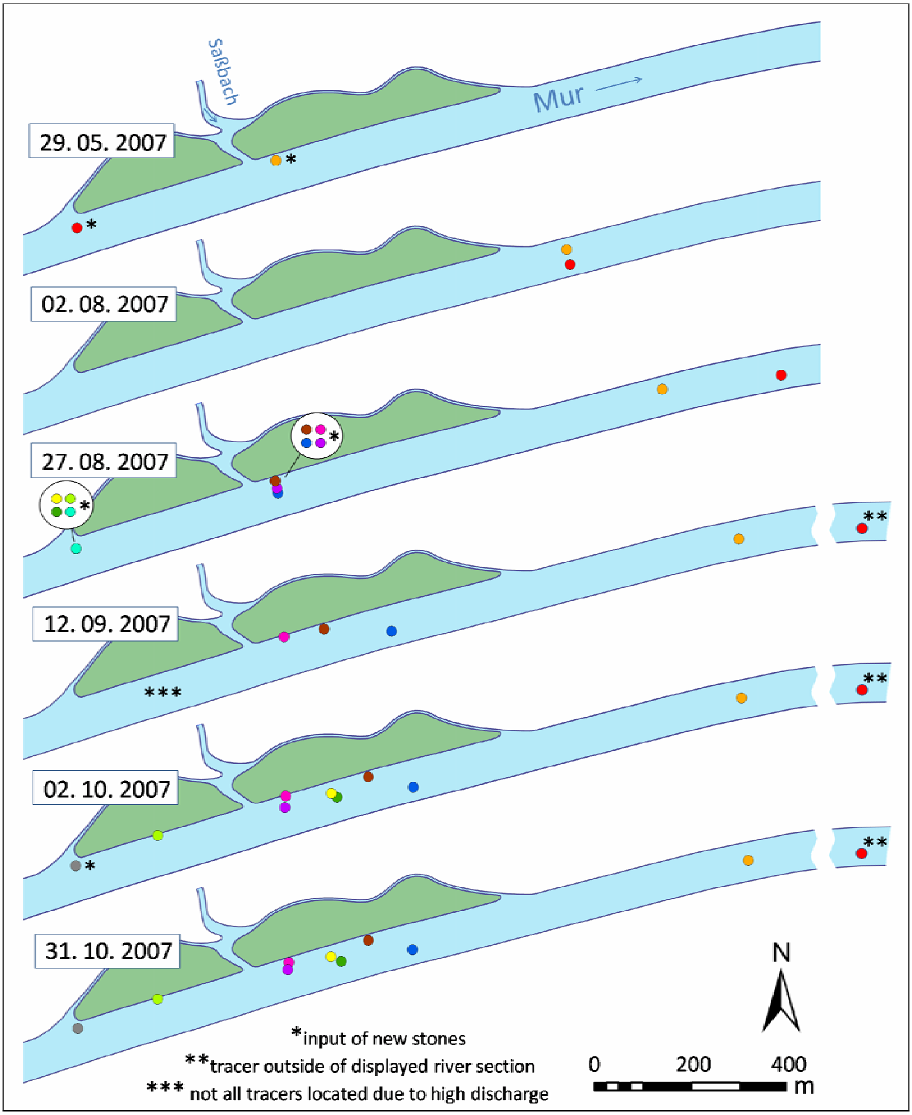

Figure 8 – Positions of tracers at several points in time.

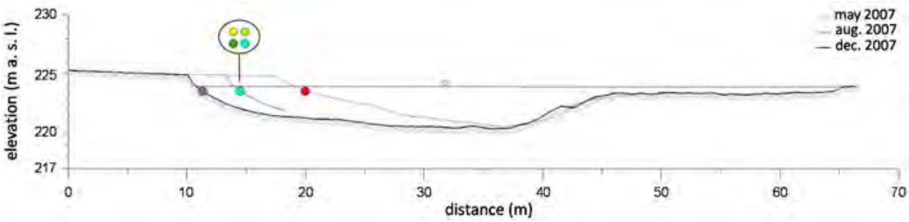

Figure 9 – Cross section with tracers inserted at the bank toe (see Fig. 8 for their transport paths).

3.3 Monitoring of riverbank stability

The riverbanks of the restored section consist of gravel overlain by silty sand of varying thickness. Sandy soils are weak in cohesion, but at unsaturated conditions enhanced shear strength due to apparent cohesion (Fredlund et al., 1978) enables the stability of even vertical banks. The riverbank's stability varies according to variations in pore water pressures as a consequence of rainfall, evapotranspiration and water stage variations (Rinaldi & Casagli, 1999). Tensiometers and gypsum blocks were installed to monitor matric suction to finally analyse the variations of riverbank stability. Positive pore water pressures are measured with two piezometers. Precipitation and water stage are measured directly at the investigation site.

4. PRELIMINARY RESULTS

Ten artificial telemetry stones representing coarse gravel were inserted and showed different transport activity. The length of the transport paths in the first investigation period from May 2007 to November 2007 varied from a few meters to more than 4 km. During larger events the tracers were transported over longer distances (up to 2.5 km) while the smaller flow peak in October 2007 (Fig. 7) led to almost no transport (Fig. 8). The results of the geometry monitoring showed high dynamism caused by even small events during the investigation period.

5. CONCLUSIONS

A combination of several methods was developed that proves to be suitable for monitoring the effectiveness of the measures. The Mur River so far exhibits the anticipated response to the measures with respect to self-initiated bank erosion and distribution of the inserted gravel. Further results are expected from a continued and even more detailed monitoring program.

ACKNOWLEDGEMENTS

The authors thank the Styrian government and water management authority, especially Rudolf Hornich, Norbert Baumann and Thomas Froehlich and the Ministry of Agriculture, Forestry, Environment and Water Management for funding and supporting this project.

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IF FLOODING IS THE ANSWER, WHAT IS THE QUESTION?

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ABSTRACT

Increasing floodplain-river connectivity has been proposed as a major tool to improve the ecological status of large Mediterranean rivers with degraded riverscapes due to lack of floods and geomorphological processes, channel incision and homogenization of the floodplain landscape by intensive agricultural use. Different actions which affect the hydromorphological characteristics of the river have been proposed to increase connectivity, which in turn would result in an increase of the flooded area (e.g., opening corridors for water flow, breaching permanently or temporarily the river banks, excavating the soil down to the aquifer level). The Ebro River is a large Mediterranean river subject to intense water flow and regime regulation as a consequence of the intense dam and bank construction during the second half of the past century. Several experiences to increase the floodplain-river channel connectivity were performed and/or planned which will result in a larger and/or more frequent flooding of the Middle Ebro floodplains. The point is to know the efficiency of actions compared with the objectives proposed. Direct opening of the river side in the floodplain downstream of Zaragoza city had a low efficiency in re-connecting the floodplain area, as it was easily closed by gravel deposits after the following flood. Opening breaches in the artificial river banks upstream Zaragoza was an efficient tool to flood large areas and decrease the impact of flood downstream. Groundwater re-connection by direct excavation was an efficient tool to obtain floodplain aquatic ecosystems at early stages of succession and to increase the riverscape diversity. Flooding land intensively used for agricultural purposes in Ranillas meander in Zaragoza resulted in relatively low-quality water compared to the quality obtained wgen flooding natural ecosystems in the Galachos Reserve downstream Zaragoza. Implementing a combination of physical actions to increase the hydrological connectivity of river and their floodplains can be a good strategy to accomplish different objectives. However, some basic actions are required if the restoration of the river ecosystem is expected, including water flow and regime restoration.

Key words: Connectivity, floodplain-river channel, geomorphic, water storage, quality, macroinvertebrates, community structure, restoration strategy.

1. INTRODUCTION

Degradation of large river floodplains is frequently the consequence of decreased river dynamics and land cover and use changes in both the watersheds and floodplains all around the world (Petts, 1989). Flooding floodplains has been proposed, researched and used, at least experimentally, for many purposes, including water storage, water quality improvement, habitat and community recovery and ecosystem restoration. This simple action may seem positively improving hydrologic connectivity, the major factor regulating floodplain characteristics (Forster et al., 2008). However, the ecological functioning of the floodplain-river system is complex and requires a comprehensive approach to address all the ecosystem dimensions involved in river-floodplain management and restoration.

The objective of this paper is to present and compare experimental actions performed to increase floodplain-river connectivity in order to evaluate them as alternative possibilities for floodplain restoration in a framework of global change.

2. MATERIAL AND METHODS

Four sites in the Middle Ebro River (NE Spain) were used as experimental sites to test the effects of natural flood restoration actions performed there. The four sites (Fig. 1) are located in the vicinity of Zaragoza city. Soto Francés is a floodplain 12 km downstream Zaragoza where a channel was opened, which reconnected an old channel with the river. Also in Soto Francés, excavations of two accreted zones were performed to re-create two experimental ox-bow lakes (COL). The effects of land cover on water quality were tested in two floodplains, a nature conserved one (Alfranca) versus a second one mostly used for agriculture (Ranillas). In Boquiñeni floodplain (60 km upstream Zaragoza) lateral re-connection and habitat re-creation by opening new secondary channels and small lakes in the floodplain were performed.

Data on different water, community and ecosystem characteristics were obtained before and after restoration actions were performed. Surface water samples (10 cm depth) were collected and analyzed following standard methods. Digital elevation models of the terrain were constructed using georeferenced mapping with a differential GPS and telemetric station. Multivariate analysis was applied to quantitative data of macroinvertebrates collected in a number of wetlands in the floodplains to distinguish the different communities. A simple hydrogeomorphic index was also used to evaluate the potential of these actions for riverine habitat improvement (Ollero et al. 2007).

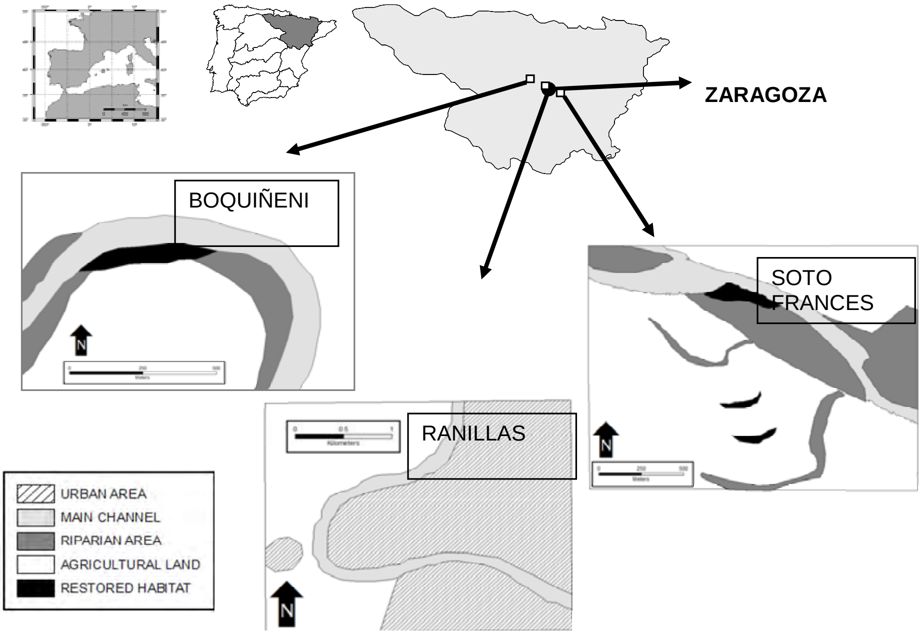

Figure 1 - Study areas in the Middle Ebro River showing the major land covers and the restored sites.

3. RESULTS

3.1 The Ebro River dynamics

The Ebro River has a significantly reduced water discharge (Fig. 2) compared to previous decades as a consequence of dams and water diversion for irrigation.

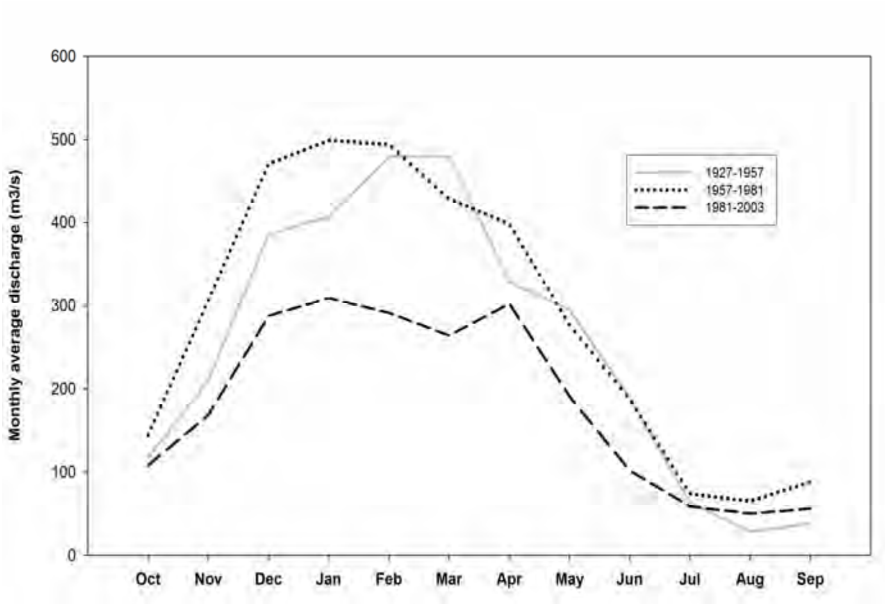

Figure 2 - Changes of the average water discharge of the Ebro River at Zaragoza during the last decades.

Large floods still take place but their geomorphic capacity is highly reduced because of dikes and artificial levees limiting transversal connectivity between the main river channel and the floodplains (Cabezas et al., in press).

3.2 Recovering connectivity through direct channel opening (Soto Frances Channel)

Slight changes of the geomorphic characteristics were observed after direct opening of the surface connection of the main river channel and an old secondary channel, which remained most of the time dry and without connection with the river. However, the opening was rapidly closed due to accumulation of gravel and woody debris after a new flood .

3.3 Increasing connectivity through excavation (Soto Frances experimental oxbow lakes)

After top soil removal and excavation to the phreatic layer the two newly created oxbow lakes increased the vertical connectivity in this accreted floodplains. Clear differences in macroinvertebrate community structure of the newly created habitats were observed compared to other wetlands in the same floodplain. Such differences were related to the relative hydrological connectivity of the sites and the life strategies of macroinvertebrates (Fig. 3 and 4).

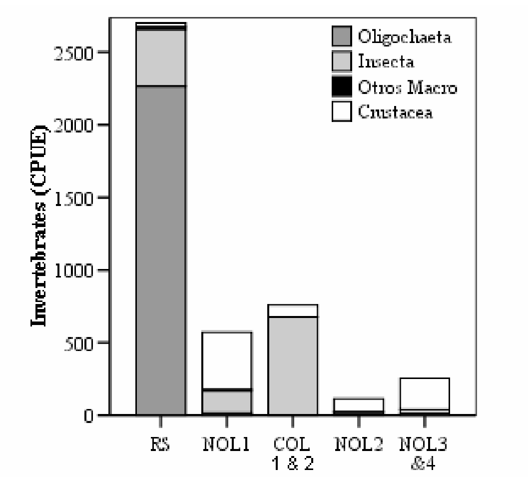

Figure 3 - Major differences in the community structure (CPUE, Catch Per Unit Effort i.e. number of individuals per sample effort unit) between excavated artificial oxbow lakes (COL) and other wetland habitats (RS:river, NOL: natural oxbow lakes) in the floodplain Soto Frances.

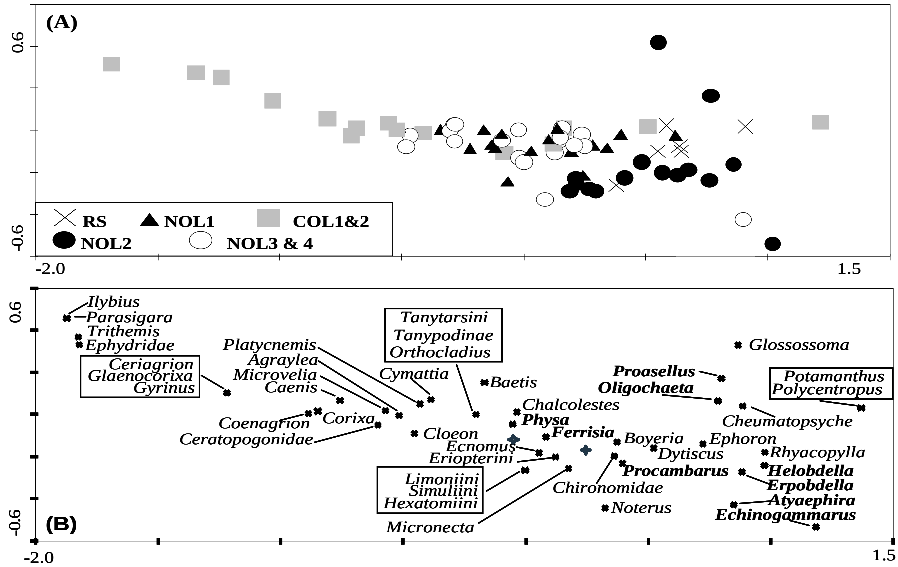

Figure 4 - Macroinvertebrate species differences between the same study sites discriminated after axis 1 and 2 of Correspondence Analysis: Samples (A) and species (B) scores.

3.4 Land-cover effect on water quality (Agricultural Ranillas versus natural Alfranca)

Agricultural land use reduced the efficiency of suspended solid and nutrient removal, as it was observed in Ranillas compared to Alfranca floodplains. However, non active floodplains may not be efficient but export both salts and nutrients during floods if the riverscape is made of homogeneous, poorly vegetated habitats, particularly in Mediterranean floodplains, because of salt accumulation in the top soil layers after intense evaporation.

3.5 Lateral channel opening and habitat recreation (Diversifying Boquiñeni floodplain)

Lateral openings and vertical excavation integrated the benefits of different actions in Boquiñeni floodplain and increased the riverscape diversity.

4. DISCUSSION

Flooding for just accumulating water temporarily is a short strategy for managing and restoring degraded floodplains, as it may increase flow regulation through artificial sluices controlling the water flow from the river to the floodplain. In large Mediterranean rivers, a more efficient strategy should involve buffering floods with habitat restoration, i.e. increasing the floodplain-river connectivity and establishing riverine corridors. This would integrate the objectives of the European Directives on floods and the conservation of natural habitats.

ACKNOWLEDGEMENTS

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OWENS RIVER (SE AUSTRALIA): DECLINE FOLLOWING EUROPEAN SETTLEMENT AND CURRENT MANAGEMENT AIMS FOR RESTORATION

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ABSTRACT

Australia has been inhabited by European settlers for just 220 years. In this time there have been significant changes to rivers either through direct modifications or indirectly through broader catchment condition changes. The settlers often set about deliberately modifying the waterways by excavating straight channels, constructing sluices, building levees, clearing out the woody debris in waterways and planting exotic vegetation, particularly willows. Dramatic changes to the catchment resulted from gold mining activity, broad scale clearing of forests, extraction of water for irrigation, over-grazing of cattle, rabbit plagues and general exploitation; which in turn influenced catchment hydrology and reduced the natural resilience of rivers to cope.

River management techniques today are varied and are often in response to some of the historical activities conducted along the rivers and in the surrounding catchment. Many rivers in Australia have large-scale sedimentation issues and in some cases, sediment slugs, mobilised in upstream reaches, continue to migrate downstream and threaten valuable riverine environments.

This paper presents the Ovens River in south eastern Australia as an example restoration and management activity. Waterway planning for the Ovens River is using a 'risk assessment' approach that considers the key values of the river, the main threats to these values and the likelihood of them occurring. The risk assessment is directing efforts towards managing the migrating sediment loads before they smother in-stream habitat as well as the removal of invasive willow species. Local communities are involved in the setting of values and priorities which then forms part of the strategic plan aimed at long term restoration and protection.

The current approach to river management is vastly different to that of Australia's early settlers and thus reflects a significant change in attitude towards waterways. Healthy waterways are now considered integral to our health and well being, as well as an asset to be preserved for future generations.

Key Words: prioritisation, planning, protection, sand, sediment.

1. INTRODUCTION

The consequences of the historical activities in the Ovens River catchment have created multiple management issues today, some of which are continuing to migrate downstream, threatening the 'heritage' status of the Ovens river.

Planning at multiple levels is undertaken in order that an informed and transparent process of prioritisation is achieved. Works are only implemented after considered planning to ensure that the investment in restoration provides confidence that local works at local sites are well chosen, justifiable and match priorities from a local to a State level.

The most efficient approach is to determine the high value assets and then focus on protecting them by determining threats to those values.

In the Ovens River catchment the Catchment Management Authority has made the necessary planning links at varied stages. State-wide priorities are used to undertake planning at regional, basin, tributary, reach, property and site levels. This planning at different stages leads to an informed basis for action.

1.1 State Planning

The Victorian State Government produced a framework document to guide decision making for the management of rivers in Victoria, The Victorian River Health Strategy (VRHS). The VRHS provided :

1. A common vision for the management of Victorian Rivers
2. A planning framework which considers environmental, social and economic factors relating to river health, with the best available science based understanding.
3. State-wide targets for river restoration.
4. Priority setting criteria for investment in river restoration; and
5. An overview of Government policy relating to the management of activities affecting river condition.

1.2 Regional Planning

The framework VRHS document and its recommendations was then used to develop the regional strategy document, The North East Regional River Health Strategy (NERRHS) which was used to guide the Government, in partnership with the community on the management and restoration of those regional rivers.

The approach to achieving the desired river health management is based on four key elements:

1. Protecting regional rivers and streams that are of highest community value from any decline in condition.
2. Maintaining the condition of ecologically healthy rivers.
3. Achieving an overall improvement in the environmental condition of the remainder of the region's rivers and streams.
4. Preventing damage from future inappropriate and/or detrimental activities.

The NERRHS was the first attempt to combine all elements of river management under one 'umbrella' document. The document integrates river health programs into a multi-disciplinary framework that considers water quality, water quantity and flow regime, wetlands, in-stream habitat, riparian flora and fauna, fisheries and recreation.

A science based tool in the form of the RiVERS database (River Values and Environmental Risk System) was used to assist in determining management priorities at the regional scale. The RiVERS data base collates a range of indices of river health and threats to river health to determine scores from which priorities for management activities can be determined at the specific stream reach level.

1.3 Local Planning

The next level of planning from the state and regional strategies is to develop a local 'Waterway Action Plan' (WAP). These plans provide:

1. Articulation and education of state and regional priorities and recommendations.
2. Refinement of the data to incorporate the local risk assessment.
3. Identification of key knowledge gaps that may require further investigation.
4. Inclusion of local information and views.
5. Generation of local support for reach based priorities prior to implementation of specific works.

1.4 Site Planning

At the completion of the WAP development process, which are at a reach based scale, priority areas and sites are relatively easily identified. Progression of these priorities into works usually requires extensive community consultation to generate ongoing supportive land management from landholders. Negotiations with landholders lead to formalised agreements called Landholder Partnership Agreements (LPA) that describe works to be implemented at the site level.

A significant amount of riparian land in the Ovens River Catchment is private leasehold of adjoining landholders therefore their participation in the planning process and acceptance of management activity is critical. Previous experience has shown that local support is usually forthcoming when the community and landholders have been involved in the planning and prioritisation. It greatly increases the acceptance of management recommendations and improves the instance of ongoing maintenance following on-ground works. The varying personalities, landscapes and issues likely to be encountered will however determine that there is no standard community and therefore no standard formula for consultation.

2. THE OVENS RIVER EXAMPLE

The Ovens River example illustrates the various levels of planning that guided site specific actions. Many of the threats to the identified values emanate from upstream tributaries. Dredging and sluicing of the stream beds for gold and tin deposits have released vast amounts of excess sediment that is moving downstream and is threatening the Lower Ovens River. The unmanaged use of exotic tree species for erosion control, particularly willows, has significantly impacted on the natural features and values of the riparian vegetation.

2.1 State Prioritisation

On a state-wide level of classification the lower reaches of the Ovens River in North East Victoria, Australia, has been listed as one of eighteen ‘heritage” rivers. This status is due to the river’s national significance. It was also identified in the VRHS as one of two ‘icon’ rivers in the state.

2.2 Regional Prioritisation

In the development of the North East Regional River Health Strategy the Ovens river was identified as a high priority based on its ‘heritage river’ status and its ‘sites of significant value’ status.

2.3 Local Prioritisation

Sediment inundation of the river environment was identified as the highest risk rating threat to the Lower Ovens River. The risk assessment conducted as part of the Waterway Action Plan process is summarised in Fig. 1 below. Geomorphologic investigations were undertaken to provide specific data on which to focus the reach based Waterway Action Plan and to assist with the Local and Site plans.

A sediment management plan was devised to maximise sediment removal as a priority river health benefit. Specific sites for were then selected for works implementation.

Values	Threats											
	Bank Erosion	Bed Instability	Barriers	Channel Modification	WQ Trend	WQ Attainment	Exotic Flora	Introduced Fauna	Loss of In-Stream Habitat	Cultivation	Stock Access	Degradation of Riparian Vegetation.
Significant Fauna						M			H		M	H
Invertebrates						H	M					H
Significant Flora							M					M
Structural Intactness							H				M	
Fish Migration			M									
Wetland Rarity			M									
Width of Vegetation										M	M	
EVC							H	M		M	H	H
Passive Recreation						M						M
Water for Irrigation				M	M							
Proclaimed Water Supply Catchment		M			M	H						
Infrastructure		H										
Land Value	M											
Tourism						M						M

Risk	High	H	Medium	M	Low	

Figure 1 - Summarised risk assessment table.

2.4 Site Prioritisation

Community consultation and planning at the local level confirmed that the scale and extent of sedimentation represented a significant threat to the health of the ‘heritage’ reach of the Ovens River. Specific sites for sediment removal by mechanical extraction were identified and implementation of works at these sites was formalised with the land managers through Landholder Partnership Agreements.

Figure 2 - The leading edge of a sediment slug in one of the tributaries of the Ovens River, pre and post removal.

3. CONCLUSIONS

Planning at a strategic State-wide level can be successfully developed to achieve site specific works when combined with relevant localised information and community consultation. Data and knowledge of important values, and the threats to them, will aid decisions on prioritisation of restoration and protection works. Planning development through the various stages can result in justifiable priorities and confidence that management efforts are maximised.

Planning at various levels, although requiring significant effort, can lead to community confidence that priorities are sound and worth adopting. Concise priorities are also valuable to agencies in setting targets and applying for Corporate or Government funding.

In a cyclic way, the work outcomes combined with the resulting knowledge and confidence gained, can lead to high value river health outcomes that continue to achieve the priorities initially identified at State level.

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AN INTEGRATED SCHEME FOR THE REHABILITATION AND MANAGEMENT OF STREAMS UNDER WATER SCARCITY CONDITIONS: THE CASE OF THE YARQON RIVER IN ISRAEL

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ABSTRACT

Rehabilitating a river in an intensive urban setting and under water scarcity conditions is a complex task that requires responsible decision at various levels, based on sound science and engineering and an atmosphere that promotes adaptive management, as well as cooperation between many types of municipalities, government agencies, NGOs and stakeholders. An additional prerequisite for success is developing and encouraging local patriotism, as opposed to direct governmental control. The Yarqon River in Israel once had natural springs with an hourly discharge of 25,000 cubic meters, which were gradually lost starting over 50 years ago due to national water policy for managing the "Mountain Aquifer", the source of the springs and since the 1950's a major supplier of drinking water. This policy, keeping the water table below spring discharge elevation, was adopted so as not to loose potential drinking water as spring discharge to the river. As a direct result of this policy, the ecological system was destroyed and the river became a sanitary and aesthetic nuisance. From the human activity perspective, the ecological damage proved to be just as negative for 6 municipalities and one regional council in terms of urban planning and the potential for recreational use. Urban planning schemes placed inferior land uses adjacent to the river and the Yarqon was lost as a potential quality area for recreation and an amenity provider to the most heavily populated area in Israel.

The Yarqon River Authority (YRA) is charged with rehabilitating the river and turning it into a recreational area in the dense urban setting. Following the decision to rehabilitate the Yarqon, it became necessary to undo adverse long term negative influences that the poor state of the river had on urban and infrastructure planning. The concept that the YRA developed is based on the Master Plan that initiated in 1994. In essence, the comprehensive plan is the basis for action plans, now in the process of implementation, that are intended to result in the rehabilitation of the ecological system to an acceptable degree of sustainability by defining and securing the necessary sources of water, with respect to quality and quantity, as well as specifying actions for pollution prevention, habitat rehabilitation, re-introducing species and invasive species eradication. The plan defines the actions necessary for two additional main issues: flood mitigation, including definition and protection of flood plains through existing statutory tools and turning the Yarqon into a major park for the large urban population. Implementing the new policies and action plans necessitated basic changes in the mode of operation in several government ministries as well as in local government elements.

Key words: water scarcity, adoptive management, master plan, flood mitigation, IWRM, wetland

1. INTRODUCTION

The Yarqon River is in part an urban river that runs through 7 municipalities in the most densely populated area in Israel. It is 28 km long, drains an area of about 1800 km^2 and is severely impacted by human activity. Before the establishment of the Yarqon River Authority (YRA) in 1988 there was no coordination between the municipalities regarding any of the river's potentials or problems. Two major processes influenced the Yarqon: diversion of the springs for domestic water supply, to the extent that spring discharge stopped, and increased pollution from sewage, low quality effluent and agricultural and urban non-point sources. This caused severe decline in habitat diversity and poor conditions in the remaining habitats. The natural fauna and flora were displaced by species tolerant to low or no flow and to pollution, and the river lost its natural services and became a health hazard and an aesthetic nuisance (Gasith, 1992; Gasith et al., 1998; Gafny et al., 2000). These conditions, which prevailed for over 40 years, influenced urban planning processes and development projects, resulting in the establishment of inferior land uses along substantial parts of the river. In 1994 the YRA initiated the preparation of a Master Plan for the rehabilitation of the Yarqon, based on the legal framework for the protection of water sources in Israel (Gasith & Pargament, 1998).

The interdisciplinary team put together by the YRA was led by an urban planner and this was the first such meeting in Israel between professionals from the planning disciplines and those from ecology and hydrology. The Authority, though not in charge of the whole watershed, operates on a watershed basis in many issues and one of the guiding philosophies is to encourage participation of its members and stakeholders in planning and policy making process, including that of the Master Plan. This was affected by using an open, trust building process, which resulted in wide and prompt acceptance of the plan and furthermore, local and national government began acting according to the plan immediately following its approval in 1996.

The YRA's Board of Directors formulated the terms of reference (TOR) for preparing the Master Plan, thus creating a wide base of agreement among the members right from the start. Preparation of the plan required a holistic overview of the river system and integration of its rehabilitation needs.

The goals of the Master Plan are (Rachamimoff & Brandeis, 1996):

1. to create and secure a “green lung” for the most populated region in Israel;
2. to change the current public attitude toward the Yarqon from a “back yard” to an urban “front yard”;
3. to rehabilitate the river’s ecosystem and improve the water quality by solving the problems created by the discharge of sewerage and low quality effluent;
4. to provide appropriate solutions for river regulation and flood hazard reduction;
5. to suggest economic initiatives for river uses compatible with the principles of sustainable development;
6. to improve the environmental and aesthetic values of the river and its adjacent corridor.

The planning process provided the impetus for moving forward towards implementing the Master Plan in all of the aspects. This approach serves as a model for the rehabilitation of other streams and rivers in Israel.

2. THE INTEGRATED WATERSHED MANAGEMENT APPROACH

The YRA’s main activities include initiating planning processes and implementing projects in addition to involvement in regional planning and infrastructure projects that may influence the river and its tributaries, with respect to the Master Plan. These activities are in the following main categories:

1. Drainage and flood control – detailed surveys and flow modelling are the basis for decision making. Plans for flood mitigation are being established on a watershed basis and include the definition and protection of floodplains and the use of abandoned quarries for floodwater storage in order to reduce peak discharges and to lower flood water elevations of the design flood. Actual changes of the river cross section will be based on the level of protection for areas in danger of inundation. The highest level of protection is designed for residential areas and the least for agricultural land. Parks and roads are in between.

2. Environmental and ecological rehabilitation – the extensive damage to the ecological system includes damage due to mosquito eradication activities. This necessitated the rehabilitation of over 20 Km of riparian vegetation and river banks, in addition to removal of invasive species.

3. IWRM and Watershed Management – water scarcity conditions call for integration of the river’s needs and the national water needs. Allocation of water for the river requires a plan to reuse the water before it flows into the section that is an estuary. Reuse projects include treatment of the river’s

water to the quality that will allow unlimited irrigation of agriculture and parks.

4. Recreation – The Yarqon serves as a major area for recreational activities, including boating. As the rehabilitation process is proceeding, so are the pressures, mostly from the municipalities, to develop parks, bicycle paths, camping grounds and other recreational facilities.

5. Maintenance – All of the plans and projects include the necessary details and fund allocations to ensure proper maintenance of the river corridor, including all of the ecology related aspects.

3. ECOLOGICAL REHABILITATION

One important outcome of the Master Plan is a Governmental Directive from 2003 for the rehabilitation of the ecological system, including definitions of water sources with respect to quantities and to qualities and additional actions specified below. The Directive, now being implemented, also defined the sources of funds for the following actions:

A. Water - allocation of water to maintain the river's continuity and reasonable habitat conditions. The sources include spring flows and tertiary quality effluent that together with the winter floods, are expected to reinstate a Mediterranean-type flow regime. The effluents will pass through a constructed wetland for cancelling out expected fluctuations in effluent quality, in addition to removal of pesticides, insecticides, compounds form medicinal sources and hormones. The designed wetland will also provide a quality habitat adjacent to the river and the park system being developed.
B. Pollution - installing pollution prevention elements such as dry weather pumping stations on urban drainage systems and working with farmers to further prevent non-point source pollution;
C. Ecology - reconstruction of runs, riffles, pools and aquatic vegetation as well as reinstating the structural and functional properties of the riparian zone;
D. Flood mitigation - adopting principles compatible with ecological requirements;
E. Coordination and limitation of building and development plans to include on-site water storage and runoff control; Designation of areas adjacent to the river as flood plain zones and safeguarding them through the Planning and Building Law;
F. IWRM - construction of a water-reuse project for the water flowing in the river. The project will begin before the water enters the estuary section and will serve for irrigating parks and agricultural land;
G. Designation of areas adjacent to the river as recreational sites and implementing suitable development projects

4. THE CRUCIAL ROLE OF THE MANAGER IN WATERSHED MANAGEMENT

The primary measure for effective management of the Yarqon watershed, or any watershed, is the ability to implement policy and projects. This implies the need for a designated organizational structure, necessary within any governance system, with a manager charged with executing policy and projects. The manager, operating by the principles of adaptive management, both inward and outward, must act with determination, professionalism and creativity to develop a policy that reflects the Yarqon's needs in view of the functions and amenities that it is expected to provide according to the Mater Plan and to act towards its implementation. The manager is the link, the glue, between the numerous and distinct elements that influence the Yarqon and its management, particularly in view of the incompatibility with most governance systems. These elements include the following types of organizations, as well as the politicians and managers at their heads:

Government ministries - initiate laws and regulate policy implementation concerning land use, building and development, transportation and other infrastructures, drainage and flood mitigation policies, public health issues and more. In countries with water scarcity, IWRM is also an important factor in defining and maintaining environmental flows. These are "top down" elements that reflect national policies.

Local municipalities - govern parts of watersheds, influence hydrology and, in many cases, seek to increase amenities associated with river corridors. The local experience and knowledge, including that of additional stakeholders, is an important and integral part of the management scheme.

Public utilities and infrastructure companies – such as electricity suppliers, sewage works, road and railroad companies, that influence the watershed in various ways.

Stakeholders - maintain an ongoing relationship with rivers such as farmers, boaters, fisherman, the public, mainly with respect to recreational interests, NGO's and "green" organizations.

The YRA initiates an open and inclusive decision making and planning processes to create consensus and understanding of the needs among a majority of partners. This includes consultations with a variety of scientists in order to create a strong scientific base for its decisions for all ecological and environmental issues and the employment of engineers and landscape architects, who use state of the art data and tools for developing and presenting alternatives to decision makers. The YRA holds meetings with participants from many types of stake holders and many of them are encouraged to participate in planning forums and other meetings designed to demonstrate the public's benefits of a rehabilitated Yarqon, including the aesthetic and economical advantages associated with the projects.

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THE PANARO RIVER (NORTHERN ITALY): DEFINITION OF POSSIBLE STRATEGIES FOR RIVER RESTORATION

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ABSTRACT

The Panaro River is a representative case of deeply-incised and degraded river located in the Northern Apennine (North Italy). A research project was funded by the Modena Province, aimed to define possible mitigation strategies for existing problems and to promote river restoration. An integrated geomorphological and ecological study was carried out, including the main following aspects:

1. Geomorphological study, including an analysis of historical and recent channel changes, bed sediment sizes, present channel forms, and geomorphic processes.
2. Ecological study, including an analysis of riparian vegetation, macroinvertebrates, aquatic and riparian habitats and diversity, fish fauna, water quality.

Based on the analysis of the present geomorphological and ecological conditions, the main problems have been identified, including the following: (1) High channel bed incision (up to 10 m); (2) Numerous ecological problems strictly related to the physical degradation. A series of strategies and measures for future river management and restoration have been identified, including: (a) delimitation of a fluvial corridor to be used to allow lateral mobility to the channel and to adopt river restoration strategies; (b) proposal of interventions of channel widening, recreation of an active floodplain (by lowering the terrace surface) and/or secondary (side) channels, strategies for increasing sediment recovery, including artificial reintroduction of gravel at present stored in the floodplain; (c) strategies to improve habitats and riparian zones by management of riparian vegetation; (d) strategies to improve water quality, by reducing organic loads, and increasing the capacity of self- purification; (e) strategies to reduce pollution from agriculture and livestock farming (buffer zones, restoration of canals, creation of wetlands, etc.).

Key words: Geomorphic recovery, Panaro River, channel incision

1. INTRODUCTION

The Panaro River is a heavily incised and degraded river. The extremely high bed incision (up to 10 m) caused in some reaches the loss of the entire thickness of alluvial deposits and the incision of the bed into the underlying clay substratum. The river suffers of a persistent deficit of sediments, discontinuous bedload flux, scarcity of sediment sources, ongoing gravel mining, and presence of several weirs. Many ecological problems are strictly related to the physical degradation, such as loss of habitats, particularly along the reaches incised into the clay substrate, interruption of lateral continuity of ecosystems, lowering of the water table with effects on the riparian vegetation. For all these reasons, a river restoration project started in 2006 (Rinaldi et al., 2008a), aimed to identify possible strategies to recover geomorphic processes and forms, and to improve the ecological conditions of the river and its corridor.

Referring to the 12 steps process for river rehabilitation (LWRRDC – CRCCH, 1999), this research project can be considered to have covered the first 6 steps (1. Vision and goals; 2. Gain support; 3. Assess stream condition; 4. Identify problems and assets; 5. Priorities; 6. Strategies) of an entire restoration process, building the basis for the subsequent steps (7. Setting measurable objectives; 8. Feasibility; 9. Detailed design; 10. Evaluation; 11. Implementation; 12. Maintenance and evaluation).

We used an integrated approach, mainly based on the understanding of the physical and biological processes and identification of problems and causes of degradation. This paper summarizes the methodologies, main results of the river problems assessment, and the proposed restoration strategies.

2. GENERAL SETTING

The Panaro River is located in Emilia Romagna, northern Apennine (Italy). The catchment has an area of about 1783 km^2;the river is one of the most important tributaries of the Po River, and has a total length of about 165 km. The catchment presents a hilly – mountainous upper zone, dominated by sandstones and clayey – marls, while the medium – lower area is mainly occupied by recent alluvial deposits. The mean annual precipitation is about 1017 mm.

The river was divided in a series of reaches: four main segments (PA, PB, PC, and PD) were defined, reflecting the major structural controls (direction and confinement of the alluvial valley floor); some segments were further divided into sub-units based on channel morphology, resulting in a total of 7 sub-reaches (PA, PB1, PB2, PC1, PC2, PD1, PD2). The study reach, having a length of about 34 km, is located along the middle portion of the basin (including the lower portion of PA, and the sub-reaches PB1, PB2, PC1, PC2).

3. RIVER ASSESSMENT

An integrated geomorphological and ecological study was carried out, including the main following aspects:

1. Geomorphological study, including an analysis of historical and recent channel changes, bed sediment sizes, present channel forms, and geomorphic processes.
2. Ecological study, including the analysis of riparian vegetation, macroinvertebrates, aquatic and riparian habitats and diversity, fish fauna, water quality.

3.1 Geomorphic analysis and problems

A detailed GIS analysis of channel changes was carried out using a multi-temporal series of maps and aerial photos (1890, 1934/35, 1954/55, 1962/69, 1981, 1997, 2000, 2007). The trends of variation in active channel width were reconstructed, based on the GIS analysis, and are shown in Fig. 1, where the progressive reduction in channel width through time is evident.

A series of sedimentological and geomorphological field surveys were conducted during the period of research. Sediment samples were collected from channel bars and pebble counts were conducted at a total of 9 locations along the sub-reach PB. Median diameter of bed sediment ranged from 27.1 to 90.0 mm (average of 49.0 mm). Previous studies and information regarding the bed-level lowering were available, indicating a range from 4 to 6 m in the sub-reaches PA and PC, and from 6 up to 10 m in the sub-reach PB.

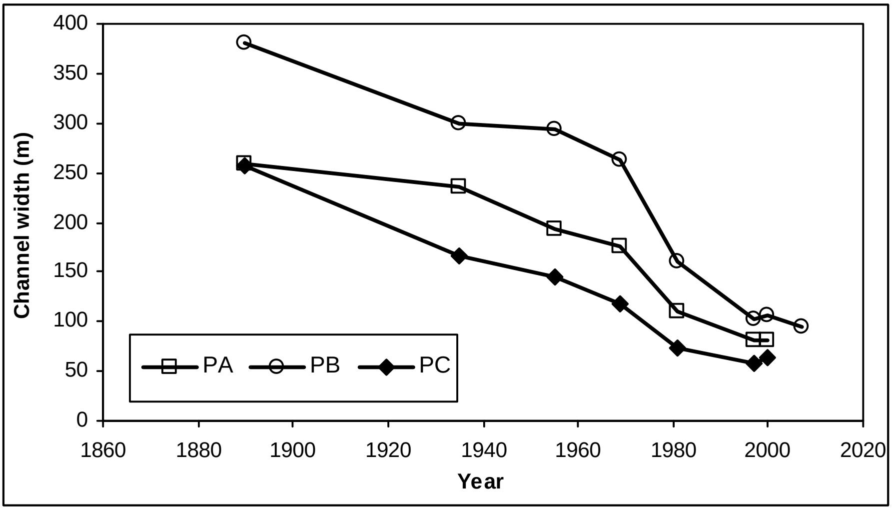

Figure 1 – Changes in channel width along the three sub-reaches (PA, PB, and PC) of the Panaro River.

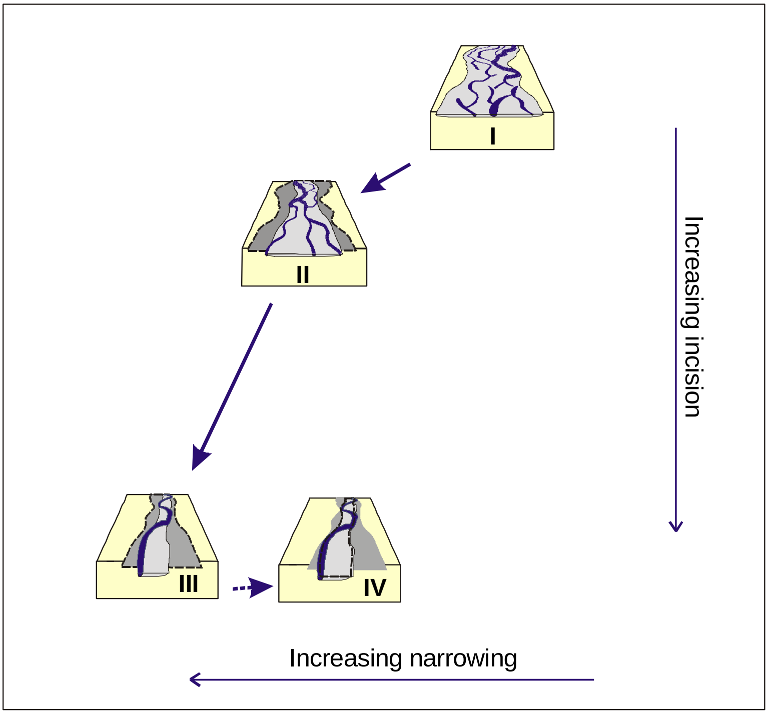

Figure 2 – Model of channel evolution for the study reach of the Panaro River.

All the information and results of the geomorphic analysis can be summarised in a channel evolution model (Fig. 2). From the model, two phases of channel adjustment (incision – narrowing) can be distinguished, with the phase of major changes occurring between the 50's and the beginning of '90s. Such changes appear strongly connected to human impacts, with quite evident causes-effects relations: intense gravel mining during the decades of major channel changes was the main disturbing factor. During the last 10-15 years, an inversion of trend of channel width (widening phase) occurred only locally along PA and PC, whereas for PB the recent photos of 2007 show a continuing narrowing process. The lack of a beginning phase of partial morphological recovery, as observed in other Italian rivers with similar characteristics (Surian & Rinaldi, 2004; Rinaldi et al., 2005, 2008b), can be related to the following factors: (1) substantial and persistent deficit of bed sediment (the channel bed in some point is incising in a clayey substrate); (2) longitudinal discontinuities (several weirs) which prevent a continuity in the flux of sediments; (3) excavation of sediment, in some cases still in progress, as a maintenance measure.

3.2 Ecological analysis and problems

A series of field survey analyses and GIS-based methodologies were performed. A continuous IFF survey was conducted to get a “first-look” useful to river characterization.

Photo interpretation of meso-scale channel habitats (riffles, pools, bars) showed a spatial correlation between weirs presence and loss of habitat extension and diversity due to impoundment (Fig. 3). Data also showed a correlation between overdeepened reaches and presence of xerophylic vegetation, probably due to lowering of the water table in river terraces.

Figure 3 – Some of the weirs along the study reach of the Panaro River, with loss of habitat extension and diversity due to impoundment, and channel incision downstream the weirs with related destruction of aquatic habitats and loss of lateral connectivity with riparian zones. A) Marano; B) between Marano and Vignola; C) Vignola; D) Savignano; E) Marano; F) S.Cesareo.

The CARAVAGGIO survey was conducted in eight locations and primarily showed the influence of weirs on changing the river to more lentic habitats. Data collected within CARAVAGGIO were also used to evaluate both microhabitat and lateral connectivity. Results confirmed the correlation between presence of weirs, overdeepening, and destruction of aquatic habitats; moreover, an evident association between overdeepening and lack of lateral connectivity was observed.

The macrobenthos community was sampled at the same eight locations. A general correlation between habitat diversification and community complexity was verified. Analyses and surveys performed on river vegetation confirmed the correlation between lowering of water table in overdeepened reaches and habitat shift to xerophylic typologies. Locations with high ecological value and hot spots of naturality and diversity were also identified.

A ten-year series of water chemical data was provided by the local environmental agency (ARPA). Main locations of organic waste dump from water treatment plants were checked, documented and marked within GIS database.

4. STRATEGIES FOR RIVER RESTORATION

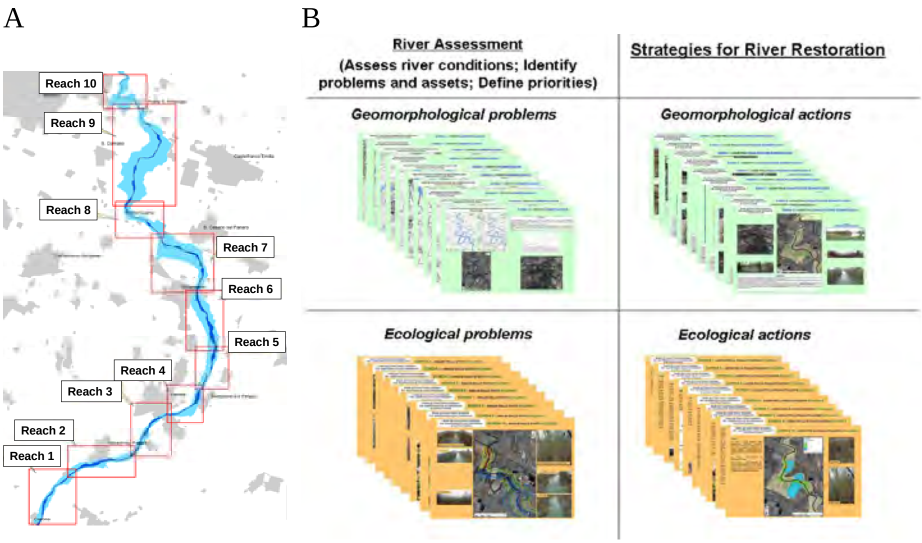

Figure 4 – Summary of the tables containing the proposals for river restoration. A) Summary of the reaches. B) Tables of river assessment and tables of strategies for river restoration.

Results of the integrated assessment phase were summarised together with the proposed strategies for river restoration in a series of illustrative tables. For this scope, the river was divided in 10 relatively homogeneous reaches (Fig. 4A), and for each one four tables were prepared (Fig. 4B): 2 tables summarising problems and assets for the geomorphological and ecological aspects respectively, 2 tables summarising interventions and management strategies for the geomorphological and ecological aspects.

4.1 Strategies and interventions for geomorphic recovery

Based on the problems defined during the assessment phase, a series of strategies were identified as suitable for promoting geomorphological recovery, including:

- delimitation of a fluvial corridor to be used to allow lateral mobility to the channel and to adopt river restoration strategies;
- proposal of: interventions of channel widening, restoration of an active floodplain (by lowering the terrace surface) and/or secondary (side) channels, strategies to increase sediment recovery, including artificial reintroduction of gravel stored in the floodplain.

Table 1 – Classification of proposed interventions for geomorphic recovery.

<table>
<tr><th>Conditions</th><th>Type</th><th>Actions Phase 1</th><th>Type</th><th>Actions Phase 2</th></tr>
<tr><td rowspan="3">Very critical morphological conditions: intense channel incision and narrowing</td><td>1.1</td><td>Creation of secondary channels</td><td colspan="2" rowspan="2"></td></tr>
<tr><td>1.2</td><td>Channel widening</td></tr>
<tr><td>1.3</td><td>Creation of active floodplain</td><td>1.3-F2</td><td>Creation of active floodplain</td></tr>
<tr><td rowspan="3">Presence of anthropic elements of disturbance</td><td colspan="2" rowspan="3"></td><td>2.1-F2</td><td>Removal of embankments</td></tr>
<tr><td>2.2-F2</td><td>Moving roads open to lorries away from the river corridor</td></tr>
<tr><td>2.3-F2</td><td>Relocation of quarries located along the river</td></tr>
<tr><td rowspan="2">Presence of opportunities to combine socio-economic needs with river restoration</td><td>3.1</td><td>Creation of secondary channels</td><td colspan="2" rowspan="2"></td></tr>
<tr><td>Type 3.2</td><td>Creation of active floodplain</td></tr>
</table>

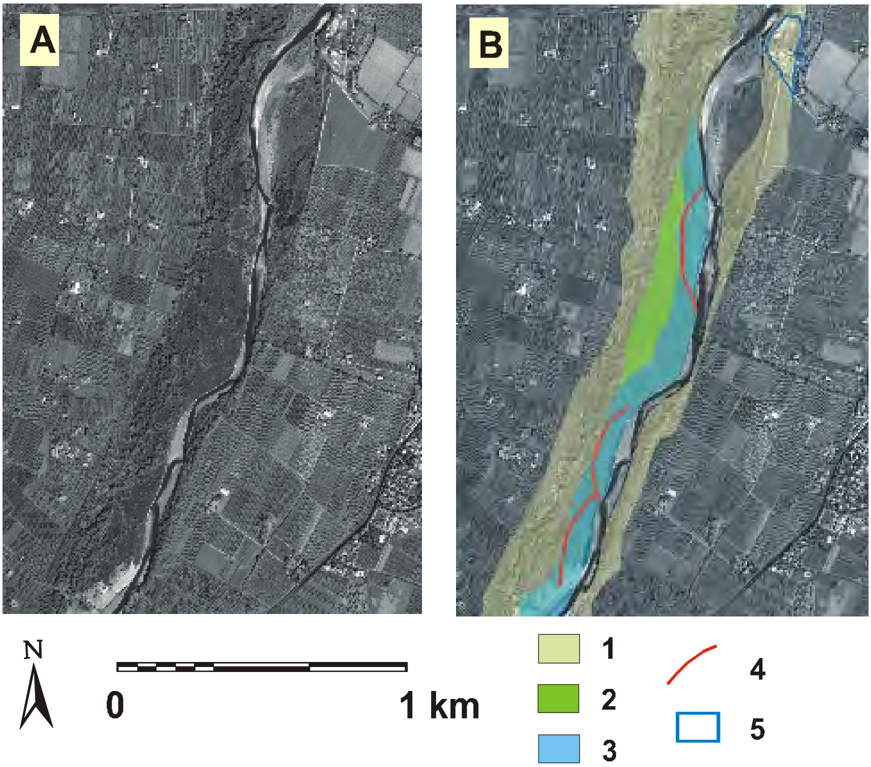

Figure 5 – Example of proposed interventions for geomorphic recovery. A) Present situation; B) Proposed interventions. 1: Delimitation of the fluvial corridor; 2: Creation of active floodplain; 3: channel widening; 4: creation of secondary channels; 5: relocation of quarries adjacent to the river.

These strategies were transformed in specific actions, and localised along the study reach in the illustrative tables. More in detail, three typologies of interventions were distinguished (Tab. 1):
(1) Very critical morphological conditions (intense channel incision and narrowing): these are actions directly aimed to mitigate geomorphic problems.
(2) Presence of anthropic elements of disturbance: they include situations not necessarily associated with critical geomorphic conditions, but which create significant disturbances to the fluvial environment (quarries adjacent to the river, roads for the traffic of lorries associated with quarries, etc.).
(3) Presence of opportunities to combine socio-economic needs with river restoration: these include situations not classified as necessarily critical from the geomorphological point of view, but where there are other opportunities to combine socio-economic needs with interventions for geomorphic

recovery (for example excavation of a terraced surface to create an active floodplain combined with already planned mining activities).

In terms of priorities and time scale of the interventions, they are divided in actions to be carried out in the short term (Actions in Phase 1), and actions in the medium – long term (Actions in Phase 2).

An example of map included in the illustrative tables (Fig. 4B) and reporting the localization and typologies of proposed interventions for geomorphic recovery is shown in Fig. 5.

4.2 Ecological strategies and interventions

The proposed ecological strategies and interventions included: (a) operations to improve the ecological value of habitats, riparian zones and wetlands, and to recover lateral connectivity. Proposal of "close to nature" bypasses to eliminate longitudinal connectivity problems caused by weirs. (b) Intervention strategies to improve water quality by upgrading existent water treatment plants with phyto-depuration plans, thus reducing point sources of pollution. General increase in physical habitat quality would permit to achieve a better water chemical status due to the restoration of river functionality. (c) Strategies to reduce diffuse pollution from agriculture and livestock farming (buffer zones, restoration of canals, wetlands, etc.).

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A MODEL BASED ANALYSIS OF MEANDER RECONNECTION

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ABSTRACT

River restoration is a widely applied measure to enhance the ecological status of riverine systems. The historical river type is a main source of information when restoring river systems. Different techniques of meander reconnection are discussed and different scenarios are analysed in detail. The effects of different forms of meander reconnections on flow dynamics, water level and river morphology, deducted on the basis of a physical model study and a 3D hydrodynamic numerical simulation of the Raab River in Austria, are analysed and discussed. Due to the diversion of discharge to the meander and the remaining flood channel, in cases of floods flow velocity and bed shear stress decrease after the flow diverts into the reconnected meander and the flood channel which leads to aggradation. The flow velocity decreases in the meander bend at higher discharges while it increases in the flood channel. The controlling parameter concerning flow diversion is the elevation of the ramp which diverts the flow to the meander and the flood channel.

A post-processing module of the hydrodynamic code RSim-3D allowed a particle tracing study based on the model of the Raab River. With this module a simulation of trajectories of conservative particles in 6 vertical levels was conducted. The vertical movements of the particles on trajectories going through the reconnected meander were investigated by calculating the number of level changes of each particle. A larger radius of the upstream meander connection leads to more level changes compared to a scenario with a smaller radius of the meander connection. This effect is attributed to the secondary flow at different meander connections.

Key words: River restoration, 3D-hydrodynamic numerical modelling, particle tracing

1. INTRODUCTION

Ecological and morphological aspects should be well investigated before restoring or rehabilitating anthropically influenced rivers (Newson & Large, 2006; Shields et al., 2003a, b). Restoring rivers was, and still is, a major goal of European and worldwide river engineering (Kronvang et al., 1998; Pedersen et al., 2007; Shuman, 1995). Morphological aspects are particularly important for a successful restoration and to minimize maintenance work. Modifications of the planform geometry of structural elements can induce undesirable morphological and ecological consequences and significant channel adjustments that, depending on the energy of flow, can result in failure of the restoration design through either erosion or sedimentation (Merritt & Cooper, 2000; Rinaldi & Johnson, 1999). Therefore, sedimentation analysis is a key-aspect of river restoration (Shields et al., 2003a).

Meander reconnection is a challenge for river rehabilitation. The morphological aspects are problematic because of sedimentation in the cut-off bend (Shields & Abt, 1989). Due to the distorted river system and hydraulic conditions, the reconnection often fails or is only preserved in the long-term by costly maintenance work.

Different characteristic discharges were applied to investigate the dynamics in the reconnected meander as well as in the flood channel. Long-term successful meander reconnection might occur when flow is permanently diverted into the meander. If the regulated river is used as a flood channel, the flow should in any case be directed into the meander at least until bankfull discharge is reached. It is assumed that rivers tend towards an equilibrium condition in which the rate at which sediment leaves a particular reach is roughly equal to the rate at which sediment enters that reach (Lauer & Parker, in press). Bifurcations may lead to significantly different equilibrium configurations (Miori et al., 2006).

2. RECONNECTION OF MEANDERS

Ever since the EU - Water Framework Directive is implemented in Austrian legislation, the main focus of river engineering has been to restore the good ecological status of rivers.

Reconnection of meanders is an applied measure of river restoration in Austria where the historical river type had a meandering characteristic (Hauer et al., 2007). So far, numerous research have focused on different types of river restoration which enhance the ecological and hydromorphological status. Some research of Shields & Abt (1989) concentrated on geomorphology while reconnecting meanders to the channel.

In any scenario of meander reconnection the diversion of the flow in the meander and the flood channel is important for the success of the restoration.

The reconnection of meanders should always be close to the natural conditions of flow magnitude and dynamics in order to reach an optimal long-term success. Fig. 1 illustrates the studied scenario where the flow is directed into the meander bend at discharges close to HQ_1. We hypothesize the ideal scenario with the dashed line: the flow should be diverted into the reconnected meander until bankfull discharge to obtain a flow similar to a natural situation. The flood channel should only be used in those cases where the discharge reaches the bankfull discharge.

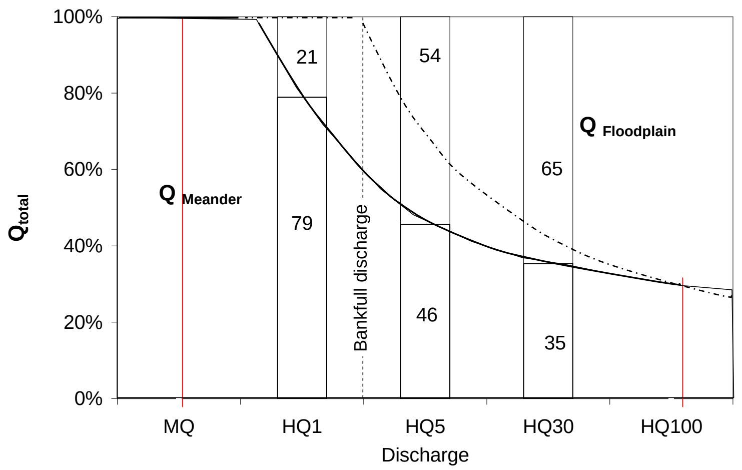


Figure 1 - Flow diversion into the reconnected meander and the floodplain at relevant discharges; the solid line represents the studied scenario A; the dashed line shows the ideal flow diversion in this scenario.

3: CASE STUDY RAAB RIVER

The study reach is situated in south-eastern Austria (Fig. 2). The soil cover is dominated by alluvial deposits and loamy materials. Upstream parts of the catchment area consist of calcareous and crystalline rocks (HAÖ-BMLFUW 2007).

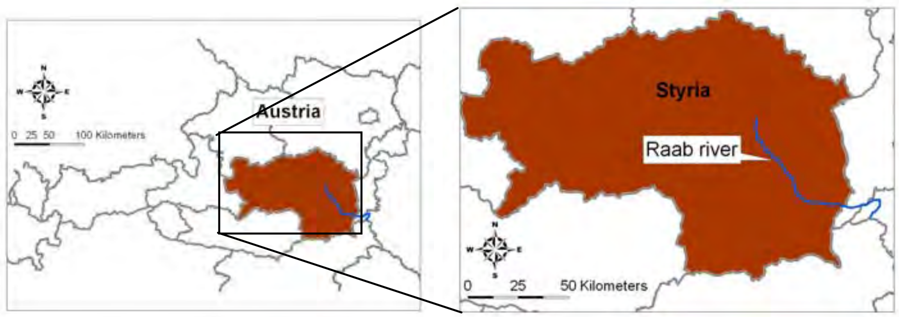


Figure 2 - Location of the Raab River (Source: HAÖ-BMLFUW, 2007).

The investigated reconnected meander drains a catchment area of 787 km². The studied river reach has an average slope of 1.5 – 2 ‰ and a width up to 25 m.

Before regulation the Raab River was a meandering river. Changes in the hydraulic regime are due to many small hydropower plants.

In this case study, the upstream connection of the meander was accomplished with a ramp. Because sedimentation in the meander leads to changes in the meander morphology it is necessary to obtain high specific stream power in the meander.

4. METHODOLOGY

A physical model study and 3D hydrodynamic-numerical simulations were conducted to study the flow dynamics in the reconnected meander. Five different scenarios were investigated (Tab. 1).

Table 1 - Overview of the different scenarios of the physical model study

Scenario	Form of meander connection	Elevation of the ramp [m a. sealevel]	Scenario	Form of meander connection	Elevation of the ramp [m. a. sealevel]
A	small radius	~ 292.2 m	**C**	large radius	292.0 m
B	small radius	292.7 m	**D**	large radius	292.7 m
E*	small radius	292.7 m			
*elevated flood channel					

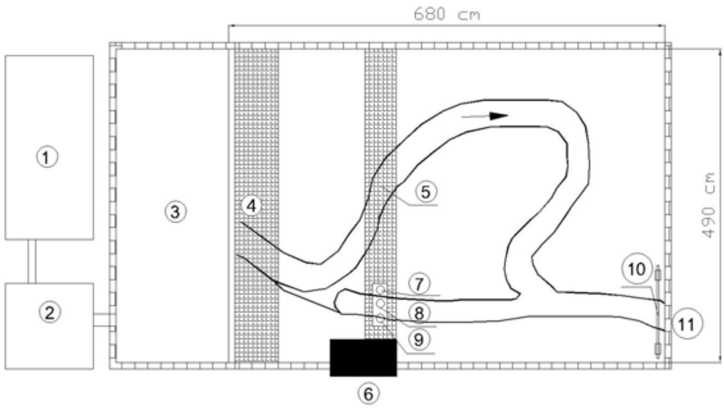
In this case study we compared the effects of the planform of the meander reconnection and those of the elevation of the ramp on the flow dynamics and the water table at characteristic discharges. The discharge values which were used in the physical model study as well as in the hydrodynamic-numerical simulation are shown in Tab. 2.

Table 2 - Comparison of discharges used in the physical model study and the hydrodynamic-numerical simulation.

Recurrence intervall	Discharge nature [m³/s]	Discharge physical model study [l/s]
1	85	6.26
5	145	10.67
30	212	15.61

A physical model of the river Raab in Styria was developed at a scale of 1:45. In order to measure water level and flow velocity at characteristic discharges, it was convenient to develop it with fixed bed. Concrete was chosen as the building material to derive the equivalent roughness. For the flood channel and the floodplains the roughness was adjusted adequately. In

Fig. 3 the physical model of the flume is illustrated along with the technical equipment.



Legend:

1	Water tank	**7**	Electromagnetic current meter
2	Discharge gauge	**8**	Ultrasonic sensor
3	Stilling tank	**9**	Laser
4	Bridge	**10**	Instruments for adjusting the downstream water level
5	Trolley	**11**	Outlet
6	Computer and display unit		

Figure 3 - Physical model with equipment.

The water surface level was also investigated to analyze the effects of the elevation of the flood channel bed on flood protection (scenario E).

In the physical model study the flow velocities were measured with a 3D electromagnetic current meter (ACM 300D). The water level was measured with an ultrasonic sensor. Both devices were fixed on a trolley which was could be moved over the entire length and width of the experimental flume.

In Fig. 4 a schematic view of the 2 different planforms of the reconnected meander are shown. Attention should be drawn to the upstream meander connection and the planform of the ramp. The radius of the connection is larger for Fig. 4(a) than for Fig. 4(b).

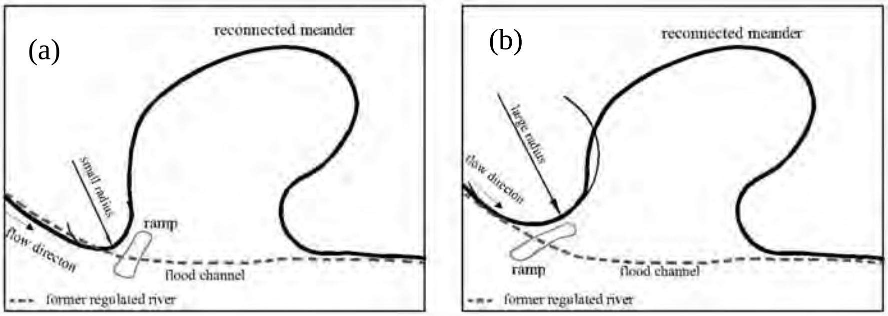


Figure 4 - Schematic view of the different planforms of the reconnection of the meander with a large (a) and small (b) radius.

5. RESULTS

At higher discharge the flow velocity ratios in the flood channel (former regulated channel) increase and at the same time the flow velocity ratios in the reconnected meander decrease because with higher discharges the flow diverges more into the flood channel. In the flood channel a higher slope as well as smaller cross sections lead to higher flow velocities (Fig. 5). When increasing the discharge, the higher water level at the downstream connection of the reconnected meander and flood channel results in a smaller energy slope in the reconnected meander. The flow velocity ratios of meander and flood channel are closely related to the elevation of the ramp. For a higher ramp (scenario B, scenario D) the flow velocity ratios increase with discharge in the meander, whereas the ratios in the flood channel decrease.

The relation between the flow velocities in the flood channel and in the reconnected meander are illustrated in Fig. 5 for different discharges; flow velocities of HQ_1 and HQ_{30} at scenario C (a) and HQ_5 and HQ_{30} at scenario A (b) are compared. With higher discharges in both cases the flow velocity decreases in the reconnected meander and increases in the flood channel, as discussed above.

A main reason for measuring the water level was to gather information about the effects of the different elevation of the flood channel bed on the water level. Scenario E shows the design of the flood channel with an elevated bed level compared to scenario B. The ratios of the water level between HQ_{30} and HQ_1 as well as HQ_5 and HQ_1 were calculated to study the effect of, for instance, sedimentation in the flood channel (Fig. 6). The rise of ratios downstream at HQ_{30}/HQ_1 is due to the higher water level at the confluence at HQ_{30} compared to HQ_1 in scenario B and scenario E. However an increase of discharge to HQ_{30} had a larger impact on the water level ratios of scenario B. Despite an elevated bed level of the flood channel in scenario E, the water level ratios of HQ_{30}/ HQ_1 were smaller than in scenario B.

Hence, sedimentation in the flood channel does not affect the water level and flood protection and does not lead to a higher water level in the studied flood channel and the reconnected meander at HQ_{30}.

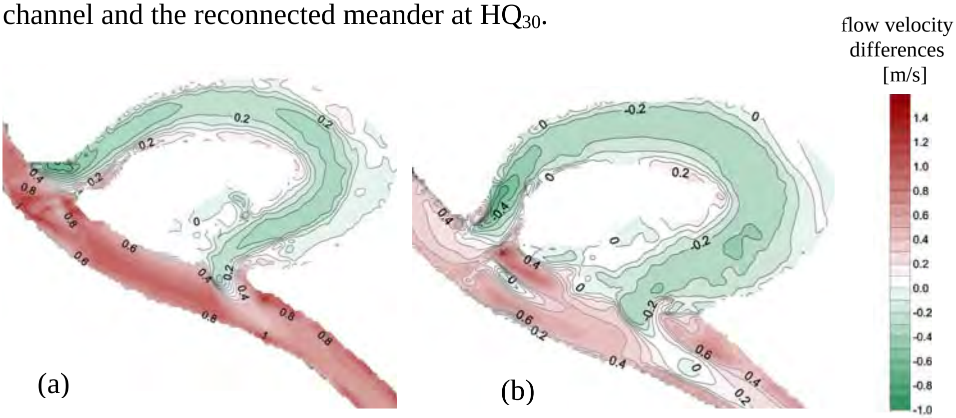


Figure 5 - Flow velocity differences between HQ_1 and HQ_{30} at scenario C (a) and between HQ_5 and HQ_{30} at scenario A (b). Flow direction is from top left to bottom right.

The water level ratios of HQ_5/ HQ_1 show the impact of the elevated bed level of the flood channel in scenario E. In this scenario the water level ratios are significantly higher than in scenario B. A rise of the water level at scenario E compared to scenario B was expected.

Particle tracing was performed using a post-processing module of the hydrodynamic code RSim-3D (Tritthart, 2005). With this module a simulation of trajectories of conservative particles in 6 vertical levels was possible. Fig. 7 gives an overview of a scenario with particles starting at level 4. Transport paths of individual granular particles of infinitesimal size were calculated.

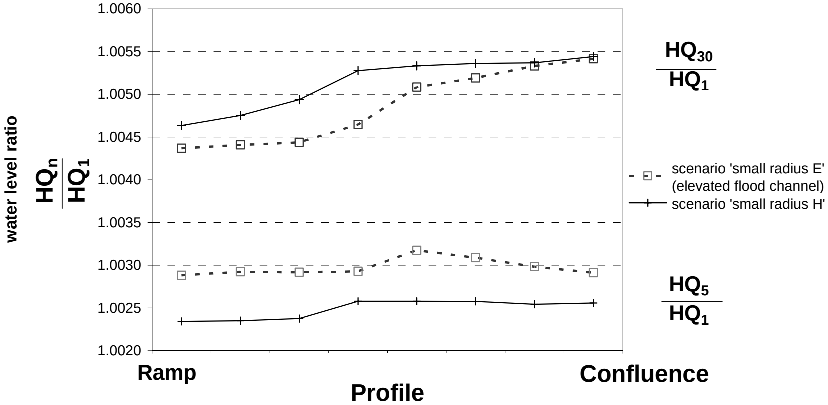


Figure 6 - Comparison of the water level ratios of scenario B and scenario E (elevated bed level) in the flood channel (f_c) at HQ_5 and HQ_{30}.

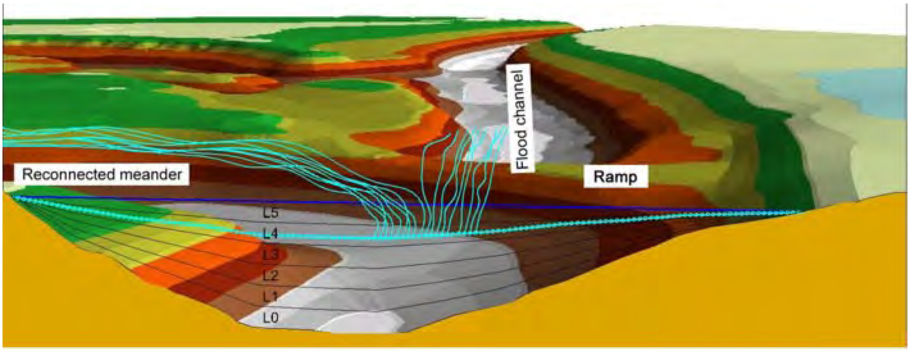


Figure 7 - Schematic drawing of the reconnected meander and flood channel; particles with start level 4 transported in the reconnected meander and flood channel are illustrated; the six vertical levels are drawn for one cross section.

The results of the particle tracing are visualized for scenario C at a discharge of HQ_{30} in Fig. 8 where the start levels of the particle at the ground level L0 (a) and the surface level L5 (b) are shown. The diversion of trajectories going into the meander and the flood channel are clearly correlated to the start level of the particles. At start level L0 the majority of trajectories move into the meander; by contrast, a higher percentage of the particles starting at level L5 are directed to the flood channel. The colours of the trajectories visualize the vertical level of each particle in 1" time-steps.

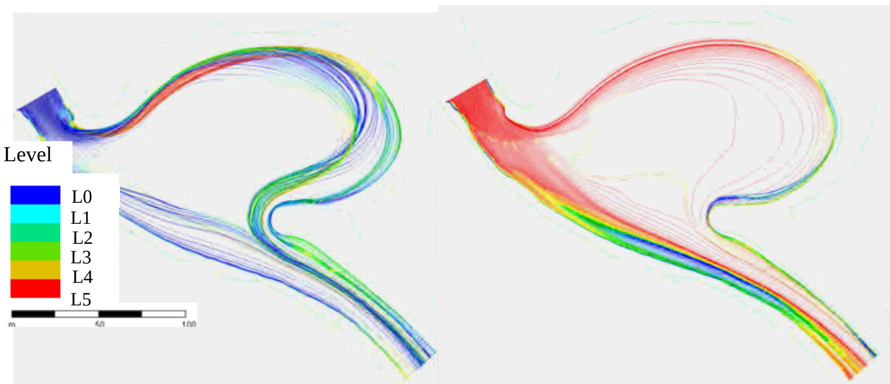


Figure 8 - Particle level changes where the start level is the ground level L0 (a) and the surface level L5 (b) for scenario C and discharge HQ_{30}. Flow direction is from top left to bottom right.

6. CONCLUSIONS

The hydrodynamic and morphological aspects should well be studied when reconnecting meanders to reach a long-term success of the projects. Therefore, it is essential to take into account the potential historical river type and the present flow magnitude and flow characteristic of the river reach. Focus should be on requiring the minimum maintenance work to avoid aggradation without disturbing the ecological development of the river system. The results of the present study confirm that best success is guaranteed if flow magnitude and dynamics are close to natural condition. If a reconnection of meander bends is performed with a ramp in the former regulated channel, the flow should be diverted into the former regulated channel (i.e. the flood channel) only in cases of floods. The diversion of discharge into the meander and the flood channel and consequently flow velocity and shear stress are governed by the elevation of the ramp. The diversion of flow leads to decrease of flow velocity and shear stress in the meander. As a consequence, aggradation cannot be avoided in cases of floods if the flow is diverted into the flood channel and the reconnected meander. The trajectories of the particles illustrate movements of the particles in the meander and the flood channel. Particles at lower levels (L0, L1) which illustrate the movement of bed load tend to enter into the meander whereas particles with start levels close to the surface levels (L3, L4, L5) in a higher percentage flow into the flood channel.

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CHAPTER 7

Session 6

Evaluating monitoring success in River Restoration plans and projects

Chairpersons

J. MANT, M. JANES

Introduction
EVALUATING MONITORING SUCCESS IN RIVER RESTORATION PLANS AND PROJECTS

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River restoration has developed significantly as a process and/or tool for improving degraded watercourses. Many examples of restoration plans and site specific projects can be found in almost every European country. Information is now being collected and used by a number of organisations to look at the distribution, variety, objectives and applicability of river restoration 'methods'. One area where scarcity of information is encountered is in success evaluation. River restoration is almost always complex, multidisciplinary and long term, all of which pose significant problems to those seeking to evaluate success quickly, cheaply and easily. Initially, many monitoring programmes used very simple approaches or ones looking in detail at only one or two of the target variables. Long term was considered to be 3 years and funding was never forthcoming.

Latterly, EU and national policy and funding has warmed to the need for better scientific evidence that river restoration can have the desired effect of improving ecological status whilst achieving other desired flood risk, water quality and social well being goals. River Basin Management Planning will require evidence based science to underpin the integration of ecological river restoration methods. This session consisted of twelve papers from ten countries and reported on large scale plans; individual projects; 10+ year monitoring evaluation; and suggestions for how to better monitor river restoration.

To begin Jenny Mant (UK) outlined the need for monitoring guidelines for project managers. There is technical guidance already available (such as Roni 2005) but there needs to be some specific guidance for managers so that they can assess when and where monitoring is appropriate and what level of monitoring is necessary across all of the many disciplines that may be involved. Project appraisal is costly and we need to be sure that we use funds wisely to ensure that the evidence base is efficiently increased. A matrix option was outlined which was aimed at helping managers to decide what level of monitoring was necessary. It was advocated that although there is a great need for intensive monitoring of some sites, expert opinion and small scale local stakeholder monitoring is just as valid in other circumstances provided that this type of evidence is initially set within clear and appropriate restoration targets. The UK RRC has a database of project information and the output from that database shows that there is still a lot of confusion about what is meant by integrated river restoration monitoring/evaluation. A workshop which brought together established UK scientists and practitioners has also indicated that there is still a lot of divergence about what is necessary for restoration evaluation.

John Parish (Canada) echoed the sentiments about the need to think about when and what level of monitoring is necessary. Indeed he suggested that in a lot of cases it may only be necessary to monitor physical processes after restoration for a short period of time, especially if it is known that there has been a range of indicator flows. If the physical processes are still working in accordance with predictions it is likely that the scheme has been a success. In Canada the main emphasis is related to flow, sediment and biological targets that are usually measured, often for five years. Many of the projects discussed were in urban settings. In Canada there is a regulatory approach to restoration and monitoring. The National Department of Fisheries and Oceans are responsible for permitting projects and insist on monitoring as part of the permit procedure. They have guidelines that tell you what you need to monitor for your given project. These are then fed back to a database which has information about tolerances that are acceptable and thus determine success. All projects have some monitoring for 2 years even if this is just repeat visits and photos. They must also have an as-built survey to compare design with actual construction.

Hubert Keckeis (Austria) also looked at urban rivers where there was very little opportunity to do much other than habitat enhancement of the banks to try to improve ecological integrity. The results of the monitoring suggested that the species colonisation is dependent on the species pool from the head waters. The project outputs were also able to help managers in terms of explaining which habitats support which species, and this is useful for new projects. Michael Schabuss (Austria) looked at the opportunities for monitoring. The paper was a proposal for monitoring on a river that is currently incising and suffers from lack of sediment transfer because of impoundment upstream. He suggested that the monitoring needs to be driven by indicator species and that there needs to be a link between the abiotic and biotic assessment, which feeds back to the discussion in both the Parish and Mant papers. He stressed the need to not only think about the primary function correlation in terms of project success for physical and ecological characteristics but also to think about the secondary feedback issues; for example, bank stabilisation implications as vegetation cover increases.

There is also an aspiration to upscale the findings and he suggested using models to do this.

Alain de Vocht (Belgium) reported on a river creation rather than a restoration project, on a watercourse where sand had been abstracted. There was no template for restoration, so the project worked closely with the design and construction teams and agreed on appropriate channel dimensions. Bullhead and Spined Loach were present so there needed to be careful design of this particular habitat. However, after one large flow event the new channel eroded and widened and then began to narrow again through macrophyte growth, before gradually reverting to swamp-like conditions. This paper raised the question of whether artificial design for species is really sustainable. The monitoring showed that the target species numbers actually declined if vegetation growth was too vigorous, thus requiring yet more intervention to actively manage the colonising vegetation. The results showed significant links between silt load and macrophyte cover, and also anthropogenic influences. The results were found to be skewed because people liked the site and decided to stock it with fish. Although this project was monitored for four years the author stated that this time period was too short because of the amount of variability (seasonal, natural dynamics, and anthropogenic).

Armin Peter (Switzerland) reported on the work undertaken on the Rhone-Thur project where in 2001/2 a 1.5 km reach had been increased in width from 50m to over 100m, allowing it to braid. The paper focussed on the evaluation of success and the tool that had been designed by the project to aid this. A software tool enables the project manager to select the most appropriate indicators for success based on the project objectives and 49 indicators grouped into nine indicator categories. The output for each is a fairly simple choice of four: none, small, medium or large success. Using this tool the Rhone-Thur project used 11 indicators and returned an overall score of medium success after six years. This standardised approach enabled the project to identify the failures and look at these in more detail. It was found after the six years that the fish community showed no improvement following the works, even though this was a target group. Further research into the literature showed that re-colonisation is slow where the restored reach is isolated. Even though the restoration was undertaken over 1.5km, there was a further 90km of adjacent poor habitat. This evaluation was able to show that morphology and habitat diversity occurred rapidly, however invertebrate colonisation was poor. The poor invertebrate and fish results suggest that much larger scale restoration sites are needed to support re-colonisation when such sites are isolated from other good habitat.

Sybille Chiari (Austria) posed the question “can recreation and ecological improvements be achieved in harmony?”. This paper recognised the additional lack of social as well as ecological functionality in degraded systems, often overlooked by physical scientists and engineers. This early research suggests that recreation is not a major objective in many Austrian (and most likely many European) restoration projects, thus there is usually little data available for evaluating success. A common argument states that recreation and ecological habitat improvement are difficult to place together due to disturbance. This paper looks at which specific recreational activities might have negative or positive impacts for ecological outcomes. An interesting finding is that there is quite a difference between intended and coincidental site visits, and that this has implications on managing people in wildlife/nature park areas, as they often require very different approaches. The long-standing non-acceptance of woody debris was still found to be true as was the common opinion that rivers should be managed as parks and not as natural places.

Robin Jenkinson (US) covered two programmes, one in France and one in the States. The Loire Nature Programme consisted of 19 participatory NGO's coordinated to input into the monitoring work for this 42,000 Ha site. The programme developed a standard monitoring protocol for the 19 groups, gave instruction and training and collected the results, which fed back into the programme reporting. This appears to be a far better organised and planned approach than many large scale but poorly funded and poorly integrated monitoring programmes and may be a good template for others to follow.

The second part of the presentation reported on the Model Watershed Programme in the Northwest US, which started in 1998. The first five-year round of funding encompassed 120 projects. The foundation providing the funds required core objectives as a pre-requisite: community support; watershed scale approach; scientific basis; and long term monitoring and evaluation. However the review of these projects found that the long term monitoring and evaluation was not being delivered due to the make up of the small NGO's and the lack of secure funding streams after the initial five years. This led to the next five-year programme (2003-2008) refining its core requirements and lengthening the funding period: measurable objectives; minimum ten years funding; long term restoration strategy; and scientific peer review of the work.

Geraldene Wharton (UK) presented two urban river projects within London where monitoring of the sites had been undertaken and evaluated. Following progress in the strategic planning of development in London, two existing documents for North and South London were being combined to provide one overall action plan for restoring rivers in the Capital city. Monitoring of completed sites would provide useful information to inform this process. A number of studies were undertaken on the two sites to assess their success. One of the problems reported was the difficulty of collecting adequate post-project data when the funding process is initially so slow and uncertain and then rapidly requires action on the ground once funds are made available.

The next speaker was Saija Koljonen (Finland). A legacy of management for timber floating has left many of Finland's 20,000km of streams degraded for their native salmonid species. In an attempt to reverse this decline more that 100 restoration projects have been undertaken but with virtually no monitoring. This paper looked at one project where monitoring had been carried out for two years pre- and three years post-works. The work was shown to have increased diversity and complexity of habitat at low and high flows. However, a further finding was that three years is not long enough to evaluate the success of habitat restoration in terms of salmon numbers. Better designed and larger monitoring programmes were called for, reflecting the papers by Mant and Peter.

Luca Mao (Italy) closed the session by reporting on work undertaken to look at the ecological benefits of constructed step/pool structures versus the alternative of high check dams, and in comparison with natural step/pool cascades. In steep catchments in Italy such engineered step/pool structures have been used where grade control for erosion prevention is necessary, and instead of the historic single large check dam approach. An assessment of the CPOM and macroinvertebrates showed that these artificial steps aiming to mimic the morphology appear to provide ecological value within the constraint of ensuring erosion control.

The papers in this session raised a number of common issues and findings:

- There is a need for sufficiently well structured project/plan objectives to produce targeted and measurable outcomes to inform essential baseline data collection. Baseline data may not be as stated (UK) and so reduce our confidence in the results;
- The time required to monitor changes (three years in Finland, six years in Switzerland and still inconclusive) has to be realistic. Only one speaker presented a long term commitment from a funding body to fund monitoring and scientific reviews (ten years in NW USA);
- Sometimes the monitoring methodology might not be appropriate for drawing the "correct" conclusions from studies (Finland). Simple monitoring might give positive but misleading results (Italy) if the detail or underlying "why" is not examined;
- For urban and recreational use river areas, social involvement monitoring and appraisal is essential. Better analysis of the possible conflicts and synergies between ecological and social functions of river restoration projects allows better understanding of the needs of nature and the use of people. Managing / steering access for users / visitors depends on the type of visitor (accidental or intended);

- Monitoring tools already exist that can be used or adapted (Switzerland). In the NW USA (www.miraoli.org) software is available to consider an alternative to pure science based assessments, which might prove better for community led initiatives;
- Plan and invest monitoring resources wisely with clear targets, goals and time frames of expectations. This demonstrates the benefit of monitoring to actual / potential funders who then might bridge the gap between lack of staff and long term commitment that is currently a constraint.

The session also raised a number of important questions for the delegates and others to consider:

- Can river restoration monitoring and evaluation be integrated with the proposed assessments for WFD?
- Should there be different levels of monitoring? Or does it all need to be intensive?
- Do we need guidelines for project managers to help them formulate sound restoration appraisal plans appropriate to the size and risk associated with the project?
- Could Europe have an approach similar to that in Canada where government insists on monitoring before giving out permits for restoration and where the permitting process includes post-project monitoring?
- Should limited resources, especially when looking at “multi-objective” projects, be better targeted to strategic sites where heavy investment might prove beneficial in the long-term?

4th ECRR Conference on River Restoration
Italy, Venice S. Servolo Island
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APPRAISING RIVER RESTORATION PROJECTS: INTEGRATED APPROACHES FOR PROJECT MANAGERS

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ABSTRACT

How successful river restoration has been, in terms of meeting stated objectives is a frequently asked question, but one which is not currently easily answered. Given that river restoration is perceived in many European Countries as a key way to tackle the requirements of the Water Framework Directive (WFD), with individual countries devising 'programmes of measures' for their river networks, the need to increase our confidence of restoration success is essential.

Although indicators have been identified for determining WFD status, when it comes to appraising river restoration techniques, there remains limited guidance about what abiotic and biotic data to collect and when, and how this can be best analysed, to answer specific restoration objectives for a range of river types and project sizes. Therefore, data collection and analysis requirements are rarely given adequate thought at a projects' inception stage and as a result, our knowledge of river restoration success remains limited.

This paper draws on the outputs from workshops held in the UK during 2006 and 2007 which highlighted some of the issues related to river restoration appraisal and outlines what is needed to develop a set of pragmatic guidelines for project managers.

Key words: river project objectives, river restoration, monitoring, appraisal

1. INTRODUCTION

Whilst the evidence-base relating to river restoration objective success or failure is growing, much comes either from ecological or geomorphological/hydrological sources and is often held within the grey literature. Post-project appraisals that examine river dynamics and process rates and then link these to ecological functions remain rare. Whilst it is recognised that there is agreement between disciplines that more integration is necessary (Vaughan et al (2007), there is little evidence that such relationships have been fostered (Hannah et al 2004); indeed the difficulties associated with making such linkages are more generally espoused with recommendations that further research is required before, for example, biotopes and ecological response can be reliably linked to hydrological indices (Clifford et al 2006).

Furthermore, as expressed by Dollar et al (2007) “we lack appropriate frameworks to guide inter-disciplinary thinking because disciplinary paradigms loose their usefulness in the inter-disciplinary arena”. Without such guidance both assessing the outcome of river restoration techniques for both biotic and abiotic aspects and predicting future management requirements will remain limited in terms of scientific robustness and confidence of project outcomes; if longer term environmental trends, such as those arising from predicted climatic change impacts, are considered then the need to increase confidence in restoration techniques is essential.

2. SETTING THE SCENE

The UK, as with most other EU countries has, quite understandably, focused more recently on collecting data that can identify current WFD water body status and pinpoint opportunities to improve current status through rehabilitation and enhancement measures. The difficulty, however, lies in determining what restoration techniques will be successful for a given set of objectives. Often river restoration appraisal focuses on answering the questions related to one discipline, this often being dependant on the expertise/interests of the project manager, rather than taking an integrated approach to understanding the linkages between habitat requirements and river processes. Furthermore, decisions about the appropriate appraisal level (e.g. cost, data, spatial and temporal collection scale, etc) of a project, is rarely taken into account at the concept stage; by the time the project is completed, funds are usually limited and appraisal (where carried out) tends to fall short of confidently answer questions related to restoration success.

Globally, a few manuals have been compiled that aim to encourage end-users to appreciate the need to include appraisal as an integral part of a project. In Australia, national guidelines (Rutherfurd et al, 2000a, 2000b) have been published that emphasis the need to define measurable objectives prior to construction. That guidance also recommends which river parameters to measure and outlines some spatial and temporal frequency of measurements in an effort to reduce uncertainty. However generally, most guidance relating to project appraisal has focused on restoring migratory and spawning habitats for salmonids (e.g. Friberg et al, (1998); Hansen et al (1996)). In the United States of America this has culminated in the publication of the ‘Monitoring Stream and Watershed Restoration’ manual

(Roni 2005). This invaluable document provides ‘best practice’ appraisal case studies for fisheries-led projects, and outlines the benefits of using the ‘before-after-control-impact’ (BACI) approach.

The need for guidelines have also been recognised by Woolsey et al (2007) who have taken steps to provide guidance on selecting indicators that focus on answering river restoration success. They also highlight the practicalities of this process with key indicators being categorised in terms of effort required to collect the information and the relevant time period for a survey (i.e. a realistic attempt at evaluating financial and time constraints).

However, a gap still remains in terms of defining what level of appraisal is appropriate for different restoration techniques and projects especially within UK river systems. Therefore, it is advocated that practical guidance would be a beneficial additional tool to help inform project managers, not only about the selection of appropriate methods, but also to identify the necessary detail of appraisal required to answer restoration objectives, based on the size and complexity of a river project. This need was further emphasised through the interrogation of the UK-based River Restoration Centre’s database of projects. Over 800 projects are recorded throughout the UK with nearly 50% stating some form of appraisal. On further analysis however, most of this appraisal has been completed on an ‘adhoc’ basis with much either being related to agency-led standardised monitoring regimes (e.g. electro-fishing, water quality sampling points etc) or non geo-referenced photography.

This observation is backed up from the information shown in Fig. 1. This summary data, based on a question sent to group of UK-based experts in the field of river restoration, with a range of disciplinary backgrounds, indicates that nearly 60% of data is collected through simple qualitative methods or via industry protocol. This is not to say that these methods are inappropriate but rather, it has led to the authors of this paper and others (e.g. Skinner et al (2007); Woolsey et al (2007)) to conclude that appraisal rationale must be integrated with appropriate initial objectives and that these must help to define where, when and why appraisal is completed so that where necessary, current data collection methods can be adapted accordingly.

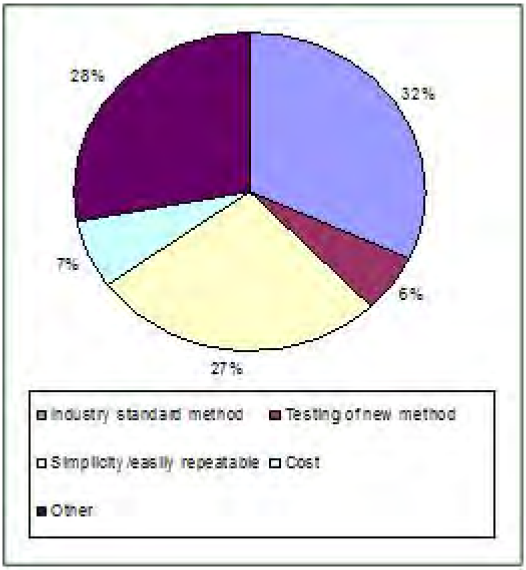

Figure 1 – Diagram showing the different generic types of appraisal methods used. Data collated from a questionnaire sent to restoration experts asking why specific appraisal methodologies are selected.

3. GUIDELINES

The need for clear, pragmatic, integrated river restoration appraisal guidelines, prompted the UK's River Restoration Centre to bring together a small group of practitioners from a range of disciplines during 2006 and 2007, with the aim of developing a decision making framework that would link measurable objectives to a suite of monitoring methods appropriate to the size, complexity and financial constraints of a project. This paper outlines the rationale behind this concept and in doing so, explains the need to develop this concept phase into a handbook for practitioners.

The rationale behind such guidelines is based on the following steps. The guidelines intend to build on the work already completed by others such as ((Woolsey et al (2007); Skinner et al (2007); England et al (2007) Roni (2005); Joint Nature Conservation Committee (2005); Palmer (2005); Armin (2006) and are a culmination of the discussion workshops held during 2006 and 2007.

3.1 Step 1: Defining objectives for appraisal

The importance of defining clear objectives has already been acknowledged in this paper. All too often though, even when objectives are set, how to answer whether or not these have been achieved and what is the appropriate spatial and temporal appraisal monitoring protocol is not adequately assessed. To help increase confidence of project appraisal success (in terms of answering river restoration and enhancement questions) it is suggested that specific appraisal objectives are set that incorporate, as far as possible, SMART targets (i.e. ones that are: Specific, Measurable, Achievable, Realistic and Time-bound) and WAFA (Worthwhile And with Future Application). This approach should help to ensure that the decision making process is ‘ranked’ in terms of what aspects of the project can realistically be appraised for a given size of project.

It is recognised that project objectives (for the purposes of this paper only physical river processes and habitats are discussed omitting social and economic objectives) can be for biodiversity (biota), physical habitat (abiota) or a combination of both. Deciding why a river restoration project is being advocated and, more importantly, where the linkages lie between the biota and abiota is key to successful appraisal protocol. Figs. 2 and 3 provide decision making trees which are aimed at helping project managers to focus on which biota are to be addressed (e.g. invertebrates, fish, plants, mammals or birds) and then to decide on which aspect of that biota’s habitat niche needs to be ‘restored’ (i.e. it helps to answer questions about which physical forms support the habitat niche(s) proposed to be created). Having chosen, in this example, biota as the overall objective, a project manager may then decide to focus on a particular species or, even more specifically, on creating habitat for one species’ life-stage, if this is deemed the missing habitat link.

The main aim of developing these decision trees is to provide a systematic approach to understanding why specific objectives are being advocated. This in turn should help define appropriate, more targeted appraisal protocol. In addition, it should help to ‘rank’ objectives. For example, a Primary Objective (PO) might be to improve brown trout adult habitat to support an increase in population over a defined number of years (and if confidence in the system allows, by a defined percentage). In such a case a Secondary (or Support) Objective (SO) would be to achieve an appropriate in-channel form able to support this population (e.g. a certain number of pool-riffle sequences in a given reach length).

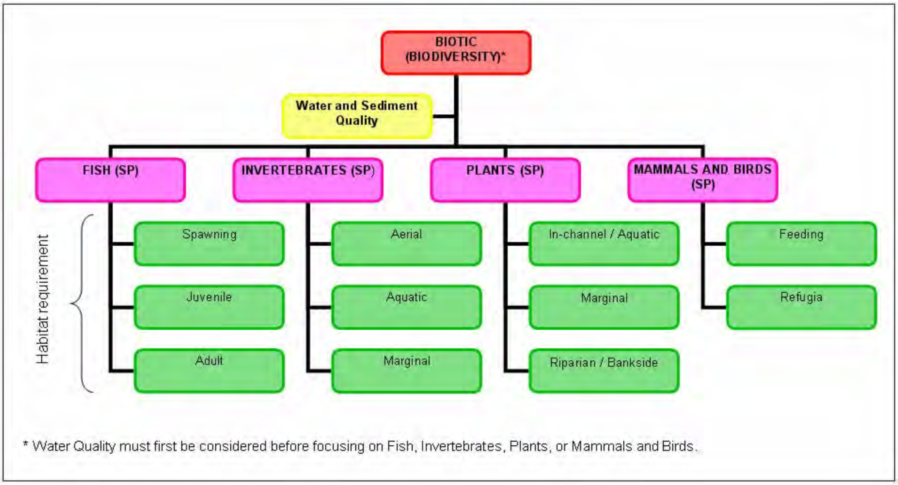

Figure 2 – Decision making tree to assess what set of habitat criteria are necessary for a restoration or habitat project. Note: Figure to be used in conjunction with Figure 3.

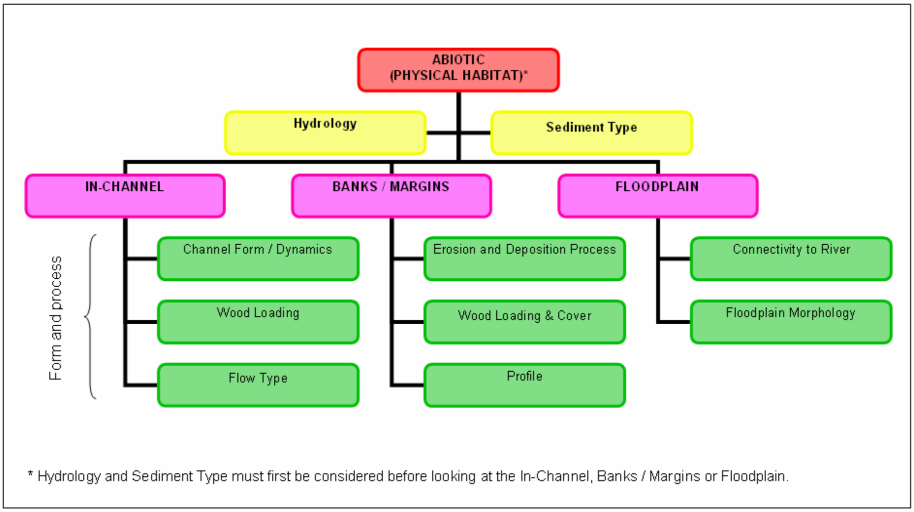

Figure 3 – Decision making tree to assess what set of forms and processes are necessary for a restoration or habitat project. Note: Figure to be used in conjunction with Figure 2.

3.2 Step 2: Prioritising monitoring

England et al (2007) provides a useful risk-based matrix approach to river restoration and appraisal, which has been modified for the purposes of the proposed guidelines. Figure 4 is an essential part of the suggested guiding principles since it enables a project manager to consider the risk (of failure) of a project (or part of a project), which can be set against project scale. For instance, in circumstances where a technique is established for a given river type, risk may be relatively low and conversely, confidence of success high. In such a case it allows the project manager to make informed decisions regarding the level of appraisal necessary for the scheme. In contrast, a large-scale project (e.g. one involving a sub-catchment or tributary), or the introduction of new technique, may represent a greater risk and therefore potentially, warrant a more detailed, fully integrated, quantitative statistically analysis with associated high financial and time commitments.

It must be stressed that this guidance should, ideally be supported by an evidence-based data set of restoration success. Whilst the guidelines can provide a 'stand-alone' framework to assess the most appropriate way of determining where to focus river restoration appraisal, an evidence database should be established in conjunction with the guidelines that teases out trends relating to specific river restoration activities. The need to establish an European 'observatory' has been highlighted at various workshops including at this ECRR conference and in situations where databases of projects exist such as the UK River Restoration Centre's these need to be further developed to house and disseminate specific appraisal outcome findings (refer to www.therrc.co.uk/rrc_themed_workshops.php).

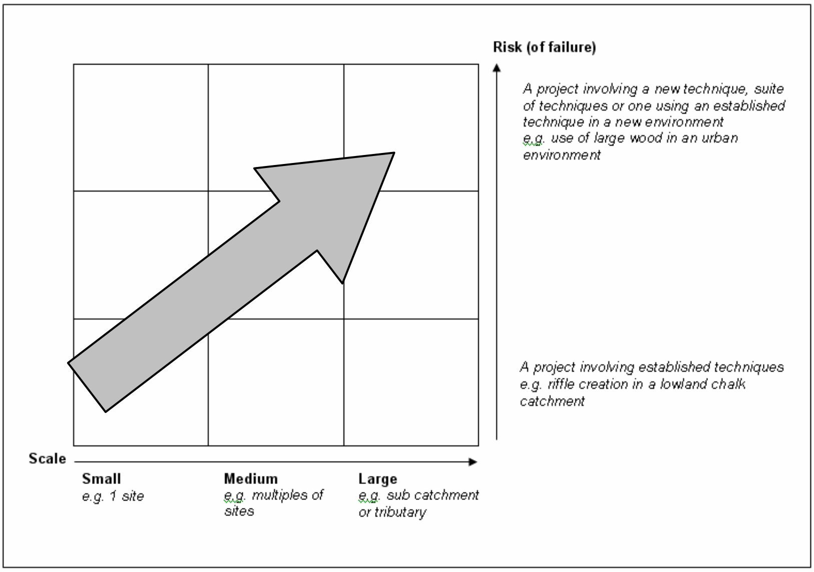

Figure 4: Matrix aimed at helping project manages to assess the appropriate level of project appraisal for a given scale and risk of project (also refer to Figure 5).

Note: ⇨ = Increasing need for quantitative, more intense appraisal techniques and analysis.

3.3 Step 3: Financial commitment

It is recognised that all restoration projects will have financial constraints. The aim of these guidelines are to ensure that monies allocated to project appraisal are apportioned early on in the decision making process. Therefore, allocating a specific percentage of the funds could be misleading. After discussion with various experts in the field of river restoration appraisal, it was concluded that smaller projects can provide important outputs and that allocating a monitoring budget as a percentage of the overall cost could result in projects not being allocated an appropriate budget. A more effective way of allocating funding should be related to whether the results of the monitoring are likely to be Worthwhile And with Future Application (i.e. (WAFA as discussed in step 1). For example, it might be that a small-scale project is allocated a monitoring budget greater than its implementation budget because it is recognised that evidence of the likely response of the river to the scheme is scarce. In such a scenario the monitoring output will have significant future application. By closely monitoring one scheme and learning from the output it is perceived that this information could be used to inform other restoration projects, ultimately reducing uncertainty and thus making future projects more cost-effective.

3.4 Step 4: Defining appropriate methods

One of the main discussions of the River Restoration Centre workshops has focused on defining a set of methods that are appropriate for restoration appraisal for a given scale and risk of a project. Outline matrices have been derived for ecology, fisheries, hydrology and sedimentology/geomorphology. The purpose of these matrices is to help project managers determine what level of data collection is acceptable for a given project. For example, as shown in Fig. 5, whilst habitat and sediment mapping, fixed point photography or simple cross-sectional surveys may be appropriate for a small-scale, low risk project, more detailed information will be necessary for a large-scale, high risk scenario. By outlining methods for both biota (ecology and fisheries) and abiota (hydrology and geomorphology) they will allow a project manager to pick the appropriate level of monitoring which can then be cross-referenced with the appraisal objectives.

Risk ↑	• Habitat and geomorphological and sediment mapping or RCS • Fixed point photography • Cross-sections and morphological variation - theodolite or differential GPS • Desk based analysis of photos/maps • Geo RHS • Fluvial audits • Low cost aerial photography (e.g. with kite)	• Habitat and geomorphological and sediment mapping or RCS • Fixed point photography • Cross-sections and morphological variation - theodolite or differential GPS • Desk based analysis of photos/maps • Geo RHS • Fluvial audits • Airborne photography analysis to include floodplain extent – levels and land use • Sediment analysis (e.g. geomorphological dynamic assessment)	• Habitat and geomorphological and sediment mapping or RCS • Fixed point photography • Cross-sections and morphological variation - theodolite or differential GPS • Desk based analysis of photos/maps • Geo RHS • Fluvial audits • Airborne photography analysis to include floodplain extent – levels and land use • Sediment analysis (e.g. geomorphological dynamic assessment)
	• Habitat and geomorphological and sediment mapping or RCS • Fixed point photography • Cross-sections -tape and level or theodolite • Desk based analysis of photos/maps • Geo RHS • Fluvial audits • Low cost aerial photography (e.g. with kite)	• Habitat and geomorphological mapping or RCS • Fixed point photography • Cross-sections and morphological variation (theodolite or differential GPS • Desk based analysis of photos/maps • Geo RHS • Fluvial audits • Low cost aerial photography (e.g. with kite) or Airborne photography analysis to include floodplain extent – levels and land use	• Habitat and geomorphological and sediment mapping or RCS • Fixed point photography • Cross-sections and morphological variation - theodolite or differential GPS • Desk based analysis of photos/maps • Geo RHS • Fluvial audits • Airborne photography analysis to include floodplain extent – levels and land use • Sediment analysis (e.g. geomorphological dynamic assessment)
Risk	• Habitat/ geomorphological and sediment mapping or RCS • Fixed point photography • Cross-sections (tape and level) • Desk based analysis of photos/maps	• Habitat/geomorphological mapping or RCS • Fixed point photography • Cross-sections -(tape and level or theodolite • Desk based analysis of photos/maps • Geo RHS • Low cost aerial photography (e.g. with kite)	• Habitat/geomorphological mapping or RCS • Fixed point photography • Cross-sections and morphological variation - theodolite or differential GPS • Desk based analysis of photos/maps • Geo RHS • Airborne photography analysis to include floodplain extent – levels and land use • Fluvial audits
	Scale →		

Figure 4 – An example of the types of data collection and when they may be appropriate to collect for a given project scale and risk

5. CONCLUSIONS AND NEXT STEPS

The work outlined in this paper demonstrates the need for project guidance and this has made significance steps towards outlining a way forward to address this gap. It is recognised however, that there are still some missing links before informative practical guidelines can be published. In particular, whilst appraisal data collection techniques and how these should be linked to clear objectives have been discussed, the current information does not adequately outline how to take into account appropriate data analysis techniques (as indicated by the arrow in Figure 4). It is recognised that this can have a significant impact on what can realistically be answered and is often over-looked at the appraisal setting phase both in terms of budget and method; it is therefore essential that analysis techniques and realistic associated costs are included in the final guidelines.

In the authors' view this paper represents a step forward towards a pragmatic 'bottom-up' driven approach to project appraisal grounded in realistic constraints and objectives. However, as with all such guidance, it will only help improve our knowledge and understanding of river restoration principles and success if this approach is underpinned by a 'top down' approach where government agencies and similar organisations, are in a position to make funds available and introduce polices that advocate the collation and analysis of project appraisal outcomes that are provided in a concise, comprehensible format, available to all project managers, to help inform the decision making process.

6. ACKNOWLEDGMENTS

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RIVER WIEN RESTORATION PROJECT: IMPROVEMENT OF THE ECOLOGICAL CONDITION OF A HEAVILY MODIFIED RIVER IN A URBAN ENVIRONMENT

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ABSTRACT

The development of the macrozoobenthos and fish fauna in two different river segments of the River Wien in the main city of Vienna, Austria, was investigated. A rapid and distinct increase in species (taxa) number, biodiversity and abundance was observed shortly after implementing restoration measures. In both groups, this pattern was accompanied by a change in community composition. The high abundance of several species indicates the development of self–sustaining populations. Monitoring of the sites in subsequent years revealed that the restored sections have a high stability and resilience. This underlines the high potential of river restoration in urban, densely populated areas.

Key words: river restoration, colonisation, biodiversity, macrozoobenthos, fish

1. INTRODUCTION

The Wien River has its source in the Vienna Woods, to the west of Vienna, Austria, at 620 m ASL. With a length of 32 km and a catchment area of 230 km^2, it is, beside the River Danube, the most important river passing through the city of Vienna. In the city, it flows into the Danube channel, an anabranch of the River Danube. The catchment area mainly consists of flysch with a very low pore volume and a low water retention capacity. Rainfall therefore leads to high surface runoff and an immediate and strong rise of the discharge of the Wien River. For flood protection, the river was placed in a deep channel in the late 19th century and the river bottom was sealed with paving stones and concrete. Although it was a masterstroke then, today´s requirements in hydraulic engineering have changed. Specifically, the role of rivers as a vital ecological link and their ecological relevance have gained increasing public and institutional interest. One key task taken up by the European Water Framework Directive (2000) is nature conservation and environmental quality. According to these guidelines, the ecological quality of the River Wien along its course through the city had to be improved. From 1992 onwards, restoration measures in two different reaches of the heavily modified river were carried out: one long reach of approximately 2.5 km length near the border of the city and a further stretch of 100 m in the densely populated area of the main city. The longer reach comprises the area of seven retention basins that were constructed for flood protection by keeping the water of the frequent, stochastically occurring flood peaks. Here it was possible to re-establish the old river course similar to the situation 100 years ago with an attendant floodplain (Oberhofer, 1992; Bauer et al., 1993; Ladinig et al., 1999). The second reach was selected as a test reach (‘Hackingersteg’) to analyse the possibility for improving the ecological integrity of a heavily modified river within the confines of an urban, densely populated area (Oberhofer et al., 1993).

After careful planning and extensive model experiments, transverse ground sills and large stones were anchored in or on top of the sealed channel. The ground sills were designed to protect against the avulsion of the gravel and should help to maintain the subsequent pools. The whole stretch was covered with gravel of different sizes, and finer sediment was used to loosely fill the interstices. Along the left bank a maintaining path was constructed, the right bank was composed of a small grassland and riparian vegetation mainly consisting of willows.

2. AIMS OF THE STUDY AND CHRONOLOGY OF MEASURES AND INVESTIGATION

In both river sections, measures were undertaken to increase aquatic habitat area, habitat heterogeneity and connectivity. According to the habitat heterogeneity theory (Ricklefs & Schluter, 1994) and several concepts of river ecosystems (Vannotte et al, 1980; Amoros & Roux, 1988; review in Ward et al., 2002) this should improve ecosystem function and therefore boost species diversity.

Tab. 1 summarises all measures and monitoring programmes. After a preliminary study of the ecological status in 1991, the first restoration was carried out in a small test reach. Based on the monitoring results of this reach, a period of large-scaled measures was conducted between 1994 and 1999. These activities were followed by a monitoring programme that lasted seven years, from 1999 to 2005. The findings of these programmes were used to construct an ecologically optimised test reach in the densely populated section in the heavily modified reach in the main city. Immediately after implementation in 2003, the colonisation patterns of macrozoobenthos and fish were investigated for a one-year period and compared with a control reach. Further investigations followed in 2007 to obtain information about the ongoing development and resilience of the newly created river reach.

Table 1- Sequence of restoration measures and ecological investigations in the Wien River in Vienna, Austria, from 1991 to 2008. MES = Measure; INV = Investigation.

Year	**(MES) (INV)**	**specific actions**
1991	INV	Occurrence and distribution of fish and macrozoobenthos along the longitudinal course of the Wien River. Analyses of the effect of a tunnelled section of the river on the activity and migration of fish.
1992	MES	Construction of the first test reach in the region of the retention basins. Complete removal of concrete from the whole river bed and construction of a new river bank. Length ~ 450 m; area ~ 3000 m².
1993	INV	Analysis of hydromorphological characteristics (sediment, depth, flow velocity), macrozoobenthos and fish fauna (diversity, abundance, size structure)
1994	MES	Removal of concrete along the heavily modified river bed and bank reinforcements of the Mauerbach River along a stretch of 760 m upstream from the confluence with the Wien River, creation of a new natural river bottom; construction of new shores by means of bio-engineering structures (wood, stones); installation of two adjustable weirs in retention basin no I. Total area: ~ 5.6 ha; Water surface: ~ 2.2 ha.
1995 - 1999	MES	Removal of concrete along the heavily modified river bed and construction of new banks in the Wien River along a stretch of 1320 m including retention basins II toV, creation of a new natural river bottom; construction of new shores by means of bio-engineering structures (wood, stones); excavation of a main channel in the retention basins III to V; installation of adjustable weirs in each retention basin. Discharge of the Wien River through the newly crated areas of retention basins III – V up to 40 $m^3 s^{-1}$. Total area: ~ 17 ha; Water surface: ~ 5 ha.
1999 – 2001	INV	“Monitoring Program River Wien”: Analysis of hydromorphological characteristics (sediment, width, depth, flow velocity), retention capacity of nutrients, terrestrial and aquatic vegetation, phytobenthos, macrozoobenthos, adult odonata, amphibans, fish, birds, mammals.
2000 - 2001	MES	Construction of a tunnel from the railroad company below retention basins VI and VII; removal of concrete along the heavily modified river bed and construction of new river banks in the Wien River along a stretch of 796 m including retention basins VI and VII, excavation of a main channel in the retention basins VI and VII; creation of a new natural river bottom; installation of adjustable weirs in each retention basin. Discharge of the River Wien through the newly crated areas of retention basins II – VII up to 40 $m^3 s^{-1}$. Total area: ~ 6.6 ha; Water surface: ~ 2.1 ha.
2001 - 2005	INV	“Monitoring Program River Wien”: Analysis of hydromorphological characteristics (sediment, width, depth, flow velocity), retention capacity of nutrients, terrestrial and aquatic vegetation, macrozoobenthos, adult odonata, amphibans, fish, birds, mammals.

2003	MES	Construction of the test reach “Hackingersteg” in a densely populated section of the heavily modified river within the main city; building of a new natural river bed on top of the sealed river bed; removal of the sealed bed and construction of special sills in limited sections in order to create deep pools (refuge); left shore: construction of a accompanying path with refugial space below; right shore: natural shore with vegetation. Length: ~137 m, Area ~ 3300 m²
2003 - 2004	INV	Monitoring of the development of the hydromorphological characteristics (sediment, depth, flow velocity) and succession of the macrozoobenthos and fish fauna in weekly to monthly intervals in the test reach “Hackingersteg”
2004	MES	Opening the path on the left shore for public use (pedestrians, cycle path).
2007	INV	Monitoring of the development of the hydromorphological characteristics (sediment, depth, flow velocity), macrozoobenthos and fish fauna in the test reach “Hackingersteg”
2008	INV	Monitoring of the development in the retention basins, hydromorphology, macrozoobenthos, adult odonata, fish.

3. MATERIALS AND METHODS

The sampling of the macrozoobenthos in the retention basins and in the adjacent river reaches started in spring 1999 and continued until autumn 2001. Sampling was carried out at 12 different sites along the longitudinal course of the river in spring and/or autumn. A total number of 94 samples were taken each year, whereby the sampling gear was adjusted according to the substrate size; therefore 24 quantitative samples where taken each year with a Hess sampler (mesh-width: 100 µm, bottom area: 0.05 m^2), 32 with a Gilson sampler (bottom area: 0,0078m²) and 38 qualitative samples with a kick net sampler.

In the restructured test reach of the River Wien in the main city sampling started immediately after the implementation and was continued in monthly intervals from October 2003 until September 2004. Then, five samples in each of five mesohabitats in the test reach (B1 to B5) and one sample in the control reach (B6) were taken per sampling date. More than three years later, in 2007, the benthic fauna was collected seasonally in the same locations but three replicates were taken in each mesohabitat and in the control reach. The sampling device was always a Hess sampler (mesh-width: 100 µm, bottom area: 0.05 m^2 in 2003/04 and 0.02 m^2 in 2007). The sampling sites B1 and B2 were situated in runs mostly downstream within the test reach; B3 was an area of slow flowing water near the left bank. High water current speeds characterised the sampling site B4 directly upon and upstream of a ground sill, and the location of B5 was mostly upstream within the test reach and subsequent to the impounded river reach upstream.

The sampled animals were sorted and counted at high taxonomic level and their densities are standardised for 1m². The community structure was expressed in terms of the number of taxa, the Shannon–Wiener diversity index and the corresponding measure of evenness (Pielou, 1975). The benthic animals were also assigned to functional feeding groups according to the ‘Fauna Aquatica Austriaca’ (Moog, 2002).

Fishing was carried out with electro-fishing gear (Honda EL 64II 8,1kW) with direct current of ca. 300 Volt and 3–4 ampere. One to three samples were taken each date and at each site. Immediately after each sample, every individual fish was identified to species level, and total length (± 1 mm) and fresh weight (± 0,1 g) were measured. Fish abundance was expressed as catch per unit effort (CPUE) in individuals per minute fishing time. Fishing time was measured for each sample with an accuracy of ± 10 s.

In the area of the retention basins, a total of 26 sampling sites including two control sites were sampled 4 times a year (spring, summer, autumn and winter). The first monitoring period lasted from 1999 to 2001, the second one from 2001 to 2005 (see Tab. 1).

In the test reach sampling began immediately after the implementation. It was done in weekly intervals after flooding to monthly intervals later on. The first monitoring period extended from November 2003 to December 2004; a second one form March 2007 to December 2007.

A non–parametric test (Kruskal–Wallis H-test) was used to test for significant differences between the years and between the test reach and the control reach.

4. RESULTS

4.1. Flood plain of the retention basins

4.1.1.Macrozoobenthos

Altogether 508 macroinvertebrate taxa were found during the investigation period from 1999 to 2001. The number of taxa was 291 in 1999, 343 in 2000 and 267 in 2001 (Fig. 1). A detailed analysis of the development, species composition, feeding groups, density and biomass of macrozoobenthos in different areas of the basins is given in Katzmann & Forster (2001).

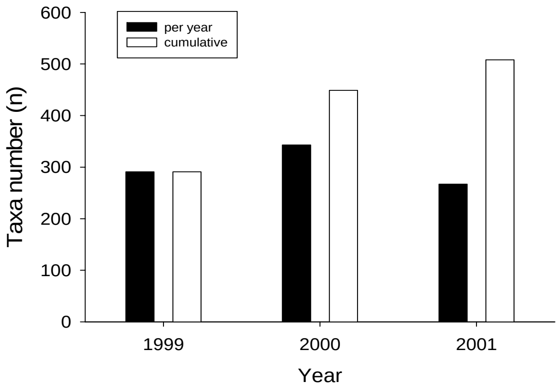

Figure 1 - Yearly total number and cumulative number of macrozoobenthos taxa in the retention basins of the Wien River after restoration.

4.1.2. Fish assemblage

A total number of 26 fish species was observed during the monitoring period from 1999 to 2005 (Tab. 1). The assemblage was composed of 20 native, 2 introduced and 4 exotic species. Despite the three-spined stickleback (*Gasterosteus aculeatus*), no introduced or exotic species occurred in higher numbers throughout the investigation period (i.e. only single individuals were observed).

Two species belong to the rhitralic guild (Schiemer & Waidbacher, 1992) which comprises cold stenothermic species with a high oxygen demand. Five species represent characteristic fluvial specialists, which are linked to flowing habitats during one or more distinct periods in their life cycle (e.g. reproduction, nurseries, feeding habitats). Ten species belong to the eurytopic guild, these are fish which can be found in many different habitats and water bodies and can be classified as generalists. Three species belong to the stagnophilic guild, whose species prefer stagnant water bodies and require macrophytes or flooded vegetation for reproduction. They are well adapted to higher water temperatures and low oxygen availability, thus representing lentic water specialists.

The number of fish species in the newly created flood plain showed a clear increase after completion of the measures (Fig. 2). A preliminary study in 1991 revealed a total number of 5 fish species in the area; after construction of the first test stretch, the number increased to 9 species. A further distinct increase to 19 fish species was observed after all measures were implemented in 1999. Subsequent investigations revealed a species number ranging between 18 and 22. This yearly variability was not accompanied by an increasing or decreasing trend over time.

Table 2 - List of observed fish species and their abundance from the monitoring period 1999 to 2005 in the retention basins of the Wien River after restoration and from the period 2003 – 2007 in the test reach "Hackinger Steg". ecol. guild = ecological guild (Schiemer & Waidbacher, 1992); RT = rhithtrale; RA = rheophilic A; RB) rheophilic B; EU = eurytopic; ST = stagnophilic; $CPUE_{cum}$ = cumulative catch per unit effort (sum of all catches over the investigation period expressed in individuals per minute fishing time).

		Retention Basins		**Test Reach Hackinger Steg**	
species	ecol. guilde	CPUEcum	Percent	CPUEcum	Percent
Phoxinus phoxinus (L.)	RT	400,3	10,216	762,8	39,810
Salmo trutta L.	RT	203,2	5,186	11,6	0,603
Barbatula barbatula (L.)	RA	669,3	17,080	323,3	16,874
Cottus gobio L.	RA	192,1	4,901	97,0	5,064
Alburnoides bipunctatus (BLOCH)	RA	0,5	0,013		
Leuciscus leuciscus (L.)	RA			0,2	0,010
Gobio gobio (L.)	RB	401,2	10,237	187,7	9,797
Abramis björkna (L.)	RB	1,1	0,028		
Leuciscus cephalus (L.)	EU	1217,7	31,073	516,8	26,971
Rutilus rutilus (L.)	EU	539,9	13,777	14,7	0,770
Perca fluviatilis L.	EU	118,6	3,026	0,2	0,012
Esox lucius L.	EU	51,2	1,306	0,9	0,049
Abramis brama (L.)	EU	34,4	0,878		
Alburnus alburnus (L.)	EU	31,7	0,808	0,3	0,013
Sander lucioperca (L.)	EU	10,4	0,264	0,3	0,017
Gymnocephalus cernuus (L.)	EU	3,6	0,091		
Carassius gibelio (BLOCH)	EU	2,6	0,066		
Cyprinus carpio (L.)	EU	1,9	0,049		
Scardinius erythrophthalmus (L.)	ST	6,0	0,152		
Tinca tinca (L.)	ST	4,3	0,111		
Carassius carassius (L.)	ST	0,2	0,006		
Gasterosteus aculeatus	Introduced	27,1	0,691		
Acipenser sp.	Introduced	0,1	0,002		
Oncorhynchus mykiss	Exotic	1,1	0,028		
Lepomis gibbosus	Exotic	0,1	0,004	0,2	0,010
Ictalurus nebulosus	Exotic	0,1	0,003		
Ictalurus punctatus	Exotic	0,1	0,002		
undefined		0,1	0,002		

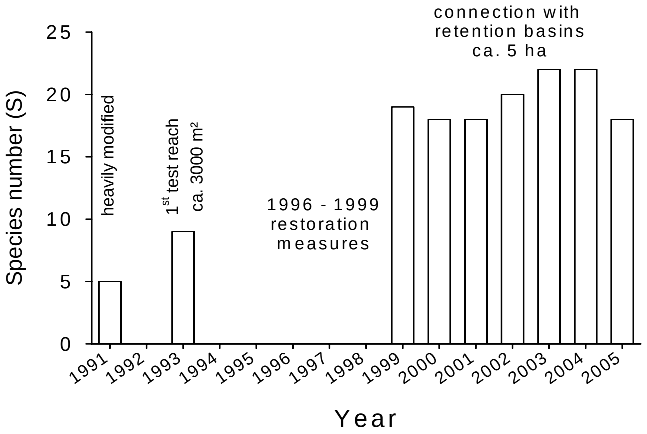

Figure 2 - Changes in total fish species number over time before and after restoration measures in the area of the retention basins of the Wien River.

4.2. Test reach "Hackingersteg"

4.2.1. Macrozoobenthos

The community structure in the test reach changed markedly during the first year after the restructuring measures. From the beginning of the recolonisation period in October 2003 until May 2004, Oligochaetes by far dominated the benthic fauna, accounting for 50% to 90% of the total number of individuals (Figure 3). Thereafter, their portion declined to a maximum of 15% because of an increased diversification of the benthic assemblages, dominated by the larvae of Chironomidae and Ephemeroptera. This pattern observed at the end of the first year of investigation was similar to that of the year 2007.

This change in community structure was also reflected in the distribution of the functional feeding groups. During the first months after the reconstruction of the river bottom, the benthic community consisted nearly exclusively of collector-gatherers (Fig. 4). Only after insect larvae increased did the grazers account for about 25% and the predators for 20%. The fraction of filterers increased in 2004 but was low again in 2007. The shredders never reached high percentages.

No significant changes in total numbers of individuals were detected between the two years of investigation and between the test reach and control reach, respectively, because of enormous temporal and spatial variations (Fig. 5a). Whereas the number of taxa did not significantly differ between the test reach and the control reach in 2003/04, it was significantly higher in the test versus contol reach in 2007 ($H_{3,133}$ = 33.2, P < 0.001; Fig. 5b). However, the control reach exhibited a significantly lower number of taxa in 2007 compared to the test reach in 2003/04. In the latter, the distribution of the individuals among the taxa was more even in 2007 than it was 2003/04 ($H_{3,133}$ = 12.5, P < 0.01; Fig. 5c).

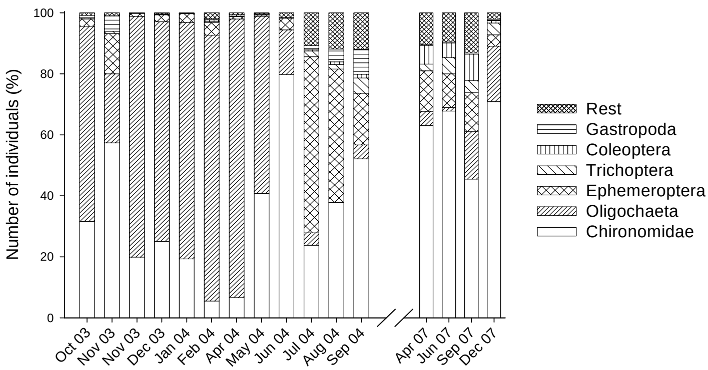

Figure 3 – Percentages of the most common macrozoobenthic taxa at the sampling dates in 2003/04 and 2007.

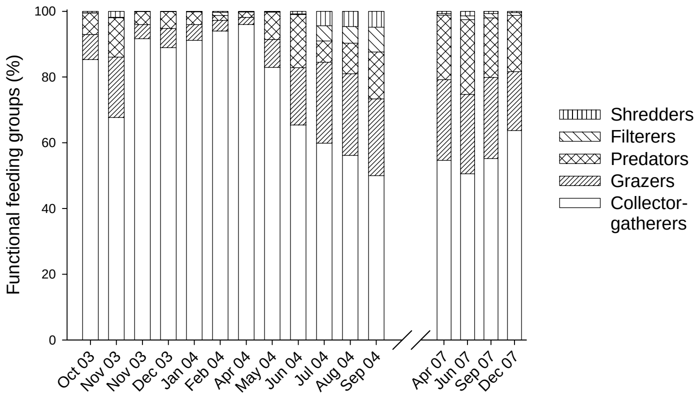

Figure 4 – Percentages of the functional feeding groups at the sampling dates in 2003/04 and 2007.

Combining these two measures, the Shannon–Wiener index shows that the diversity was significantly higher in the test reach 2007 compared to the test reach of 2003/04 and the control reach of 2007 ($H_{3,133}$ = 24.9, P < 0.001; Fig. 5d).

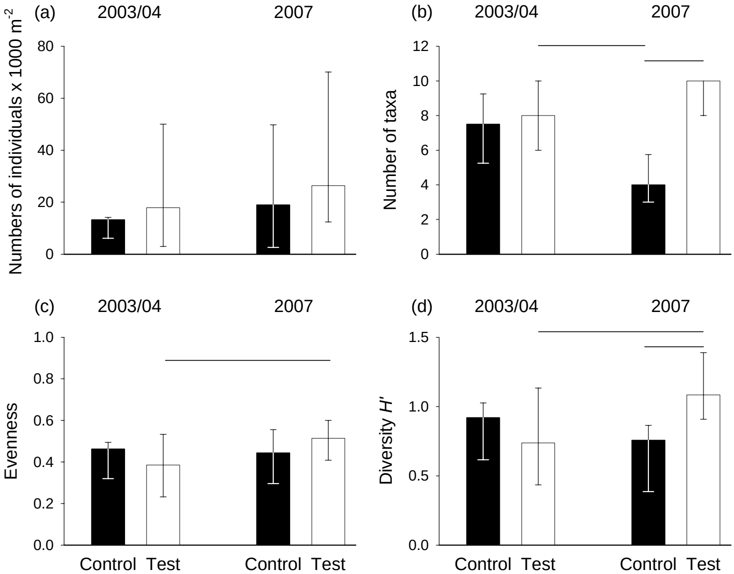

Figure 5 – Medians (± interquartile range) of the years 2003/04 and 2007 in the test reach and the control reach of (a) the total number of individuals, (b) the number of taxa, (c) the evenness and (d) the Shannon–Wiener diversity index *H'*. The endpoints of the horizontal lines indicate significant differences (P < 0.05).

4.2.2. Fish assemblage

In the test reach, a total of 13 fish species were observed since the implementation in 2003 (see Tab. 2). Six species belong to the rithralic and rheophilic guilds, another six to the europtoic guild, and few individuals of one exotic species were observed. Similar to the pattern in the retention basins, a marked increase of total species number was observed after the restoration measures in 2003 (Figure 6). The diversity index in the restored reach was significantly higher compared to the control reach, and it also increased with time, which was not the case in the heavily modified sections (Fig. 7).

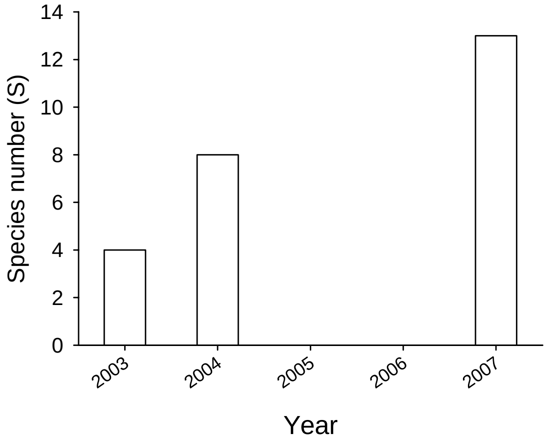

Figure 6 – Changes of species number in the test reach “Hackingersteg” after construction in 2003.

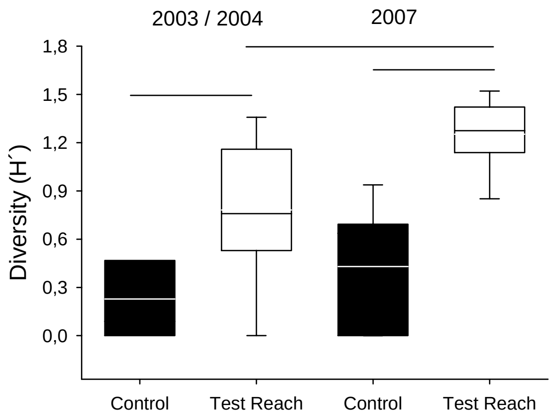

Figure 7 – Comparison of the diversity index (Shannon-Wiener) of the fish assemblage in the test reach “Hackingersteg” with the control reach immediately after construction and three years later. The endpoints of the lines indicate significant differences (P < 0.05).

5. DISCUSSION

5.1 Macrozoobenthos

In addition to gravel, much soil and fine material was heaped upon the river bottom during the restoration of the River Wien. The thick cover of silt persisted for nine months and was elutriated no earlier than June 2004. The high number of oligochaetes at the beginning of the recolonisation period may be due to this sediment composition. As this layer became removed by successive high water events, other taxa, especially larvae of insects, additionally invaded and/or became more dominant. At the end of the first year, the number of taxa and their relative abundances were not different from that after three years. This indicates that the colonisation process was completed (a stable assemblage established) after about one year. Although the control reach was dominated by chironomids rather than by oligochaetes, and therefore exhibited a completely different community structure compared to the test reach back in 2003/04, the number of taxa and the diversity were similar in both stretches. In contrast, in 2007 the diversity in the test reach was markedly higher than in the control reach. Interestingly, despite the large discharges at high water events, the difference in community composition between the test reach and the control persists. The smaller variation in densities and distribution of the individuals among the species suggests more stable assemblages in the test reach. This also demonstrates the success in terms of the sustainability of the restructuring.

5.2. Fish assemblage

Both restored areas were colonised almost immediately after the completion of the restoration measures. In both reaches, species number increased markedly shortly after the implementation, and a further increase with time indicates the establishment of new populations. This is also expressed in the high abundance of a large portion of observed species, demonstrating the development of self-sustaining populations.

A clear difference in species numbers and species composition between the two reaches is evident. The area of the retention basins is distinctly larger and comprises a large variety of different habitats (Keckeis et al., 2001), whereas the test reach “Hackingersteg” has only limited spatial potential for the development of the system. Nonetheless, even under this constricted situation, increases were observed both in the number of species of different ecological guilds and in biodiversity with time. Although the connectivity of the River Wien with the Danube in the upstream direction is strongly limited, the system gains advantage from a large network of streams in the catchment area. These streams are located in a natural environment and function as source for the colonisation of the newly restored sections. The results of the present study suggest a very high ecological potential for river restoration in urban, densely populated areas.

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ECOLOGICAL EVALUATION OF A TECHNICALLY RESTORED LOWLAND WATERCOURSE IN FLANDERS, BELGIUM

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ABSTRACT

In the past, river continuity was damaged by excavation activities and small lowland watercourses were led into and out of the artificial lakes in the region. In 2004 a reach of 1.3 km of the small, channelized lowland brook, Voorste Nete, was diverted because of sand mining activities. The sinuosity of the new reach of the Voorste Nete was based on old maps, aerial photography and field measurements. The new brook was hydrologically isolated with a bentonite mat preventing water loss due to a decline of the groundwater level. Apart of a low sinuosity of 1.13, several artificial quarter bends reinforced with stones are present.

The ecological restoration of the Voorste Nete was evaluated in eight surveys over a four-year period (2004-2008) and compared with downstream and upstream reference transects. The morphology, macrophytes, invertebrate and fish community were monitoring both in spring and autumn. The results show a rapid colonization of the new reach. The largest morphological changes have taken place in the first months after construction as a result of heavy rainfall. The new reach differs from the reference transects in the presence of shallow zones along the banks and higher variability in water velocity. Water - and marsh plant communities dominated the new reach after two years. The macro-invertebrate fauna increased in diversity and the fish community shows the same diversity as in the original course or reference transects. Significantly higher abundances, higher numbers of juveniles and more stable populations of Three-spined and Nine-spined Stickleback and Stone loach are present in the newly constructed brook.

Key words: stream restoration, lowland stream, macro-invertebrate community, fish community

1. INTRODUCTION

Most streams in Flanders, Belgium have been heavily modified during the last two centuries. In the sandy Campine region, small streams have been normalized or realigned in order to drain and optimize the agricultural use of the valleys (Brookes, 1990). After World War II normalization of streams and drainage of valley grounds were intensified, changing the hydraulic characteristics of the system severely (Keller, 1976). Management of the normalized streams is very intensive. Yearly or biannual mechanical weed clearance and less intensive sediment removal have been conducted for over 50 years by local, provincial and regional authorities.

Historical maps illustrate that the Voorste Nete, a first order stream, has been channelized and straightened earlier than 1850. The valley was taken in use for extensive agricultural purposes. In recent decades, due to the intensive agricultural use of the valley, as well as the discharge of domestic wastewater, the brook has become very eutrophic. As a result, the growth of emergent vegetation has been stimulated (Petersen et al., 1982). General stream management for this type of streams includes yearly weed cutting.

In the region, sand mining is an important economic activity. In the past brooks were led into and out of the sand pits during and after excavation. Because both aquatic systems are totally different in faunal communities, the diversion and maintenance of the integrity of the brook was proposed. The diversion of a reach of 1.3 km of this brook was proposed in the environmental impact assessment. A restoration of a more natural course was proposed as mitigation. The aim was to re-establish a brook with good structural and habitat quality in order to realize an ecological surplus value. A monitoring was set up to evaluate the effectiveness of the mitigation and to study the evolution over time of the new reach.

2. MATERIAL AND METHODS

2.1 Study site

The Voorste Nete is an upstream tributary of the Witte or Kleine Nete in Dessel (Flanders, Belgium). The surrounding land is used as farmland with increasing maize cultivation in recent years. This lowland stream has a gentle slope of 0.97 ‰ and an average width of 2 m. Flow varies between 180 m^3/h and 480 m^3/h depending on the season. The sinuosity of the upstream reach, the project area and downstream reach were 1.09, 1.08 and 1.13 respectively. In spring 2004 a 1.3 km straightened and channelized reach of the Voorste Nete was diverted to the south of the planned wet sand excavation and a weak meandering was restored. The new reach is situated in a narrow stretch between the canal Bocholt-Herentals in the south and the sand excavation in the north. From equations in Leopold and Wohlman (1957) a meander amplitude of 5 to 8 m was calculated and a meander length of 20 to 30 m. The width of the meander belt should be 7 to 10 m. The slope of the new 1.9 km reach is 0.6 ‰. Because of the diversion and the presence of a contaminated area, eight squared bends are presented. The bends were lined with cobbles and stones and planted with *Alnus glutinosa* in the outside curves. Substrate from the old reach was reused in the new diverted reach in order to improve ecosystem recovery.

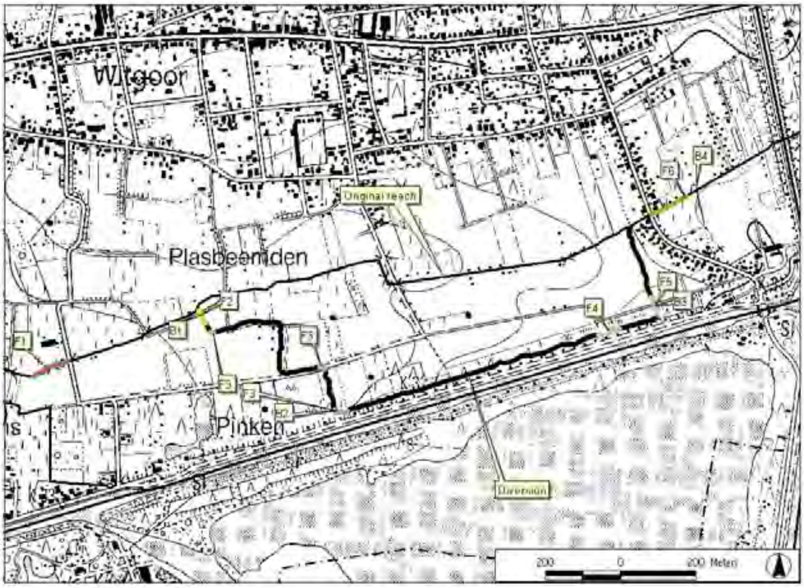

Figure 1 – Map of the Voorste Nete (Dessel, Belgium) showing the original reach and the diverted, restored reach. Numbers indicate sample locations for macro-invertebrates and fish.

The new reach of the Voorste Nete was hydrologically isolated from the groundwater because of the risk of drying out during wet sand exploitation. A bentonite mat five metres in width was placed underneath the streambed. The sides of the bentonite were placed upright for 0.5 m. The bentonite lining was filled with the original sand from digging out the new reach. Originally, the newly created streambed had a weak meandering channel pattern (sinuosity 1.1), and was 1 m wide at the bottom and 2 m wide at the top. In August 2004 a summer storm caused severe erosion and had a noticeable impact on the profile.

In the first three years, mechanical weed clearance was only conducted once in the upstream reach of the diversion in autumn 2005 because of water obstruction. In December 2007 mechanical weed mowing was executed for the total stream.

Figure 2 – Upper row (a and b): original reach of the Voorste Nete. Middle row (c and d): Excavation of a 5 m wide stretch for placing the bentonite mat and refilling with the original sand. Bottom row (e and f): Diverted reach of the Voorste Nete, dug out in sand filled bentonite lining with transferred substrate from the original reach, and the same stretch 6 months later during first monitoring showing the changes in dimensions caused by a summer storm in 2004.

2.2 Sampling strategy

The morphology, macrophytes, invertebrate and fish community were monitored both in spring and autumn over a three-year period (autumn 2004

- autumn 2006). Monitoring of the fish community was extended until spring 2008 and the macro-invertebrate community was additionally sampled in spring 2007 and 2008. The fish community was evaluated in eight surveys over a four-year period (2004-2008) and compared with downstream and upstream reference transects.

Morphology was assessed from the bank, and in each sampling site for fish, water depth and water velocity (Marsh-McBirney Flowmate 2000) were measured in three transverse sections. The type of river bed substrate was also noted. Aquatic macrophytes species were identified and vegetation on the higher banks was characterized. Macro-invertebrates were collected by kick sampling and a hand net, specimens were collected from water plants and stones according the Flemish standard technique (NBN T92-402). Three sampling sites in the diverted reach (B1, B2 and B3) and one upstream reference site (B4) were sampled (Fig. 1).

The fish community was sampled by electrofishing (DEKA 3000 Lord). Four sampling sites in the diverted reach (F2-F5) and two reference sites (F1 and F6), one upstream and one downstream, were sampled (Fig. 1). The length of sample reaches was 200 m in reference sites and 180 m in the diverted reach. In the first summer, local anglers introduced fish caught in the nearby canal. Several Roach, numerous Perch as well as a few Bream, Bleak, Rudd and Bitterling were introduced. Their populations disappeared within the next two years. Data analysis was only performed on non-introduced species.

2.3. Data analysis

Data analysis was performed in Statistica (Statsoft). Variables were tested for ANOVA assumptions and if necessary log(N+1)-transformed. Tukey HSD and Tukey HSD for unequal sample size were used as post-hoc tests. Differences between the diverted or restored reach and reference transects as well as season were tested. If assumptions were not met, the Mann-Whitney U test was used.

3. RESULTS

3.1 Habitat variables

A clear trend in water quality is noted throughout the monitoring period. The upstream reference site has the lowest oxygen concentration and highest conductivity (Fig. 3). This is caused by discharge of domestic wastewater a few kilometres upstream.

Highly significant differences (Mann-Whitney U test) were observed between spring and autumn sampling in several habitat variables: oxygen concentration and saturation, conductivity, water depth and water velocity (maximum, average and standard deviation). In spring, oxygen concentration and saturation was higher and conductivity lower. In spring average, maximum and variability in water depth are lower while variables related to water velocity are higher.

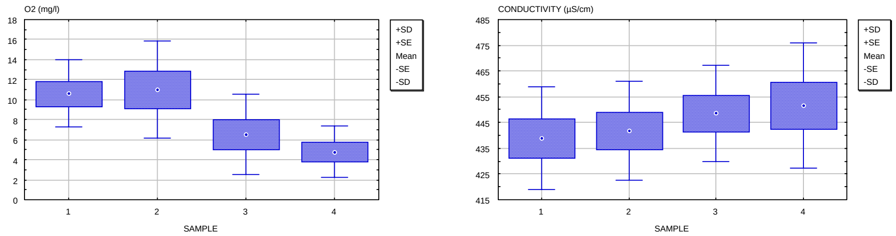

Figure 3 – Average oxygen concentration and conductivity for the four macro-invertebrate sampling sites in the Voorste Nete (2004-2008).

3.2 Morphology and vegetation

Significant differences in minimum depth (p = 0.0499), variation in water velocity (p = 0.0348) and width (p = 0.0078) were detected. Width increased in the new reach due to the thunderstorm in the first summer, creating a wider profile and more shallow water zones near the river banks (Fig. 2f). Macrophytes rapidly colonized the new reach. Both in the reference and diverted reaches the emergent aquatic vegetation increased significantly over the first three years (Tab. 1). From autumn 2006 the stream system merely changed into a flow-through swamp system. Pioneer vegetation colonized the banks in 2004. In 2005 poorly developed vegetation comprising *Bidentetea tripartiti*, *Phragmitetea* and *Convolvulo-Filipenduletea* was established. By 2006 *Bidentetea tripartite* was dominant but *Convolvulo-Filipenduletea* and *Phragmitetea* were expanding.

Table 1 – Percentage of emergent aquatic vegetation in the diverted and reference reach in the Voorste Nete in autumn 2004, 2005 and 2006.

Emergent aquatic vegetation	Diverted reach			Reference reach		
	autumn 2004	autumn 2005	autumn 2006	autumn 2004	autumn 2005	autumn 2006
Absent				7.6		
Sporadic	52.2	0.2		20.2	7.5	
Present Š 33 %	47.8	13.6	18.5	58.9		7.5
Present 33 - 100 %		86,1	81.5	13.4	92.5	92.5

3.3. Macro-invertebrate community

In general, the total number of invertebrates in the diverted reach increased over the first three years. Numbers dropped after weed clearance in winter 2007. The number of Trichoptera remained relatively stable in the first three years with increasing aquatic vegetation (Fig. 3). Ephemeroptera rapidly colonized the new reach, but their numbers gradually decreased over time (Fig. 3). The number of Odonates increased with expanding vegetation in the first two years. The number of Mollusca was very low in the first year.

3.4 Fish community

The old reach had a fish population comprising 7 species. Six months after installing the diversion 12 species were found (Fig. 4). At least 6 species had been introduced by anglers but totally disappeared after two years. The number of species gradually decreased as vegetation expanded and dropped to 4 species in spring 2007. After weed clearance, 7 species were encountered again, including Spined loach (*Cobitis taenia)*, a Natura 2000 species that inhabits the Witte Nete downstream the study site.

A significantly ($p = 0.0192$) higher number of Three-spined stickelback (*Gasterosteus aculeatus*) were present in the diverted reach. This trend can be seen in Nine-spined stickelback (*Pungitius pungitius*) as well but the difference is not significant ($p = 0.0670$). For Stone loach (*Barbatula barbatula*) a trend towards higher numbers in the diverted reach in comparison with the reference sites can also be observed ($p = 0.1968$). For Gudgeon (*Gobio gobio*) and Eel (*Anguilla anguilla*) no differences in abundance can be noted ($p = 0.3603$ and $p = 0.5744$ respectively) (Figure 5). The total number of fish in the diverted reach is significantly higher in respect to the reference sites ($p = 0.0232$). From the type species in the system, Three-spined stickelback and Stone loach, more stable populations are present in the diverted reach where populations hold more juvenile individuals than in the reference sites.

4. DISCUSSION

Results of monitoring studies of stream diversions or restoration should be interpreted with care. A higher manmade variability in mesohabitats after construction has an impact on the results and does not always reflect dynamic natural conditions. This human impact is not only the result of the design and realization; local people and children also had an influence by building stone or sand dams and introducing fish. Short term evaluations mostly fail to detect significant changes in biotic variables such as macro-invertebrates or fish communities (Lepori et al. 2005, Pretty et al. 2003). Other changes are caused by temporary conditions shortly after restoration. As in this study, macro-invertebrate and fish communities respond rapidly to the changed environment but shift to a different situation within a period of approximately three years (Friberg et al. 1998).

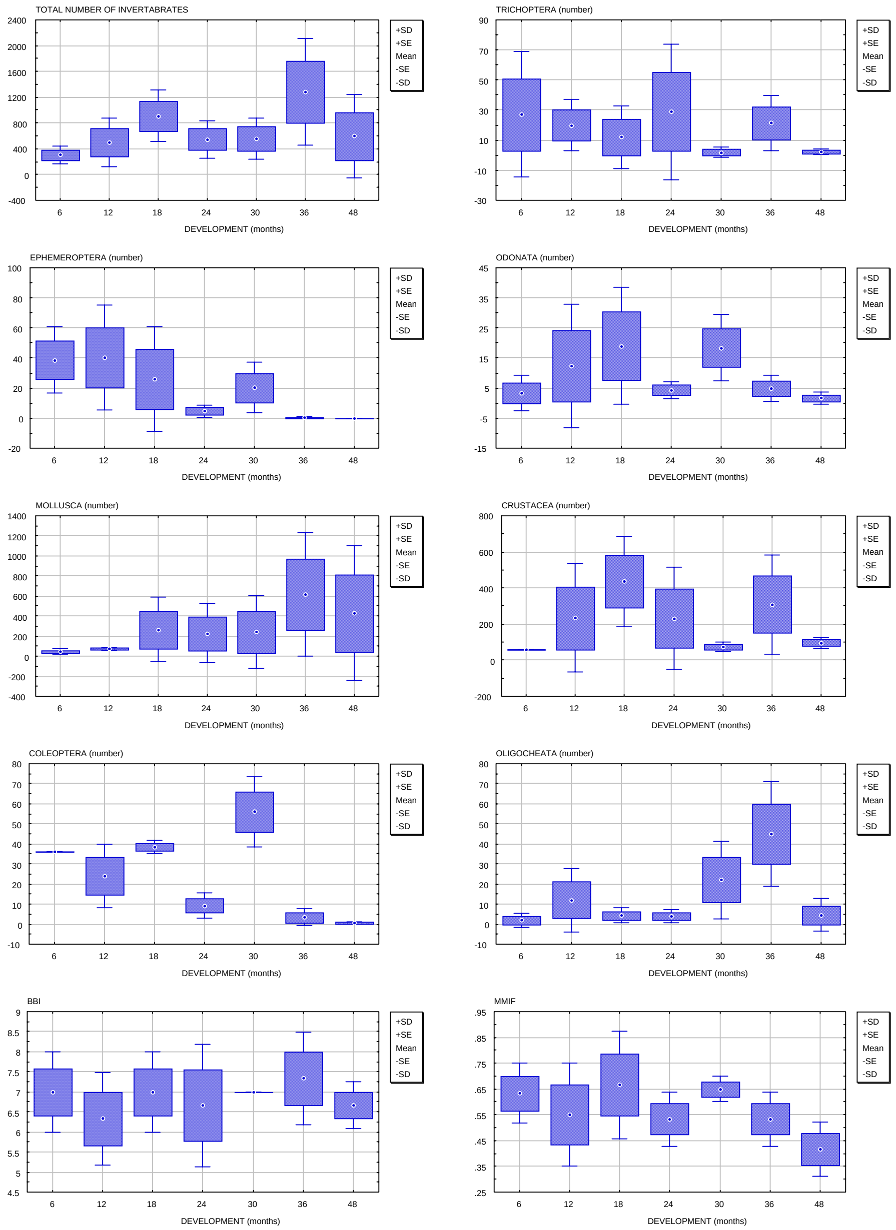

Figure 4 – Total number of macro-invertebrates, number of Trichoptera, Ephemeroptera, Odonata, Mollusca, Crustacea, Coleoptera, Oligochaeta per sample in the diverted reach of the Voorste Nete and calculated Belgian Biotic index (BBI) and new multimetric index for Flanders (MMIF).

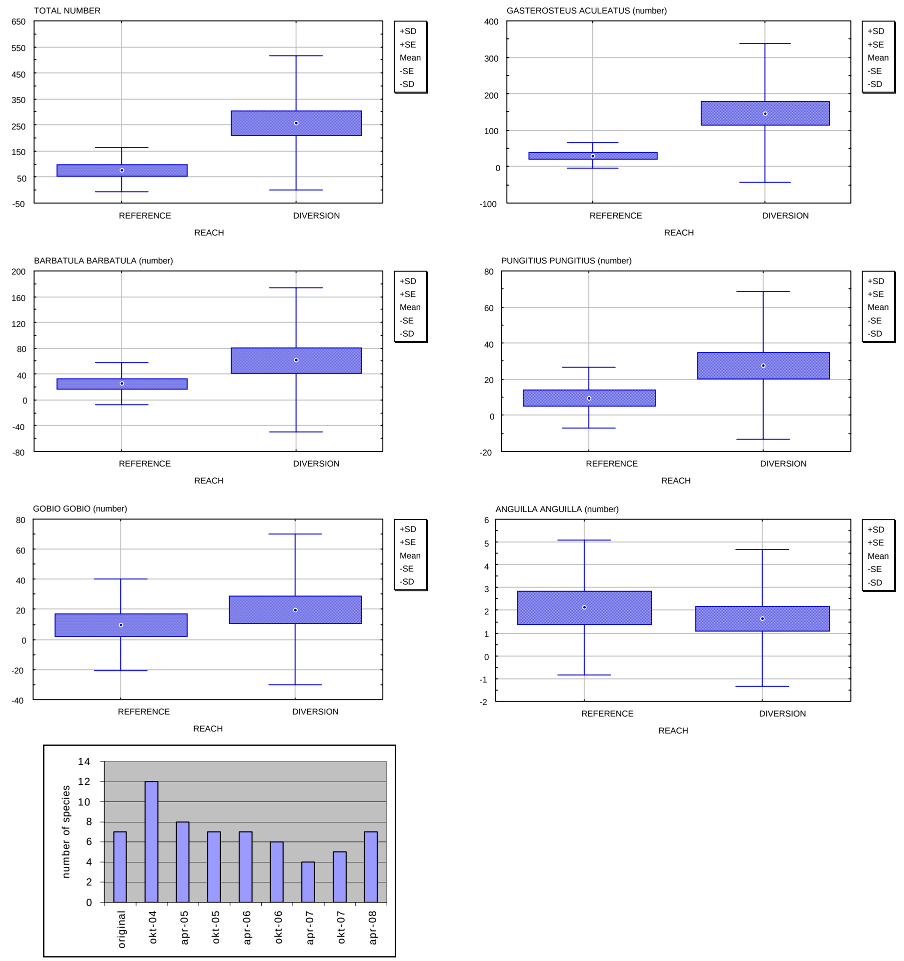

Figure 5 –Total number of fish, number of Stone loach, Three-spined and Nine-spined stickelback, Gudgeon and Eel in the reference sites and diversion of the Voorste Nete. Number of fish species in the old reach and the eight sampling campaigns in the diverted reach of the Voorste Nete.

5. CONCLUSIONS

Based on old maps and oral history, the upstream reaches of small streams in the Campine region are mostly man-made (Burny 1999). Before waterlogged valleys were integrated in the extensive agricultural system, water found its way through swamps and winter-inundated wetlands. The water dynamic was too low to establish an open channel. The presence of peat soils or wet sandy soils on soil maps still indicate these former conditions in valley the Campine region.

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RIVER RESTORATION - THE LONG ROAD TO SUCCESS?

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ABSTRACT

The aim of river restoration projects is often not to return rivers to their original condition, but primarily to restore the essential processes and elements of the degraded riverine ecosystem. The degree of success depends, among other things, on the extent to which goals were formulated at the beginning of the project. In addition to stakeholder involvement, political acceptance and establishing services for society, however, restoration projects should also have sufficient ecological goals. The Swiss "Rhone-Thur" project recommends an assessment tool for restoration projects. To apply this assessment tool to a particular case, we performed a comprehensive monitoring study on the River Thur. Using 11 different indicators, the overall assessment showed medium success for the project. We observed large success for river bank improvement, medium success for hydrogeomorphology and service to society, but only slight improvement for vegetation, and no change for the fish community.

Our results show promise for the fish habitat, but there has been no change to the distribution and density of fish species from channelized to restored river reaches as yet. Fishes in rivers strongly reflect habitat conditions over a wide range. In order to restore the fish fauna to a state comparable with historic conditions, long and connected river reaches have to be restored. However, long-term improvement for fish assemblages can take years/decades. Network maps will help in setting restoration priorities for future planning.

Key words: River restoration, assessment of success, indicators, fish, Thur River

1. INTRODUCTION

In Switzerland, wide-ranging engineering work over recent decades has transformed rivers and streams into straight, embanked ecosystems. Approximately 40% of the streams and rivers of the Swiss Midlands are heavily impacted, artificial or in culverts (Woolsey et al., 2005). The most obvious consequences for streams are that interactions with the riparian habitat and the groundwater are lacking. In addition, the streams are fragmented by numerous migration barriers for aquatic organisms, specifically for fish species with poor swimming and jumping abilities. However, the most severe structure-related impact for fish in Swiss rivers is the loss of instream habitat due to the simplification of the channel structure. In alpine regions, hydrological deficits (residual flow, hydropeaking) are the main causes of the degradation of the streams' ecological integrity. Many recreational areas along the river corridors have been lost due to channelization. Flood protection measures of the past have proved inadequate, and improved measures are required for the future. A new philosophy for flood protection facilitates synergies with ecological aspects, so as to provide more space for rivers and restoring streams, so that the dwindling fish populations will ultimately increase. In summary, there is great potential for river restoration.

River restoration is complex; morphological, biological, social, economic and political components make up substantial parts of the planning procedure (Wolsey et al., 2007). Irreversible changes in the catchment area often mean that restoration projects do not aim to return habitats to their pre-existing, unimpaired condition. The aim is primarily to restore essential processes and elements of riverine ecosystems. In Switzerland, the most commonly mentioned goals for restoration are:

- re-establishing a dynamic flow regime
- increasing structural diversity
- re-establishing continuity of flow
- improving bedload regime.

The degree of success depends, among other things, on the extent to which goals were formulated at the beginning of the planning process. In addition to stakeholder involvement, political acceptance and establishing services for society, however, restoration projects should also have sufficient ecological goals.

2. METHODS

Local widening of river beds is one of the most important measures in Switzerland for improving river dynamics. Between 2001 and 2002, the River Thur at Schaeffaeuli (Cantons Thurgau/Zurich) was widened from 50 to 100 m on both banks, over a stretch of 1.5 km. The river bank was secured using conventional and bioengineering methods. The widenings have improved river dynamics significantly. Restoration objectives were selected to assess the success of the river widening. The primary goal of the river restoration was flood protection for people, settlements, agriculture and traffic routes. The second goal was ecological improvement of the river ecosystem; and the third, to provide recreational space for people and to stop river bed erosion.

In order to document changes after restoration and to assess river restoration success, we carried out a study using 11 indicators. In the Swiss "Rhone-Thur project" Woolsey et al. (2007) list 17 indicator categories with a total of 49 indicators to assess success. However, the number of indicators studied often has to be restricted to a smaller set, depending on the budget for success monitoring. The following indicator categories were used to assess the success of restoration measures on the River Thur: recreational use: 3 indicators; fish: 2 indicators; hydrogeomorphology and hydraulics: 1 indicator; project costs: 1; river bed: 1; river bank: 2; vegetation: 1.

Effort levels for surveying indicators and time periods during which surveys are relevant are given in Woolsey et al. (2007). A detailed method sheet was developed for each of the indicators (Woolsey et al., 2005, www.rivermanagement.ch). To evaluate the success of restoration we used a proposed matrix comparing standardised indicator values before and after restoration measures were taken. These values lie between 0 and 1 and represent the degree of naturalness or the degree of satisfaction within the examined indicator. A value of 0 defines the unnatural condition, and the near-natural condition is set to 1. These values are set to non-dimensional values. In Tab. 1 the allocated values are averaged to obtain a final value between 0 and 1.

3. RESULTS

Table 1 - Standardised indicator values by project objective before and after restoration.

Indicator category	**Indicator**	**Before**	**After**	**Success of indicator category**
A. Recreational use	Numbers of visitors: provision of high recreational value	0	1	medium success
	Variety of recreational opportunities	0.6	0.8	
	Public site accessibility for recreation	0.4	0.7	
B. Fish	Species abundance and dominance	0.4	0.4	no change, failure
	Diversity of ecological guilds of fish	0.4	0.4	
C. Hydrogeomorphology and hydraulics	Variability of visually estimated wetted channel width	0	0.7	medium success
D. Costs	Project costs: was the budget adhered to?		1	large success
E. River bed	Clogging of hyporheic sediments	1	1	no change
F. River bank	Width and degree of naturalness (vegetation, soil composition) of riparian zone	0	1	large success
	Degree and type of anthropogenic modification	0.2	1	large success
G. Vegetation	Succession and rejuvenation of plant species on floodplains	0.2	0.4	small success

For the indicator category recreational use, the before average value is 0.33, and the after value is 0.62. This represents a medium success.

Grouping these indicators enables us to make the following assessment: medium success for service to society and medium success for the environment and ecology. The economic sector is represented by a single indicator (costs). The overall success of the project is medium.

4. DISCUSSION

From the viewpoint of recreational use, the restoration project is quite successful (medium success). A large number of visitors are attracted by the natural river morphology, and success is apparent.

Two indirect indicators (C, F) for the environment and ecology suggest that the habitat has improved distinctly, and are mainly responsible for the overall result of "moderate success for the environment and ecology". However, the result is less promising for the direct ecological indicator category (B, G). While the vegetation indicator measures small success, the two fish indicators show no improvement of the situation after restoration. No increase in either the number of fish species or in fish abundance was observed, except for the local increase in winter densities in the widened section's well-structured backwaters (Weber et al., in press).

Furthermore, the latest monitoring results from summer 2007/winter 2008, (Schager & Peter, unpublished) indicate no changes in the situation. Six years after completing the restoration work, the fish have still not responded to the observed change in habitat diversity. From the fish perspective, the widening of the River Thur is not yet successful. For a comprehensive interpretation of the results, the ecological conditions for the whole River Thur should be considered. Concerning morphology, 65% of the lower 90 km of the River Thur is classified as artificial or strongly impacted, because the restored reach is still isolated from sources (habitat and population) and demographic support. Recolonization processes take place very slowly, and after recolonization fish still have to persist in the restored habitats. However, persistence depends on the size and the degree of habitat isolation. Populations persist primarily in larger, less isolated habitats (Dunham et al., 1997).

Dunham et al. (2003) emphasize that the dynamics of recolonization for fishes probably take place over long (> 10 years) time scales. Detenbeck et al. (1992) found that fish population recovery time was substantially longer (5–52 years) for press disturbances, in comparison to pulse disturbances (up to 6 years). Community parameters displayed considerably shorter recovery rates than population metrics. River channelization should be considered as a press disturbance, whereas pulse disturbances are non-persistent, short-term events. In the River Thur, trout and grayling did differ greatly from historical data (22 native fish species documented), and no improvement was observed due to the restoration. In comparison with other taxonomic groups, Dunham et al. (2003) found that salmonid fishes were slowest to recover. There is less information available on the response of nonsalmonid fishes to instream habitat enhancement (Roni et al., 2005).

5. CONCLUSION

Physical habitats and river morphology recover more quickly from press disturbances (river channelization) than fishes do. The fish recovery time may depend on the size of the restored area (the larger the better) and on the degree of connectivity, but also on the structure and size of neighbourhood communities and related processes (dispersal, migration). These processes are considered in the network dynamics hypothesis (Benda et al., 2004), which views watersheds as interconnected networks (space, time, processes). Network maps can help to identify the greatest likelihood of physical heterogeneity and biological hotspots. However, successful river restoration requires thorough planning in order to achieve morphological improvements, societal acceptance and flood protection. Long-term improvements for fish assemblages can take years or even decades because they depend heavily on landscape, stream network condition and related processes. Because Swiss streams and rivers are highly channelized, much time will be needed to achieve a distinct improvement for a multi-species fish fauna.

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LINKING ECOLOGICAL AND SOCIAL ASPECTS OF RIVER RESTORATION – FIRST EXPERIENCES FROM A CASE STUDY ON AUSTRIAN RIVERS

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ABSTRACT

Flood protection and ecological improvement recently acted as driving forces to restore degraded river sections in Austria. Re-establishing social functions has mostly been an unintended side-effect of river restoration. However, when spatially limited or ecologically sensitive restored areas get exposed to high visitation levels, recreation benefits might impair the ecological achievements of restoration.

Within the project “Future options for the development of riverine landscapes – space requirements for multifunctionality”, extent and potential problems of recreation are investigated on restored or close-to-nature sites along three Austrian rivers (Enns, Drau, Lech). On-site data collection includes recreational data, e.g. direct observation, face to face interviews with recreationists and experts as well as hydromorphological and ecological data. Gravel-breeding birds (Common Sandpiper, Little-Ringed Plover), which often benefit from restoration measures but react sensitively to disturbances, are used as an indicator for sustainable recreational use.

First results show that number and frequency of recreationists in restored areas strongly depend on the distance to residential areas and infrastructure, in particular parking sites and bicycle routes. Accessibility plays a major role for the distribution of hikers and bikers, while boaters show more disperse patterns of distribution. Concerning the breeding success of the indicator species, endurance and intensity of disturbances are crucial factors.

Further steps of the project aim to derive spatial and structural prerequisites of restoration measures enabling both ecological integrity and recreational use.

Key words: river recreation, multifunctionality, social functions

1. INTRODUCTION

River degradation due to human impacts caused not only ecological deterioration but also restricted social functions of riverine landscapes. Up to now flood protection and ecological deficits were the driving forces for river restoration in Austria. Social deficits have hardly ever been addressed explicitly. However, in most cases the improvement of recreational options by river restoration measures is accepted as a positive side-effect. Within an integrated management approach social functions should already be considered in the planning process. Furthermore, the objectives for the extent of riverside recreation should be framed, in order to allow an evaluation of restoration success. Hostmann et al. (2006) state that setting precise objectives, especially in terms of ecology and socio-economics, is a prerequisite for transparent planning of river restoration projects. Woolsey et al. (2007) propose ‘provision of high recreational value’ as an objective for the assessment of river restoration success.

To guarantee the success of ecological restoration it might in addition be important to consider that high visitation levels or high-impact-activities could impair ecological achievements. Therefore, recreational objectives should be framed in a way that sustainable levels of recreational use are not to be exceeded. So far in Austria little is known about interactions between social and ecological functions of rivers, making a definition of ‘sustainable recreational use’ rather difficult. Adding to this problem, there is a lack of data concerning the distribution and intensity of riverside recreation for Austrian rivers.

To fill this gap and to improve understanding of the impact of recreationists, their distribution, behaviour and also preferences need to be surveyed (Cessford & Muhar, 2003). Concerning people’s perception of restoration measures, a case-study carried out in Switzerland showed that people prefer highly natural rivers and require options to access and use these rivers (Junker et al., 2003).

Within this project insights should be gained on what the visitors appreciate about their rivers, which prerequisites make them use riversides and what prevents them from using them.

2. PROJECT CONTEXT AND STUDY SITES

This paper has been prepared in the context of the research project “Future options for the development of riverine landscapes – space requirements for multifunctionality”, conducted in the framework of the Doctoral School Sustainable Development at BOKU University of Natural Resources and Applied Life Sciences Vienna, Austria (duration 2007-2010).

The research questions of this project are:

- Which spatial and structural prerequisites enable both ecological integrity and recreational use at close-to-nature and restored river sections?
- What are the needs of different types of recreational use (e.g. extent of areas, structures, accessibility, visitation levels)?
- Which ecological effects are caused by different user groups respectively by the concomitant occurrence of different user groups?
- What principles for future planning of river restoration measures and for managing riverine landscape can be derived?

Concerning the selection of study sites the project focuses on alpine gravel bed rivers: River Enns in Styria, River Drau in Carinthia and River Lech in Tyrol. The latter is one of the few examples in Austria where recreation aspects have explicitly been considered in a restoration project. These three rivers cover a wide range of protection statuses, including the categories national park, nature park, and EU-Natura 2000 sites, and allow the comparison of close-to-nature sites to impaired and to restored sites. In total, nine study sites on these rivers have been selected for this investigation.

Figure 1 – Examples for investigation sites at River Enns. Left: restored site (Salzburgersiedlung). Right: close-to-nature site (Johnsbachmündung).

3. METHODS

Within the project both ecological and recreational data are collected. Concerning the ecological status, prior studies provide data concerning fish populations and hydromorphological aspects (Muhar et al. 2008; Zitek & Schmutz (in prep); Preis & Muhar (in prep.); Jungwirth et al. 1996). Therefore, in our project on-site investigations mainly focus on spatial analyses of the selected sites and their surroundings that are relevant for both habitat quality and recreational usability.

As indicator species for riverside habitats gravel-breeding birds (Common Sandpiper *Actitis hypoleucos* and Little Ringed Plover *Charadrius dubius*) are mapped. Being flagship species for river banks, they depend on dynamic processes in rivers. They often benefit from restoration measures, but react sensitively to disturbances. Therefore, their distribution and breeding success is analysed within the context of recreational use intensities and patterns at restored but also close-to-nature sites.

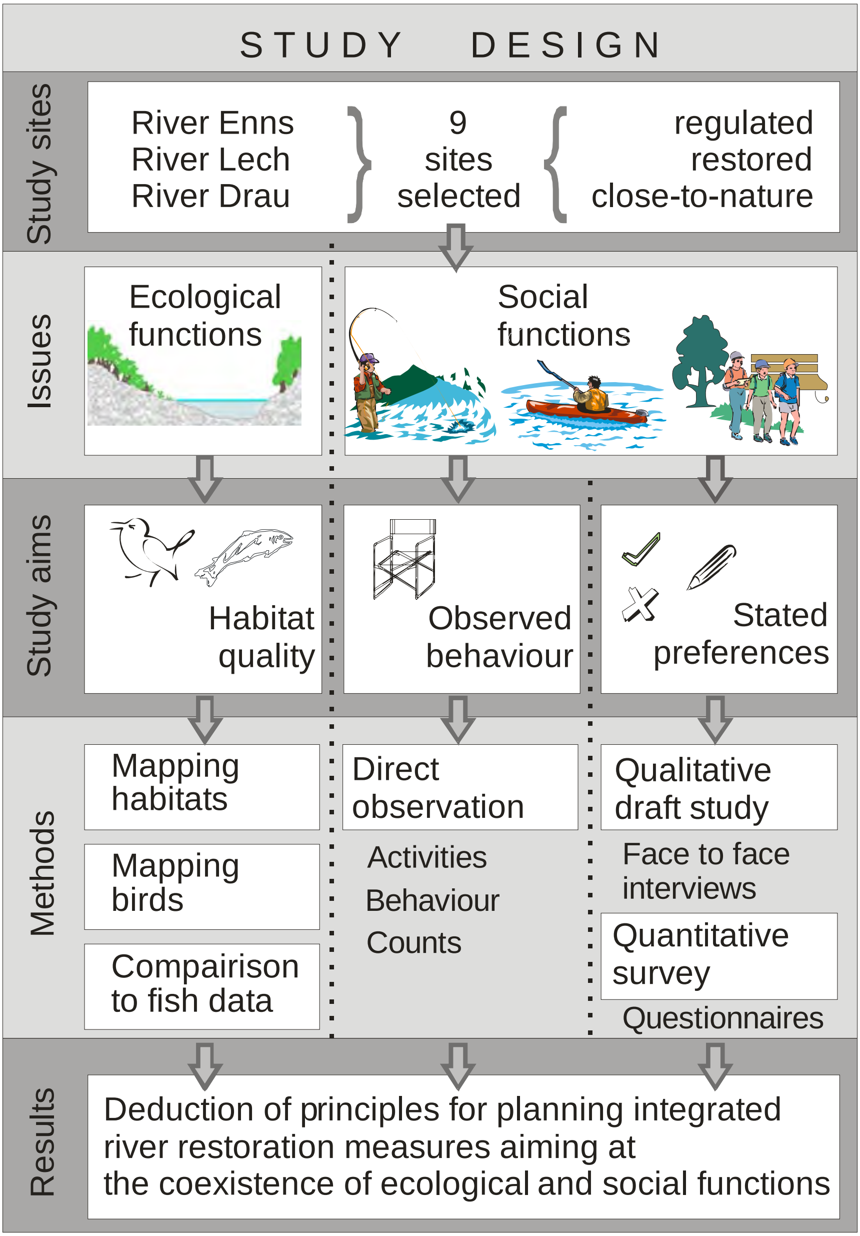

Figure 2 – Research methodology.

To get an insight into the characteristics of riverside recreation both objective and subjective aspects need to be considered. The way people really behave sometimes differs from how they think they behave (self assessment vs. actual behaviour). Therefore, two methodological approaches were chosen.

The objective approach includes direct observation, documenting parameters like observed visitor numbers, duration of stay, activities and use patterns. Direct observation is carried out on peak-days following two modes. In the first mode, the observer stays on one site for the whole day, collecting detailed quantitative data about all visitors. In the second mode, a longer river section (20-30km) is observed by canoeing down the section and recording all users and activities within the section. Although not all parameters can be documented with this method, e.g. the duration of stay, it still allows the identification of recreational hot spots along the river section and gives a rough estimate for their recreational potential.

The subjective approach was set up to reveal how recreationists perceive the river and what they appreciate about the setting. The first step was to carry out a qualitative draft study at River Enns, to explore which issues seem to be most relevant for riverside recreationists. Based on the draft study, a questionnaire was developed for the subsequent quantitative survey along all three rivers carried out in summer 2008.

4. PRELIMINARY RESULTS

As a first step the selected sites were characterised using relevant parameters for riverside recreation and ecological habitat quality (Table 1).

Table 1 - Characterisation of investigated sites.

River	River section	Morphological Status	Habitat quality for gravel-breeding birds	Accessibility for visitors	Proximity to bicycle route	Visibility fom land-side
Enns	Salzburgersiedlung	Restored	- bad	+ easy	+ close	+ good
	Aich	Restored	0 medium	+ easy	+ close	+ good
	Johnsbachmündung	Close-to-nature	+ good	+ easy	+ close	+ medium
Drau	Dellach	Restored	+ good	- difficult	0 medium	- bad
	Rosenheim	Restored	+ good	0 medium	- far away	+ good
	Spittal	Restored	0 medium	+ easy	0 medium	+ good
Lech	Häselgehr	Close-to-nature	+ good	- difficult	+ close	+ good
	Forchach	Close-to-nature	+ good	+ easy	+ close	+ good
	Weißenbach	Close-to-nature	+ good	- difficult	0 medium	+ good

Preliminary results, gained in the first three years of the project, support the assumption that the number and frequency of riverside recreationists strongly depend on the distance of the investigated sites to residential areas and infrastructure, in particular parking sites and bicycle routes.

Concerning the range of observed activities the results, based on so far 73 hours of direct observations, show that the majority of people stopping at close-to-nature or restored sites just takes a short rest or stands at the riverside contemplating the river for a few moments, not performing any particular activity. Children and younger people tend to use the riverside far more actively pursuing activities like swimming, playing or throwing stones.

Basically there seems to be a difference between intentional and accidental visits. In particular local residents tend to visit restored sites with the explicit intention to spend some time at the river. In most cases intentional users bring along certain equipment for riverside recreation like boats, angling equipment, picnic baskets, camping furniture, etc. By way of contrast, accidental users mostly perform linear recreational use like cycling or walking along paths passing that way restored sites more or less by coincidence. A prerequisite for accidental use is that the restored site is visible from the landside and also easily accessible. The latter seems to be less important for intentional users who are already familiar with the locality. A further key factor enforcing accidental use is the installation of benches along the riverside. Where recreational use is not intended for ecological reasons, water surfaces, like side-arms or ponds, and dense shrub vegetation seem to act as very efficient natural barriers.

Within the group of intentional users, boaters play a special role in terms of distribution patterns. As they are not restricted by accessibility from the landside, they are free to use also remote sites that act as area of retreat for sensitive species like gravel-breeding birds. This issue is mainly relevant for rivers showing high numbers of boaters, like one investigated section at River Enns (Johnsbachmündung).

Concerning the influence of recreational activities on the indicator species (Common Sandpiper *Actitis hypoleucos* and Little Ringed Plover *Charadrius dubius*) the duration and intensity of disturbances act as additional factors determining their breeding success, accessory to natural factors like habitat quality, discharge conditions, food supply and predation. In the upcoming phase of the project, one focus of the investigation will be in which way habitat selection of these species corresponds to recreational use patterns and intensities.

5. CONCLUSIONS

Usually the objectives of river restoration are clearly set in terms of ecological or hydrological benefits before measures are put into practice, whereas objectives for recreational benefits are hardly ever prearranged explicitly. If recreational issues are considered within the planning process, the objectives are mostly diffuse lacking intended intensity of recreational use, distribution patterns or range of activities. Of course, the relevance of social functions differs from one site to the next depending on spatial and natural settings.

Therefore the identification of key parameters determining the recreational potential provides an auxiliary tool in terms of an integrated management approach. The results of the first year of the project indicate that out of the set of various parameters influencing riverside recreation, two parameters appear to play a major role on the subsequent use intensity and should therefore be considered before putting restoration measures into practice. One parameter is the distance of restored sites to residential areas, paths and bicycle routes. This parameter is particularly relevant for the occurrence of activities depending on outdoor equipment. The second parameter is also vital in terms of steering users: the accessibility of restored sites. Woolsey et al. (2007) propose "public site accessibility" as one out of 49 indicators to assess river restoration success. The character of the access path leading to the riverside – e.g. slope, surface – definitely affects the options for recreational use.

The growing range of issues that should be considered in an integrated management approach could expand the scope of restoration projects to an extent which might not be manageable in practice. Therefore within the next steps of the project the actual range of influent parameters for riverside recreation will be assessed as a result of user observation and surveying. Subsequently a set of key parameters will be extracted, providing a tool to integrate social aspects when planning future river restoration measures.

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ECOLOGICAL PERFORMANCE OF ARTIFICIAL STEP POOL STRUCTURES FOR STABILIZING MOUNTAIN STREAMS

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ABSTRACT

This paper presents a comparative evaluation of the ecological response to traditional (high concrete check-dams) and morphologically based (low boulder check-dams) grade-control works built in a boulder-bed river (Maso di Spinelle, Italian Alps) where both structures have been present for more than a decade. Results show that both types of stream control works alter the macroinvertebrate communities and reduce their diversity with respect to natural reference conditions. Similarly, retention of coarse organic matter is higher in the presence of a natural bed morphology. In contrast, macroinvertebrate abundance is lower in the natural reach where hydrodynamic conditions are likely a limiting factor. Artificial step pool structures feature the highest abundance and the intermediate diversity of macroinvertebrate communities. Overall, the morphological restoration approach based on artificial steps appears to be the best trade-off between the need for limiting channel incision and the maintenance of a good level of ecological functioning.

Key words: check dams, fluvial morphology, bed incision, macroinvertebrates

1. INTRODUCTION

High-gradient (channel slope > 3-5%) streams often exhibit a natural step pool architecture, which likely represents a self-adjustment towards higher channel stability (Abrahams et al., 1995; Lenzi et al., 2006) partly because of the great deal of flow energy dissipated in the hydraulic jumps (i.e., spill resistance) at each step pool unit (Wilcox et al., 2006). The same physical process has long been "utilised" in the construction of staircase-like sequences of grade-control works such as check-dams to inhibit bed incision in steep channels (Comiti et al., 2005).

However, in the Alps, “classic” check-dams are tall (> 2 m, but up to 10 m) concrete structures which cause unnatural impoundments and channel widening upstream, severe disruption of the longitudinal river continuum (sediments, organic matter, biotic communities), and a strong “artificialisation” of the mountain landscape. Such adverse environmental impacts have led over the past two decades to several stream restoration projects involving check-dam removal and/or substitution with stone ramps. Furthermore, new torrent control projects across the Alps have implemented low check-dams and bed sills built with boulders and logs adopting fluviomorphological criteria. Such an approach presents clear advantages in terms of visual impact and construction costs, whereas its capacity to resist high-magnitude flood events depends on structure type (Lenzi, 2002). Nevertheless, the actual ecological benefits brought about by these boulder check-dams mimicking natural steps units are not known, thus hampering a scientific evaluation of their “pros and cons”.

The purpose of the present paper is a comparative assessment of the ecological response to traditional (high concrete check-dams) and morphologically based (low boulder check-dams reproducing step pool sequences) grade-control works built in a high-gradient, boulder-bed river (Maso di Spinelle, Italian Alps).

2. STUDY AREA

2.1 Maso di Spinelle characteristics

The Maso di Spinelle is a perennial tributary of the Brenta River (Province of Trento, Northeastern Italy), having the hydraulic and morphological characteristics of a boulder-bed stream (Fig. 1; Tab. 1).

Precipitation occurs mainly as snowfall from November to April, with runoff being dominated by snowmelt in May and June. Annual peak discharges are usually associated with cyclonic storms in early autumn. Forests (mostly conifers, such as Norway spruce - *Picea abies* and European larch - *Larix decidua*) cover 53% of the basin. Basin geology is represented by metamorphic (schists, gneiss) and intrusive (granite) rocks. Quaternary deposits dominate along the channel, with talus often resting on moraine and fluvioglacial sediments rich in very large boulders (intermediate diameter > 3 m). Some of these boulders were noted to have caused flow diversions during large flood events, leading to bank failures.

Figure 1 – Looking upstream to the Maso di Spinelle catchment. The tall check-dams built in the 1980s are visible in the channel.

Table 1 – Main characteristics of the Maso di Spinelle River.

Characteristics	Value
Catchment area (km^2)	45
Mean annual precipitation (mm)	1200
Minimum elevation (m.a.s.l.)	909
Maximum elevation (m.a.s.l.)	2561
Length of the main channel (km)	10.0
Mean channel slope (%)	13.8
Bed morphology	Step pool, cascade

2.2 Types of river control works in the Maso River

In the 1980s, following the large damages that occurred during the extreme (R.I. > 100 yr) flood event in 1966, when the streambed incised for 10-15 m and widened from 10 to 50 m, 13 check-dams in reinforced concrete were built along the most degraded channel reach. Check-dam height and spacing are approximately 9 m and 90 m, respectively, with a mean channel slope (crest-to-crest) of about 10%. The actual bed slope on the "step tread" between two consecutive structures (measured in 2005) ranges between 2 % and 4 %. Bankfull channel width is about 17 m.

In 1996 and 1997, after an intense (R.I. 50-75 yr) flood event in 1993, grade-control works were considered to be necessary upstream of the reach previously described. About 30 boulder check-dams were built along a 400 m reach, with height varying between 1 m and 2.5 m and spacing from 10 m to 24 m. A morphological criterion to design step height and spacing according to bed grain size distribution (D_{90} ~ 1.5 m) and channel slope (varying from 12.5% to 16%) was adopted (Lenzi, 2002), following the flow resistance maximisation proposed by Abrahams et al. (1995). The control works successfully resisted an intense flood event in 1998 (R.I. = 20-25 yr), with minor bed adjustments (Lenzi & Comiti, 2003). Bankfull width ranges from 15 m to 25 m, whereas the actual bed slope between artificial steps is about 4-5%. Fig. 2 shows images of both types of control works.

Just upstream of the reach stabilized with the above described artificial steps, a channel segment not affected by control works is still present, which features a dominant cascade morphology (*sensu* Montgomery & Buffington, 1997) with occasional step pool units stretching across the entire cross section (bankfull width 15 m, slope 10%). The abundance of large boulders leads to frequent tall steps (up to 1.5 m - 2 m) as well as to a chaotic bed arrangement, which make the flow very turbulent and aerated (Fig. 3).

Figure 2 – Different torrent control works in the Maso di Spinelle river: “traditional” reinforced concrete check-dams (TR, left) and “artificial steps” (AS, right).

Figure 3 – The “natural” reach (N) in the Maso di Spinelle river, which served as reference conditions for the comparison with traditional and boulder check-dams.

3. METHODS

The ecological effects of grade-control works in the Maso di Spinelle were evaluated by analysing the macroinvertebrate community (taxa composition, diversity, abundance) and the short-term retention capacity of coarse organic matter at three different stream conditions, i.e. traditional check-dams (TR), artificial steps (AS), and natural (N) reaches, as described in the previous section.

Macroinvertebrates were collected in July and August 2005 (summer low flows) using a 500μm-Surber net at two morphological units, i.e. runs and pools. Three different units (sampling sites) for each unit type were investigated for each reach, and for every sampling site 3 replicates were taken (Panazzolo, 2006). Flow velocity, water depth and grain size measurements were also taken at each sampling site by an electromagnetic current meter, a stadia rod and a calibre, respectively. Macroinvertebrates were identified in the laboratory to the taxonomic level required by the IBE method (Extended Biotic Index; Ghetti, 2001), i.e. genus for *Plecoptera*, *Ephemeroptera*, *Odonata*, *Tricladia*, *Hirudinea* and family for *Trichoptera*, *Coleoptera*, *Diptera*, *Eteroptera*, *Crustacea*, *Gastropoda*, *Bivalvia*, *Oligochaeta*.

Measurements for assessing the short-term retention of coarse particulate organic matter (CPOM) were carried out following the procedure developed by Siligardi et al. (2000), which implies: i) selection of homogeneous reaches; ii) sudden injection of *Ginkgo biloba* leaves (in this case 500 leaves for every test) at the upstream reach end; ii) counting of the *Ginkgo* leaves passing the downstream reach end at fixed time intervals; iii) creation of time-retention cumulative curves.

"Leaves tests" were performed in summer 2006 and 2007 (Checchinato, 2008) during low flow conditions (flow discharges of 1-1.7 m^3s^{-1}, measured by the salt dilution method). A 110 m reach was selected in the "natural" reference channel reach (N), and two tests were carried out. Within the "artificial steps" reach (AS), a 44 m sub-reach was considered where macroinvertebrates were collected (6 tests). Finally, in order to discern the role of the large pools present below each check-dam in the stream reach controlled with traditional high check-dams, both crest-to-crest (93 m, TR, 4 tests) and pool-to-crest (66 m, TR no pool, 3 tests) measurements were carried out. Leaf counting was subsequently normalised by reach length to make inter-reach comparisons possible. After each test, the *Ginkgo* leaves were sought along the channel bed to determine preferential retention sites (Petersen & Petersen, 1991; Siligardi et al., 2000).

Finally, for the reaches TR, AS, and N, the IBE values and classes were calculated using the collected data on macroinvertebrate taxa and abundance (Ghetti, 2001), and the IFF (Fluvial Functionality Index, Siligardi et al., 2003) method was also applied.

4. RESULTS

4.1 Macroinvertebrate communities, IBE and IFF

Table 2 reports a summary of the data relative to the macroinvertebrate analysis in the Maso di Spinelle. Looking at reach-scale data, it is evident that TR features the lowest number of taxa, the reference reach N the highest number, and AS lies roughly in between. Also, the macroinvertebrate population in TR is dominated by rather tolerant taxa such as *Simulidae* and *Limonidae* (Diptera), and *Baetidae* (Ephemeroptera).

In contrast, taxa typical of very aerated flows on very coarse substrates were very common in reach N, such as: *Epeorus*, *Rhytrogena*, *Ecdyonurus* (Ephemeroptera); *Odontoceridae*, *Psycomyidae* (Trichoptera); *Blephaceridae*, *Athericidae*, *Empididae* (Diptera); and *Hydraenidae* (Coleoptera). An intermediate taxa configuration characterises AS reach. The same trend is apparent from a combined analysis of the two diversity indexes (Margalef, Shannon) reported in Table 2. The IBE method is not able to capture these differences (all reaches fall within Class I, i.e. no alterations) even though reach N scores slightly higher (11 *vs* 10). Conversely, the IFF index appears directly correlated to taxa numbers and diversities (see also Ballestrini et al., 2004).

Interestingly, macroinvertebrate density (organisms per m^2 of streambed area) shows a different pattern, being at a maximum in the AS reach with TR and N featuring similar, smaller values (Tab. 2).

Table 2 – Macroinvertebrate diversity and abundance in the three reach types (TR=traditional concrete check-dams; AS=artificial boulder steps; N=reference “natural” reach). Data referring to the two morphological units (runs and pools) are shown, as well as total/average values at the reach scale.

Reach type	TR			AS			N		
Morpho Unit	run	pool	reach	run	pool	reach	run	pool	reach
Replicates	9	9	18	9	9	18	9	9	18
N° Taxa	20	18	21	23	19	25	23	19	27
Density (org/m^2)	562	259	410	683	434	558	557	232	395
R (Margalef)	3.18	3.07	3.04	3.44	3.03	3.49	3.57	3.41	3.99
H (Shannon)	2.30	2.10	2,36	2.33	2.16	2.35	2.47	2.05	2.46
IBE value			10			10			11
IBE class			I			I			I
IFF values			181-210			229-241			290-290
IFF class			II-III			II			I

From Tab. 2 it is also evident how a systematic difference in macroinvertebrate diversity and density exists between the two morphological units (i.e. "fast" and "slow" habitats, Tab. 3), across the different reaches. As already noted in other mountain streams (e.g., Buffagni & Comin, 2000), coarser units characterised by fast-flowing water (i.e., riffles and runs) present higher diversity and density compared to deeper, slower areas covered with finer sediments such as pools.

Table 3 – Average hydraulic and grain size characteristics measured during summer low flows at the macroinvertebrate sampling sites, differentiated in morphological units. Mean velocity represents the average velocity across a vertical profile.

	TR		AS		N	
	run	pool	run	pool	run	pool
Water depth (m)	0.25	0.37	0.24	0.25	0.33	0.38
Mean velocity (m s^{-1})	0.62	0.21	0.51	0.21	0.52	0.10
Mean grain size (mm)	103	32	59	43	79	23

4.2 Short-term CPOM retention

The short-term dynamics of CPOM retention, as measured by the *Ginkgo* leaf tests described in Section 3, is depicted in Fig. 4 where only one run per reach is shown for clarity.

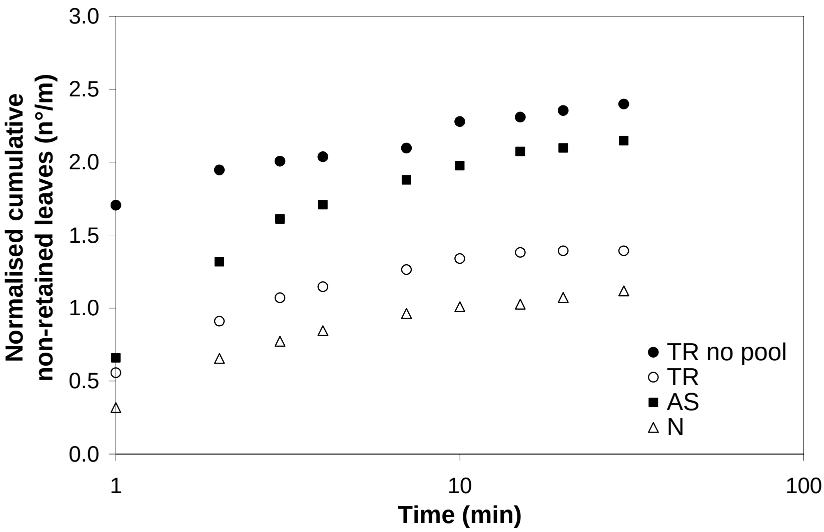

Figure 4 – Examples of cumulative curves of passing (i.e., non-retained) leaves normalised by reach length (number of leaves per metre of streambed length). Time refers to minutes after the first leaf reached the downstream end. "TR no pool" is a sub-reach of TR excluding the large pool formed below the check-dam.

Fig. 5 shows for all the tests the variations in the final value of non-retained leaves (i.e. the “quasi-asymptotic” value attained at 30 min). Variables in both graphs (i.e. number of leaves passing through a reach without being trapped) represent the opposite of retention because it actually is what measured in the field.

Clear differences emerge among the analysed reaches with regard to both the temporal evolution and the final values. The reach stabilised with boulder check-dams (AS) features the steeper relationship with time (Fig. 4), the lower retention capacity and the largest *intra*-reach variation (Fig. 5), possibly due to its larger channel width and complex morphology which may lead to different travel paths even for slight changes in flow discharge and location of leaf injection. As expected, the reference “natural” reach (N) is characterised by high retention capacity, but both the temporal trend (Fig. 4) and final values (Fig. 5) are very similar to the reach with concrete traditional check-dams (TR).

However, Fig. 4 and 5 illustrate how such similarity is likely to be due to chance, because when CPOM retention along the traditional check-dam reach is evaluated excluding the large (about 10 m long and 2 m deep) pool below the structure (reach “TR no pool”), the final retention values diminish and the temporal trend of leaf transport exhibits a much faster initial stage (3 times higher within the first minute), suggesting a lack of different retention structures along the streambed.

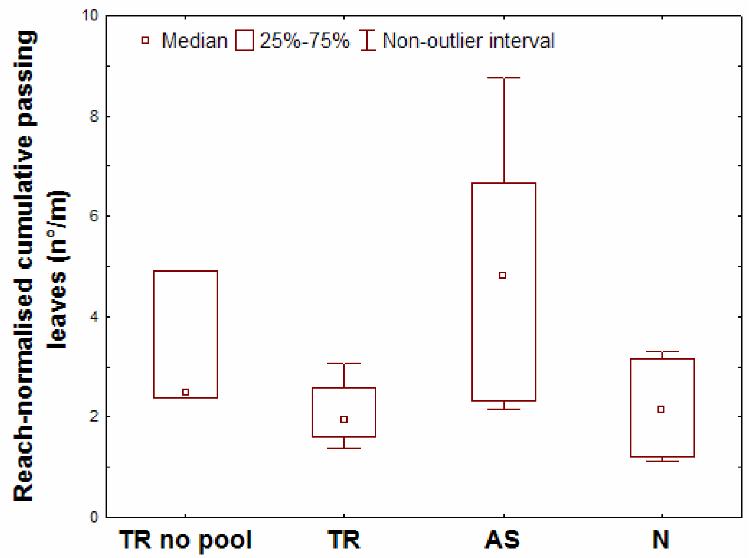

Figure 5 – Box plot of final (i.e. after 30 min) cumulative leaf counts (normalised to reach length). The number of tests for the different reaches is reported in the text (Section 3).

Unfortunately, only a small fraction (< 2-3%) of the retained leaves could be found along the streambed after each test was concluded, and therefore the indications gained by their location (e.g., trapped by cobbles, stranded on bars, floating in pools) does not have any statistical significance. However, it was noted that in the reach TR most of the visible leaves were either whirling towards the banks of the large pool, or were deposited at its lateral water edges. Furthermore, many autochthonous leaves were noted lying at the pool bottom, indicating its "sink-like" role for coarse organic matter. The ecological effects of this localised CPOM storage, possibly re-activated only during moderate to large flows able to "flush" it out of the pool, are likely different from those associated with shorter term retention by smaller pools and cobbles/boulders trapping very effectively on a natural bed morphology.

5. CONCLUSIONS

Channel reaches stabilised by boulder check-dams mimicking natural step pool units are characterised by higher abundance and diversity of macroinvertebrates when compared to reaches controlled by means of high check-dams. On the other hand, with respect to "natural" step pool/cascade reference reaches, the artificial step pools show lower diversity with a lack of the most reophilic taxa, even though the spatial density is higher. This is likely due to "milder" (i.e., lower unit stream power) flow hydrodynamics resulting from the imposed wider cross sections.

Also, the artificial step-pool reach exhibits a lower CPOM retention capacity than the reference reach, possibly because of its artificially simplified morphology (lack of large boulders) coupled to lower flow velocities. Reaches featuring high check-dams appear to be good at retaining CPOM, but most of it is actually "trapped" in the large pools below each structure and thus is poorly available to benthic communities.

Overall, this study indicates a relatively good ecological performance of artificial steps structures, or at least their superiority to traditional approaches. Smaller, more frequent artificial steps appear to be a valid alternative to high, long-spaced check-dams, which significantly alter natural bed slope, flow energy and sediment size. The same artificial steps demonstrated satisfactory flood control effectiveness over a 10-year period, in particular during the 1998 event (R.I. 20-25 yr). However, in those situations (e.g. densely urbanised basins) where population safety must be guaranteed for flood events > 50 yr, concrete or boulder/concrete structures are required.

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CHAPTER 8

Session 7

Key issues and challenges in Decision Making Processes to implement river restoration

Chairperson

A. NARDINI

Introduction

KEY ISSUES AND CHALLENGES IN DECISION MAKING PROCESSES TO IMPLEMENT RIVER RESTORATION

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River Restoration always involves diverging objectives, conflicting interests of different stakeholders, or actual conflicts amongst social groups or even nations.

"Conflicts", in this broad sense, do not concern only trans-boundary rivers: conflicts at the national and local scales, particularly from the perspective of local communities, involve perhaps a less visible dimension, but nevertheless occur in an incredibly high number of cases, covering most of a nation's territory, and therefore they are very important: modifying the concessions for water withdrawal from a river including ecological minimum flow requirements, managing a multipurpose/multi-actor water reservoir or building a new one, or giving back space to rivers to reduce downstream flooding damages are simple examples of extremely frequent and often harsh conflicts.

A <u>better way of making decisions</u> is not an optional item, it rather looks as an unavoidable requisite to give a real content to the sustainability declarations. The "cost" of not improving/changing the way decisions are made is extremely high: public opposition, discontent, delays, additional economic costs, ineffectiveness, inefficiency, ...

In particular, planning is either impossible or useless because decisions made are then ignored. Without planning, no generalized restoration of our rivers can be achieved.

The needed improvement should be able to merge *participation* (the "cloud of the public") with that of *rationality* (the "cloud of know-how"):

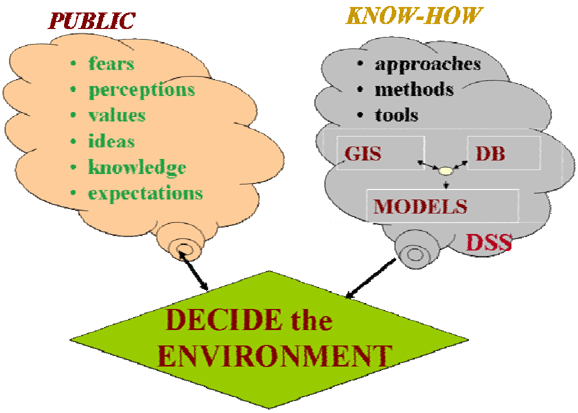

Figure 1 – The challenge for improving environmental decision making: merging the socio-psychological dimension with the rational/expertise dimension.

Objective

Get insight in the key areas of weakness related to decision making in river restoration projects and plans, and share key ideas and relevant successful or failure experiences to face them.

Arguments of the session

NOTICE: The following section is intended to stimulate participants and to focus the issues we would like to discuss. Negative aspects (weaknesses) are therefore enlightened, but of course we are expecting also positive contributions that show how to overcome such difficulties.

A good RR project/plan should comply with the criteria for "good decision making in environmental problems", which is unavoidably a participatory process. A typical scheme can look like this:

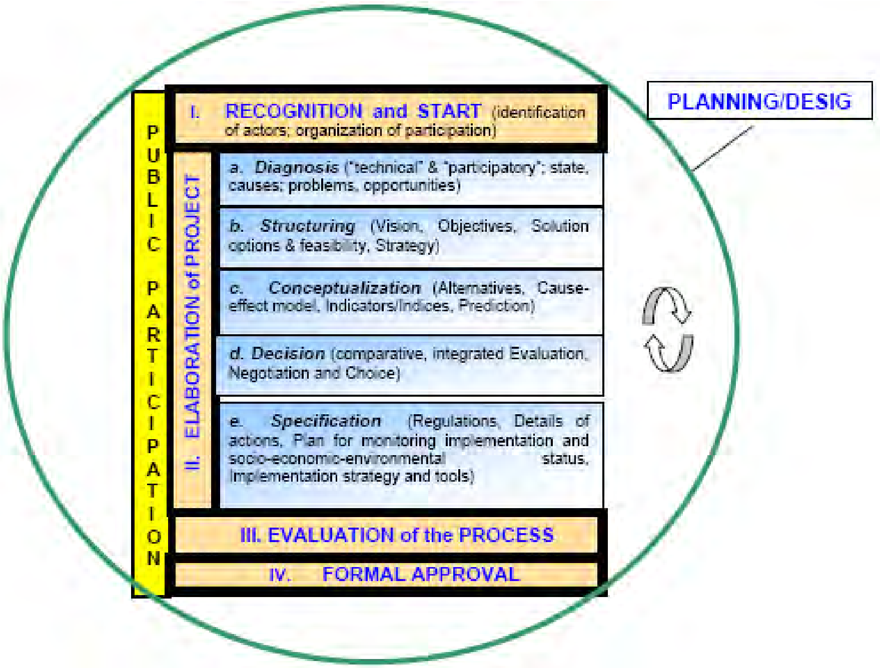

Figure 2 – An ideal scheme for a rational participatory Decision Making process.

This scheme is however hardly applied in real practice. Key issues underlying this reality are:

- Typical weaknesses of "participation", as inadequate institutional setting, absence of recognized power by formal Decision Makers (or fear to lose power); limitation to communication rather than true participation with scarce or no real use of feedback from people, scarce sharing of information, lack of "participatory culture", etc.
- The link between the "rationality cloud" (know-how) and that of "participation" (the public) is still too weak and the two channels go far apart one from the other. In other words: **i)** DMs and the public tend not to rely sufficiently on a rational, well informed ground; and **ii)** system approach and tools (models, Decision Support Systems,…) are often not used in practice, while they are often used as a mere maquillage
- Mathematical models adopted to forecast future behaviour, particularly when ecosystems are involved, are too data-eager and, because of this, can hardly be applied reliably and within acceptable limits of time and money
- The evaluation framework is often unsatisfactory: there is no real integration amongst the typical, still separated, traditional

approaches/techniques (Cost-Benefit Analysis, Multicriteria Analysis, and the whole family of Environmental Impact Assessment items, including Strategic Impact Assessment etc.); there is no sufficient support from them to address conflicts and negotiation.

Finally, an open issue is how to measure the ecosystem status and how to judge whether it is good or not: should we confuse its value with that of the environmental services it provides (so relegating it to a servant of other purposes), or rather recognize it also deserves …good conditions for its own sake? Which indicators and indices are sensible and usable? How can we forecast their change according to several alternative possible actions?

After the Conference

Presentations ranged from participatory issues -like, in particularly, creating involvement and information basis, a common vision and strategy (even supported by suitable software programmes)- to examples of choices of technical solutions, passing through the planning problem with examples of how to choose amongst alternatives in a multiobjective framework , including how to deal with uncertainty and critical considerations about the appropriateness and effectiveness of Decision Support Systems, and a comprehensive challenging urban restoration decision making process, or how to prioritize the candidates RR projects and even assessing an adaptive management program.

4th ECRR Conference on River Restoration
Italy, Venice S. Servolo Island
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ESTABLISHING AN AUSTRALIAN RIVER RESTORATION CENTRE: CONTEXT, PRIORITIES AND PROGRESS

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ABSTRACT

Australia is a continent of great diversity, with rainforests, deserts, tropical savannahs and alpine areas. This diversity is reflected in the many different types of rivers, streams and creeks that are the lifeblood of a mostly dry and thirsty continent. We know that only about one third of Australia's river systems remain in first-rate condition, another third show clear signs of degradation, and the remainder are already in poor condition and getting worse. Without water and the river systems that sustain its quality, Australia's rural, urban and unique ecological communities cannot survive. This paper discusses the range of institutional changes that have taken place in response to this urgent need to improve river management in Australia, including the introduction of water markets and trading, the appointment of managers with a specific role in allocating water for the environment, and the devolution of responsibility for some river management decisions to catchment based authorities. It will discuss the problems that have arisen as a result of a lack of capacity in skills, knowledge and financial resources to plan, implement and evaluate the success of river restoration projects.

Many agencies, groups and individuals are keen to get involved and help improve the health of our river systems, but are unsure about priorities for action, the works needed, or how to ensure funds are spent to best effect. It is within this context, that this paper discusses the establishment of an Australian River Restoration Centre (ARRC) as a way of helping communities overcome the uncertainty that characterizes river restoration. The reasons for establishing an ARRC will be outlined, as well as reference made to how existing European River Restoration Centres provided the inspiration for the ARRC. The paper discusses some of the premises upon which the ARRC will be based, including the founding principle that for river restoration to be successful, people need to be valued and supported as an important resource in their own right. The paper argues that people are an important resource for river restoration, as it is the personal connections that people feel to their stream, creek or section of river that motivates them to get involved. In Australia, local communities are relied upon to undertake many of the

river restoration projects, often voluntarily, as the scale of work required cannot be covered by government agencies alone. As a result, proposed scientific and engineering solutions need to also pay attention to the social or cultural environment within which these communities operate.

The paper concludes with an overview of progress to date in setting up the ARRC and plans for the future.

Key words: Australia, River Restoration Centre, capacity, community, sharing knowledge

1. INTRODUCTION

Australia is well-known as the driest inhabited continent. Although the population is small compared with the area of land, competition for water resources is intense and increasing. Most of the larger river systems in the south have been regulated for human use, and there is pressure to repeat this in the tropical north. Evidence from river and riparian condition surveys at the national level, and by State and Territory bodies, shows that only one third of Australia's river systems remain in sound ecological condition, another third show clear symptoms of degradation, and the final third are already in poor condition and getting worse (National Land and Water Resources Audit, 2002).

Periodic droughts, like the current one, exacerbate the competing demands from water users and further threaten the condition of our rivers and waterways. Climate change predictions all suggest an overall reduction and greater level of variability in river flows in the future, placing greater pressure on water users and our ability to maintain healthy river ecosystems.

Australia has made significant investments in research and development to better understand the dynamics and driving forces behind our rivers and riparian systems. It has generally not been possible to import concepts from the northern hemisphere, as Australian rivers are subject to quite different influences, for example, an old and mostly nutrient-poor landscape with a very high coefficient of rainfall variability. Some excellent progress has been made, although our knowledge of tropical and inland river systems is still rudimentary. There remains, however, a significant disconnect between the knowledge held by scientists and researchers, and the people now charged with the on-ground management of rivers. This has been made more difficult by the gradual dissolution of expertise formerly present in State and Territory agencies.

While water planning has taken place elsewhere in the world, the comprehensive and integrated way that it is being done on a mass scale in Australia is unprecedented. Right across the country, Water Resource Plans are being developed and implemented to allocate volumes of surface and groundwater to different purposes and to the environment, typically at a catchment level. Once established, they become binding legislation enacted by state ministers. The mosaic of catchment-based Water Resource Plans across the landscape is linked to state water legislation and, in turn, to the overarching national regulatory framework, to comprise the basis of water allocation across Australia (Mackenzie 2008). Four levels of government are involved, all with different roles and responsibilities, yet reliant on constant dialogue and discussion to ensure Water Resource Plans meet the needs of all involved. This approach means that achieving the central objective of water reform – a nationally consistent approach to the management of water – relies upon sound technical advice, processes to negotiate how best to allocate water within a context of competing demands, and organisations able to share information and work together to achieve common goals.

Developing Water Resource Plans is not easy, and many local catchment communities are feeling daunted by the responsibility that is being thrust upon them. There are real issues about whether the capacity of some of the catchment organisations responsible for the development of these plans is sufficient. ome key aspects of the technical information needed are missing, for example, knowledge about how flow variation affects in-stream and riparian ecology, and the links between floodplain and aquatic ecosystems. Providing technical information and planning assistance to these communites as they attempt to develop plans for the long-term sustainability of their region, is very important, yet generally under resourced.

2. THE NEED FOR AN AUSTRALIAN RIVER RESTORATION CENTRE

It is within the context discussed above, that there is now an urgent need to better manage Australian rivers for multiple objectives. To do this, we need further sound science to underpin effective management and, most importantly, we need to invest in the link between river managers at all levels, with people who have the required technical knowledge. This is where an organisation is needed that can work with scientists and river managers to translate research findings into practical on-ground results. The Australian River Restoration Centre (ARRC) will meet this need, and be an impartial broker and provider of knowledge about river and riparian management. The term ‘Restoration’ in its title, encompasses improved river management, river rehabilitation, and maintenance and restoration of crucial river functions within different landscapes.

The essence of effective river restoration is about the interaction between the environment and people. Our rivers have vital economic, environmental and cultural values, however, most organizations working in this area focus on biophysical or economic aspects of rivers, rather than the people who live, work and play along our waterways. The ARRC beings with the premise that people are the most important resource for river restoration, as it is the connections people feel to rivers that will motivate them to protect, care and act to restore them for current and future generations. Involvement by local people is crucial because most river management is long-term and on-going, and does not match the typical three-year funding cycle of government programs. This need for local support and action is reflected in the mission of the ARRC that is to:

Support, facilitate and provide opportunities for Australians to work together to protect, maintain, restore and celebrate our riverine environments

The ARRC will connect people with an interest in river restoration, whether they are scientists, irrigators, conservationists, government employees or someone with an interest in their local creek. The ARRC is needed because it is difficult for these people to work out who is doing what in river restoration, where they can go for information, who can help them with their river restoration goals or project, or how to find and collaborate with others in their region doing work in river restoration. The ARRC will be able to link, connect, facilitate and provide opportunities for people to access the information and skills they need to accomplish their river restoration objectives. In summary the ARRC is needed because:

- Australia is spending around $A100 million each year on river management projects, but evaluations suggests that many do not achieve their objectives. Few projects are evaluated after completion, so we are not learning from past successes and mistakes.
- Much of the technical understanding of processes that drive the health and functioning of rivers and riparian lands is not readily accessible to river managers, nor in a form that they can readily apply.
- There is no national pathway for people to quickly access technical advice to help them in understanding the causes of river degradation or to plan projects to reverse it.
- Many restoration projects have short time frames, small amounts of money, and high staff turnover, all of which go against the building of local knowledge and capacity for action over the tong-term.
- Many researchers are frustrated that science is not being used fully to inform and support good river management.

- Many river management bodies and groups are unaware of what others are doing, even though they could learn and save resources from the experience of others.
- Although scientists are generally aware of research developments overseas, there is no mechanism to help river managers share knowledge about best practice in river management between countries, for example between the programs operating in Canada, the USA, Europe, Asia, South Africa and New Zealand.
- There is a large and growing demand for education and training in river management and restoration that is largely unmet.
- There is a need to better link river and riparian management into the context of whole catchment management, including the economic and social contexts of different communities.
- There is an urgent need for something like the ARRC to continue the work of past programs that are now completed.

The ARRC will provide an efficient and effective way to develop and share information about all aspects of river and riparian management. This will add substantial value to past and current public and private investment, help to build local and regional capacity and confidence, and inform national debate about the use and management of our waterways and water resources. There is no other organization in Australia whose objective is to develop and broker scientific and technical information specifically for end-users working in river management. Our integration of the socioeconomic with the biophysical aspects of river management is also unique.

3. BUILDING ON SUCCESS

The ARRC will build on the success of Land & Water Australia's[1] National Riparian Lands R&D Program, which ran for thirteen years and significantly improved our understanding of Australian river function, and the management actions that can protect, enhance and restore riverine environments. The Program ended in 2006 and, as a result of its success in translating science into meaningful and relevant material for people, there is now a need to continue work in this 'space', so that end-users can have ongoing access to the products, training, workshops and scientists involved. The proponents of the ARRC, Dr Siwan Lovett and Dr Phil Price, managed the National Riparian Lands R&D Program for the thirteen years of its

[1] Land & Water Australia is one of thirteen Rural Research & Development Corporations that work to bring researchers, agricultural industries and government together to invest in projects that will ensure long-term sustainability of Australia's rural communities, socially, economically and environmentally. For more information www.lwa.gov.au

operation, so they bring with them the relationships and knowledge to continue the legacy of the Program and develop it further through the ARRC.

There are also a number of other river initiatives underway across Australia. The ARRC will act as a clearing house for rivers information by bringing together 'the best' river management knowledge and information materials. In so doing, it will provide an efficient, effective way to share knowledge about all aspects of river and riparian management or restoration. For example, it will develop guidelines that describe practical methods to achieve particular outcomes, it will put people in touch with experts who can provide specific or technical advice, it will organise workshops so people can share their findings and experiences, and it will establish exchange programs to keep new ideas flowing into communities across Australia. The ARRC will use an interactive web portal to enable anyone who seeks advice to contact the people able to provide it.

The ARRC will be modelled on the successful European River Restoration Centres (hence its title). It will operate independently and work to develop a reputation for sound, impartial advice and support. It will be linked to the European Centres as well as initiatives in North America, South Africa, Canada and Asia. These connections will provide opportunities for Australians to share their experiences and learn from techniques applied elsewhere.

4. PROGRESS

Much of the past twelve months has been spent developing the framework required for the ARRC. The ARRC is being established with an independent Board of Directors and will be run as a not-for-profit business. It will sell its services and products, reinvesting the proceeds in its operations, and aims to become partly self-sufficient over a three-year period. ARRC proponents are now seeking business and private sponsors to assist the organisation through its start-up phase by providing financial support and access to business skills.

One of the proponents of the ARRC, Dr Siwan Lovett was awarded a Winston Churchill Memorial Fellowship to travel to Europe and learn more about the European River Restoration Centre model. She is currently undertaking this trip, with the European Centre for River Restoration Conference in Venice, an important component.

The ARRC has a Strategic Plan that is now being circulated to potential sponsors. The website is also up and running at www.arrc.com.au, and strong relationships with Land & Water Australia have meant that all the river related information generated through the National Riparian Lands R&D Program is available at this site. The range of information will be expanded in the latter half of this year.

Some of the top Australian scientists in river and riparian management have indicated their support for the ARRC, and it is hoped that groups will come together under the ARRC banner to apply for river management work and disseminate it to end-users. These links are fundamentally important, as goodwill, trust and confidence in the people working for the ARRC will contribute to the success of the organisation.

A project examining the feasibility of establishing an Australian River Restoration database has been undertaken by Dr Siwan Lovett, Dr Phil Price and Professor Peter Davies (Univeristy of Western Australia) and, pending feedback from key government agencies, it is hoped that funding can be secured to establish this vital piece of national infrastructure. Should the funding be forthcoming, the ARRC is the ideal organisation to develop and manage such a database.

5. CONCLUSIONS

The ARRC offers investors the opportunity to be a part of a national hub for river-related information and activities. It will be the first point of contact for any person or organisation wanting to know about rivers — whether they be a farmer, irrigator, journalist, ecologist, student, Rivercare group facilitator or catchment management employee. Anyone with an interest in rivers will be able to access the ARRC's services.

The ARRC's emphasis is on the active involvement and interaction of people by developing relationships, building trust and confidence, empowering people to act and increasing individual, organisational and community capacity to improve the management of our rivers. We want to celebrate river restoration as a positive step towards maintaining the health of our water resources. The ARRC will be established for the long-term, in contrast to some land and water management programs that support projects for only two- or three-year time frames. People who access the ARRC's resources will be confident that the advice, information and events offered will be independent, relevant, science-based and have continuity now and into the future.

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MAGDALENA RIVER MASTER PLAN: A COMPREHENSIVE MANAGEMENT AND SUSTAINABLE USAGE PROJECT (MEXICO CITY)

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ABSTRACT

The Magdalena River is the last river course within the Federal District of Mexico City flowing without being piped. The problem it shares with the other rivers of the Mexico Basin is a high degree of pollution in its final portion. The National Autonomous University of Mexico (UNAM) was chosen as the institution to design the Master Plan that will organize and standardize the river's rehabilitation. Drafting the Master Plan is a pioneer experience for urban river management in Mexico, as it is the first time that a multiobjective management framework is available before implementing any hydraulic work –a sequence that sounds logical with these projects, but that rarely happens in this Country.

The Magdalena River system has been fragmented by hydraulic interventions such as trash racks, water treatment plants, regulating reservoirs, piping of a river section now used as a roadway, and alterations at the two outlet points: the western trap and the Churubusco River. The latter is actually a wastewater collector. In addition to this fragmentation, the Magdalena River is a "hidden river". It has lost its value in the urban area because it has been incorporated into the drainage system. In spite of these characteristics, the river also has certain strengths that support the restoration initiatives. The natural area is an important biodiversity refuge. It has young and well-preserved forests, and the water quality is optimal, so that part of the flow is used as drinking water.

The Master Plan's draft is underway, although the final document will not be ready until the summer. The Plan's most important advances include four general management strategies, these being: 1. An ecosystemic management that will include sustainable local development and soil preservation; 2. Revaluing the river's urban and landscape features; 3. A comprehensive management of the river and its hydrological basin; and 4. New governance in handling natural resources.

Keywords: Master Plan, Magdalena River, Mexico City, UNAM

1. INTRODUCTION

The Mexico Basin has an extension of 9,600 km2 and holds one of the World's biggest cities —Mexico City, with a population of 20 million inhabitants. The basin is also known for the drying of its lake system that has been occurring for the past three centuries. During the colonial period, constant floods lead the population to perceive lakes and rivers as very dangerous. This social representation set the foundation of the hydraulic paradigm, which is still in place to date. It calls for water ejection from the basin using artificial outlets. It was not until the mid-20th century that a critical position emerged to confront the dominant paradigm, suggesting the recovery of the basin's lakes, particularly Texcoco Lake. Lakes would be the natural stop to the City's urban growth. They would restore the region's environmental balance, and would provide a local water supply (Cruickshank, 2005).

One of the key elements of the hydrological and environmental problems of the Valley of Mexico's Metropolitan Area is the lack of organization for what concerns river rescue. This is made evident by the pollution of every single river in the Valley, as practically all of them have been converted into the city's sewages. This is the context in which sectors such as civil organizations, authorities and the academia began organizing around one common goal: to rescue the last alive river that enters a city with an open riverbed, the Magdalena River.

Their efforts were brought together under the Promoting Group for the Rescue of the Magdalena River Basin, an organization created in March 2007 by instructions of Marcelo Ebrard, the Federal District's Chief of Government. The current government's decisive support is evidenced in the priority it has given to the river's rescue project, in addition to having sustainable development be one of its central axis.

The Promoting Group selected the UNAM as the academic institution that would head the Master Plan. Such an honorable choice is based on the University's historical presence in the basin, as shown by the considerable number of studies undertaken in different fields of knowledge. Writing the Plan is a pioneering experience in the country's river rescuing efforts. Although projects have been carried out in other cities, none have had the multiobjective and multidisciplinary point of view of this Plan, nor the government's willingness to wait for the document's final format before starting the executive projects.

The Plan's works began in November of 2007 when the Multidisciplinary Working Group (GTM, acronym in the Spanish Language) was formed inside UNAM. The group unites and organizes work experience from different specialists in the School of Architecture, School of Sciences, the Institute of Geography, the Institute of Engineering, the Institute of Ecology, and of the University Program on City Studies.

We hope to have the final document's version ready by this summer. It will be the result of the interaction between the social and technical/scientific areas, decision-makers in several agencies in the Federal District, and the political sub-districts involved in the project. The Plan aspires to become a model to be followed in urban river recovery in the region.

2. THE MAGDALENA RIVER'S GENERAL CHARACTERISTICS

The Magdalena River originates at 3600 meters a.s.l. in the Cruces Sierra, in the Cuajimalpa political sub-district, Mexico City. It runs 14.8 kilometers through forested areas before it enters the City, where it flows for 13.4 kilometers until it joins the Churubusco River. The latter is completely piped, is part of the sewage network, and is one of the City's main roadways. The fact that 52.5 percent of the river still runs in a natural settings, and that 47.5 percent of it is already inside the urban area leads to two very different forms of the river relating to its surroundings. The natural condition in which it is born is transformed radically in the City, where the river becomes a vector that collects a set of negative anthropic impacts.

A noteworthy factor in this defining trait is that the tributaries feeding the flow come from different sources, while in nature, the river is fed by springs and surface runoffs of excellent quality. In the City, it is fed by wastewater from the sewage network.

Figure 1 – Magdalena River Basin

Similarly to many urban rivers worldwide, the Magdalena River has been fragmented by a series of hydraulic works, indispensable to delimitate the basin in an urban area. The first alteration of the river that needs to be taken into account is due to the construction of trash racks. These were built to confine organic matter and avoid the sediment deposition in the drainage system downstream. The 57 dikes are an undesirable factor because they interrupt the continuity of aquatic ecosystems.

The second important hydraulic work that modifies the river is the drinking-water plant located in the transition area between the natural and urban settings. The plant uses 250 liters of water per second. A second plant will soon be added to this one and will begin using 200 liters of water per second. This will probably dry up part of the river, since its average discharge at low water level has been estimated to be 500 liters per second.

The third intervention is the Anzaldo Dam. This dam is actually a regulating reservoir. It was built in the ‘30s and was intended to control the maximum flow of river runoff in the area, mainly the Magdalena River. However, the urbanization of neighboring catchments meant that the dam has been receiving discharges from other rivers that had been diverted artificially. On top of this, the Eslava River’s discharge must be considered, as it joins the Magdalena River before discharging into the dam. The Texmaloya Stream also joins it, and part of its discharge drains into the urban drainage collectors and part runs on the surface. Therefore, water from five neighboring sub-basins join naturally and artificially where the dam is, and the water is terribly polluted (Cisneros, 2008).

The fourth interference built in the river’s path is its incorporation into the western trap as a first exit point. A sewage tunnel expelling water from the Mexico Basin, and running south to north forms this hydraulic work. The trap collects water from 14 rivers, both at low water level as well as during the rainy season, although capture increases during the rainy season to avoid floods by saturation of the sewage networkdownstream.

The fifth important intervention on the Magdalena River is piping the river and turning it into a roadway. Magdalena River Avenue is 4.5 km long and its purpose is to join the Periferico, and Av. Revolucion and Insurgentes. Finally, the sixth and seventh intrusions upon the river occur in its last reach (measuring 1.6 km), where it regains its open river bed. At this point, with the support of other collectors, the river receives flow from the Chico River and San Angel River; both of these have been wholly incorporated into the sewage system. With such additional discharges, the river joins its second important outflow, the Churubusco River, which is also piped and serves as one of the city’s major roadways.

These interventions created different functions for the river in its relationship to the City. It supplies drinking water, it forms part of the sewage system, it is a major causeway, and helps control flooding in the southwesterly part of the City. In spite of the roles it plays, the river does not have a comprehensive management scheme that would help potentiate its strengths and create new services in the recreational, ecosystemic and economic areas.

3. COMPREHENSIVE DIAGNOSIS

Two basic concepts were used to formulate the comprehensive diagnosis of the Magdalena River Master Plan: interdisciplinarity and social participation. Initial consensus was reached thanks to the workshops held with the specialists participating in the GTM. The differences of the various scientific languages creates conceptual distances in specialists that are difficult to overcome. This is why answering transversal problems was fundamental as it allowed each researcher to focus his research object from a public policies' point of view.

The Master Plan has permanently incorporated different perspectives and rationales from social actors across the basin in its natural and urban settings. The task has not been simple since each group (researchers included) has its own representation of what they would like to do with the river. Some are different, and occasionally mutually exclusive.

The SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis was used to facilitate an interdisciplinary and intersectorial debate. Translating scientific research results into value judgments opened the door to build a common problem between specialists, stakeholders, and citizens. The goal was to have a cognitive and axiological platform that permitted a basic consensus about the main processes on the Magdalena River basin in order to take the next step towards general management strategies.

Next, we shall describe the main processes in a synthetic way. These were identified by diagnosis and are based on data coming from scientific research, as well as on the social actors' perceptions expressed during the participative planning workshops.

3.1 Natural area in good state but under threats

One of the Magdalena River's most important strengths is the preservation state of its natural area. It has soil that favors infiltration, vegetation coverage in good state, and a high degree of biodiversity representative of tempered forests. This situation has to be highlighted since the surrounding forests near the City are showing serious problems due to illegal settlements and a lack of forest management. Several factors have favored nature preservation in the area, including the basin's topography, which is difficult to access.

An example of the area's biodiversity is shown by its 48 endemic species, particularly reptiles. Also, 66% of the vegetation (1,997.6 hectares) is in good condition, and approximately 70% of the forest's individuals are juvenile. Another relevant characteristic is that the space is relatively small, and three of the four most important forests, representative of the country's tempered forests (Quercus, Pinus hartwegii and Abies religiosa) coexist within a reduced altitudinal range (2500-3870 meters above sea level). These factors turn the forest in the Magdalena River basin into one of the most important forests in the Federal District (Almeida & Ramos, 2008)

Due to a joint evaluation, other threats were also identified. If such threats are left to grow, they can seriously alter the area's natural environmental balance. In this sense, human activities such as unregulated tourism and cattle husbandry pressure the environment. For example, extensive sheep and cattle grazing has affected 14 percent of the basin's surface. The forest in the area has been disrupted by induced pastures. Erosion by water, lack of forest fire prevention, and illegal wood logging are other degrading processes that need to be corrected.

Therefore, the main threat to nature is an unlawful invasion of the conservation areas, resulting in illegal settlements. This problem is shared by the political sub-districts in the southern periphery of the Federal District, since they are the main receivers of new population settling against the law, although this is done generally under the covered consent of local authorities. Five illegal settlements are located in this area on soil favoring infiltration. Some of them are growing on gullies and slopes, and are becoming prone and vulnerable to landslides (Aguilar & Santos, 2008).

3.2 A clean river in nature, turned into a sewer in the City

One of the river's most radical transformations, as it moves from natural into the urban setting, is the change in water quality. In the natural section, the Magdalena River Biochemical Oxygen Demand (BOD) values are less than 2.4 mg/L, and dissolved oxygen values are higher than 5.6 mg/L, typical of natural water. On the other hand, 60 direct discharge pipelines are found in urban areas without counting all of the sewage system connections discharging into the river's flow. Some of these discharges have values of 385mg/L, typical of residential wastewaters (Orta & Mazari, 2008).

To solve these issues, authorities decided to build a system of marginal collectors running alongside the river or under it, to receive wastewater inflow. However this solution is not the best one due to the terrains characteristics. Collectors have broken, dumping wastewater once more into the river. To date, both treatment plants located on the basin cover very specific goals, reason why they do not contribute comprehensively to the river's rehabilitation. One definite problem showing this system's paradoxes is purchasing treated water from the most important green area that the river crosses inside an urban setting. The Coyoacan nursery is the country's first forest nursery, and buys treated water costing 37,500 Euros per year. The

Magdalena River crosses the nursery before disappearing permanently in the second sewerage point, but is extremely polluted at this point.

3.3 A "hidden river" which has lost its structuring value of the urban space

As described earlier, the Magdalena River was not integrated as part of the city's urban development. The lack of the river integration is shown by wastewater discharges, as well as by other elements such as garbage confinement, lack of accessibility, and the invasion of the river floodplain. This situation has turned the river into a "hidden river" for most of the city.

In spite of this situation, there are many public spaces and historical buildings with an important cultural value along the river's urban span, and have an enormous potential of being linked to the river's recovery. There are over 15 areas with an important historical, recreational, cultural, and sports value (Mazari & Meza, 2008).

Undoubtedly, the structural underlying problem is that there is no strategy in place to manage the river comprehensively and on the long-term. Although a complete legal framework exists at different government levels with regulations that could contribute to clean the river and preserve its basin, there are no planning or land laws that integrate environmental aspects with urban, economic, agricultural, touristic and social features.

4. THE MASTER PLAN'S GENERAL STRATEGIES

After the comprehensive diagnosis was made, a target image was designed by bringing together the aspirations and ideals from social and political actors, and specialists' knowledge. The targeted image helped outline the rescue's general strategies, and organized lines of action that were stated during the GTM and participative planning workshops. Although this phase is still in a draft form, we can state that the Plan's general objective lies in recovering the river's public nature for the benefit of the City.

4.1 Ecosystemic management to integrate sustainable local development and defend soil preservation

The Magdalena River basin has not been considered to be a comprehensive area where different natural and social processes meet. Government interventions, especially in the natural part, are limited to sectorial actions like reforesting activities or construction of trash racks. Other areas of government interest lie in the urban sprawl over conservation soil, although the authority's tolerance towards illegal settlements tends to be a structural cause of such growth. In spite of these actions, issues such as soil restoration, diversity preservation, and strengthening ecotourism which would give rural communities a way to receive economic income remain untouched. This, would be one way to help discouraging negative practices like unlawful sale of land, illegal logging and ample cattle husbandry in forbidden areas, in order to help preserve the natural setting.

We believe that the Master's Plan first strategy is to confront the issues in the basin's natural areas, a necessary element so that the river and its elements can continue to provide ecosystemic services to the city. This integral vision would open the door to an ecosystemic management.

An ecosystemic management would: a) preserve nature in a healthy state; b) generate ecotourism and local sustainable development; and c) stop illegal urbanization on conservation soil.

4.2 Urban-landscape revaluation of the river

The city turned its back on the river as it grew. Citizens cannot access it in the city, but do receive foul smells from it and an unpleasant landscape. We can state that for many, the river is a dump and an undesirable element whose destiny should resemble that of the other urban rivers: pipe it and turn it into a new street. The Plan wants precisely the opposite: to recover the river's dignity and turn it into a governing element of urban landscape. The second strategy of the Plan tries to meet this objective. The river's urban-landscape revaluation is intended to create new functions so that people can return to it. We want the river to be a public space where social gatherings happen.

The strategy intends to: a) revalue the river and turn it into an organizing element of urban space, and b) create a landscape corridor with recreational, cultural and sportive public spaces.

4.3 Comprehensive management of the river and its hydrological basin

In addition to continue to use the river as a source of drinking water, we want the river to become the axis of a linear park inside the city. We have to clean the river to reach this goal. This objective actually is the foundation of the Master Plan's third strategy: a comprehensive management of the hydrological basin. The only aspect of the river that had been taken into account was its water flow, but in reality other aspects of the river, such as groundwater flow, rain water, and treated water have to be evaluated as well.

Implementing this strategy will allow us to: a) preserve the river pristine form in nature, b) clean the river that has been converted into sewerage in urban areas, c) maintain and update protection works to regulate the river, and d) protect river' sustainable uses.

4.4 New governance in natural resources management

Different social actors have become interested in the river's rescue. The creation of the Promoting Group was the first effort undertaken to create a common space where actors can express their interests and wishes.

However, putting the Master Plan in place has to be a task belonging to everyone during each stage. Continuing the efforts of the Magdalena River's rescue will be possible if we can have new governance in management of natural resources. This new governance would distribute responsibilities between participating government agencies, as well as to the civil society. The new governance will help: a) build a comprehensive planning and legal instrument, b) achieve a scheme based on effective intergovernmental coordination, and c) unify social participation in the rescue.

5. CONCLUSIONS

The Magdalena River Master Plan is intended to promote a new paradigm in urban river management in the Mexico Basin. It seeks to transform the use and social representations of the rivers considered today as part of the sewage system. The change in paradigm in urban river management points towards recovering the river value as places of multiple opportunities for environmental, social, recreational, cultural and economic activities. This change underscores social phenomena regulation as the sine qua non element needed to achieve sustainable use in any ecosystem. In other words, the Master Plan tries to design socio-cultural solutions to sanitize the river and to sustain technical projects in the long run.

Enthusiastic citizen participation shows the level of interest that the river's rescue has awakened in our City. However, the amount of trust in the project is very fragile due to past experiences, where the project was only used as part of the local authority's demagogy. If this project does not provide immediate results, although keeping a long-term perspective, we might lose the only possibility in our City's history to change our relationship to water and to the river, elements that form part of urban landscape.

Finally, we are aware of international initiatives in urban river recovery. Different master plans from America, Europe and Asia have been our source of inspiration to draft the Magdalena River Master Plan. They are the global reference frameworks that helped us to ponder upon our specific problem and reaffirm the fact that it is possible to have a new relationship between Mexico City and water. One way of changing this relationship is by valuing the importance of urban rivers.

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OPTIMA LOBAU: FUTURE SCENARIOS FOR A SUSTAINABLE MANAGEMENT PERSPECTIVE OF AN URBAN FLOODPLAIN

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ABSTRACT

The alteration of riverine landscapes has led to increasing efforts in water management, also concerning rehabilitation and restoration activities, especially in areas of high nature value. The Lobau floodplain within the city limits of Vienna for example has undergone severe changes mainly due to altered ground- and surface water connectivity and urban development in the last 20 to 100 years, which resulted in a change of habitat structure and distribution, and of vegetation cover. The Lobau also plays a central role in the regional water balance, including flood retention and groundwater recharge, and for the socio-economy of the area (recreation, education). An innovative ecosystem management scheme needs to optimally balance conservation and restoration objectives and to harmonize the partly contradicting ecological and socio-economical requirements.

Therefore, we developed an approach based on a multi-criteria decision analysis (MCDA). The strength of such an interdisciplinary strategy is to involve technical, natural and socioeconomic sciences to identify indicator/criteria sets, develop integrated models and include them in the MCDA. The approach is based on the creation of scenarios which describe possible future conditions of the floodplain as hydrological responses to different hydraulic management measures, and sub-scenarios based on one dominating use type. Models in the fields of ecology, hydrology and geomorphology predicting the changes due to the potential water management measures are analysed and the results of selected indicators from all fields were incorporated in an out-ranking MCDA. We present the approach and first results of the MCDA.

Key words: Danube River, decision support system, interdisciplinary approach, floodplain management

1. INTRODUCTION

Floodplains are one of the most threatened ecosystems worldwide. Within the Danube river basin for example, aerial estimates demonstrate that about 80% of the pristine floodplain areas are lost today (WWF, 1999). The remaining areas show a distinct decline of ecosystem functions and services. Due to multiple ecological and socio-economic demands and constraints, sustainable management approaches are urgently needed; moreover, the understanding of these complex systems is in most cases limited, especially the interaction between different drivers and demands. Various conflicting societal demands and utilizations tighten the potential solution space. As a consequence, recent studies emphasize the importance of an interdisciplinary scientific approach for the revitalization of urban floodplains which should be based on the application of modern river ecosystem concepts that form the background of a conceptual framework for management decisions (e.g. Amoros & Bornette, 2002; Nienhuis et al., 2002; Ryder & Miller, 2005). With respect to a sustainable development of the ecosystem, management approaches have to be based on predictive geomorphological, hydrological and ecological models as well as on the comparison with reference conditions or guiding images which give an insight into the complex interactions of the different compartments. Especially, within urban areas, ecological objectives have to integrate the many-fold, often conflicting social and economic demands and involve local and regional stakeholders in a participatory process in order to raise public support for the proposed strategies (Hargrove et al. 2005).

However, the integration of the various ecological and socio-economic aspects of urban floodplain management often confronts managers and scientists with several problems. The incomparability of quantitative and qualitative data, the weak measurability of certain aspects, especially as regards social qualities (e.g. aesthetic values), together with contradicting objectives, may hamper the comparison and evaluation of different management strategies. A sustainable management approach for urban floodplains, hence, needs an evaluation method which has the power to overcome these problems (Faucheux et al. 1998).

In this paper we present first results on an interdisciplinary approach for identifying potential solution for a sustainable development of an urban floodplain. Because of the multi-objective nature of the floodplain management, we used an integrated model framework and a Decision Support System (DSS). The approach links scientific research with management issues in a transparent and reproducible way through the application of a multi-criteria decision aid (MCDA) method. We used an integrated approach, mainly based on the comprehension of the physical and biological processes and identification of drivers and factors of degradation. In this paper the methodologies, approaches, first results of the research are summarized.

2. CASE STUDY AREA: URBAN FLOODPLAIN LOBAU

The Lobau is situated along the left bank of the Danube at the eastern border of the city of Vienna and has a total size of about 2300ha (Fig. 1). During the major regulation of the Danube in the 19th century, this former dynamic floodplain was disconnected from the main channel by the construction of a flood protection dam (Hein et al. 2006). Today, the Lobau represents a groundwater-fed and back-flooded lake system where sedimentation and terrestrialisation processes prevail.

River engineering has not only led to a reduction of most of the basic ecosystem functions, but also to a drastic shift in the structure and composition of habitat types and vegetation cover. The reduced hydrological dynamic favours the establishment of rare but atypical species of dry meadows. Nevertheless, due to a still existing complex mosaic of aquatic, semi-aquatic and terrestrial habitats, the Lobau features an extraordinary high biodiversity. The floodplain has been designated as UNESCO Men and Biosphere Reserve, Ramsar site and Natura2000 area and constitutes a part of the Alluvial Zone National Park.

Because of its proximity to Vienna, societal demands, including flood protection, drinking water supply (5 groundwater wells) and recreation (more than 600,000 visitors per year) play a considerable role in floodplain management. Land- and water use issues like forestry, agriculture and sports fishery are currently regulated by the National Park Authority, but still need to be considered and harmonized in future management schemes.

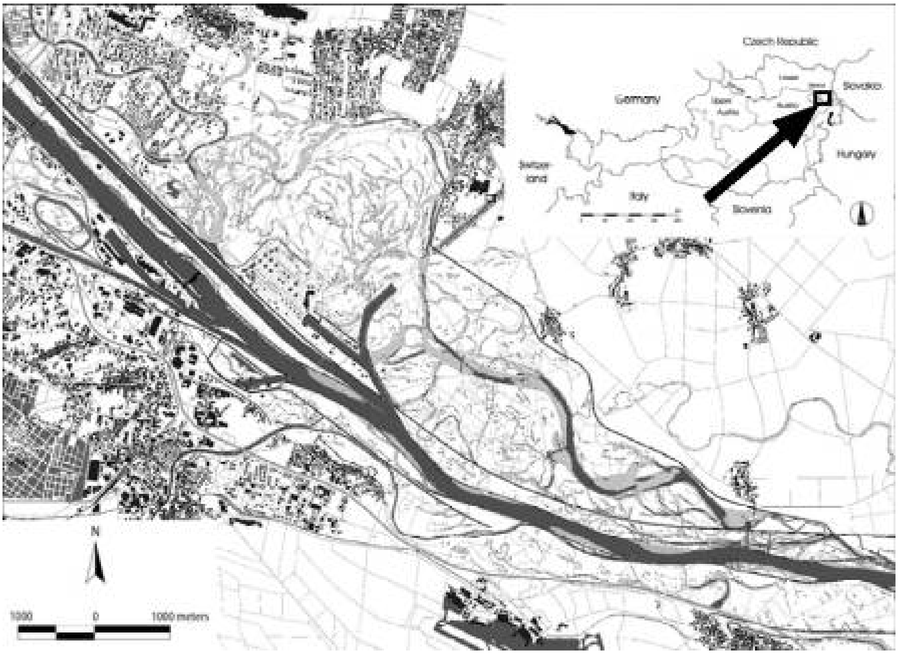

Figure 1 – Project area Lobau at the eastern border of Vienna, Austria after Hein et al. 2006.

3. SCIENTIFIC APPROACH

The underlying assumption of the used approach is that complexity is a vital part of our life, and has to be taken into account in decision making processes. Complex systems like urban floodplain ecosystems cannot be captured adequately by a single type of representation or analytical perspective (O´Connor, 1994). Thus, it is assumed that there are multiple allocation possibilities instead of a unique optimal solution, which require a ranking with regard to specified multiple criteria. The MCDA approach in this project is based on the creation of scenarios which describe possible future conditions of the floodplain as hydrological responses to different hydraulic measures (Fig.2). The scenarios, thus, mark corner stones of a “possibility space of the system” which represent potential images of the Lobau on the assumption of changed hydrological exchange conditions. In order to guarantee a clear and exact demarcation of the different scenarios, the alternatives cover a wide range of hydraulic measures, including different degrees of connectivity ranging from complete isolation of the floodplain to a single side-arm rehabilitation and full re-integration into the flow regime of the main channel (Fig. 2). The creation of the scenarios is based on the analyses of the historical development of this area and on hydro-geomorphologic models which take into account the current flow and sediment regime (e.g. lack of coarse bed load and fluvial dynamics, pronounced flood peaks).

Figure 2 – As an example, model showing the maximum reconnection (restoration of surface connectivity) for the area based on historical analyses.

In a following step, the main scenarios have been differentiated into sub-scenarios based on to the effects of the maximum development of one dominating ecological and socio-economical demand (Fig. 3). In a participative transdisciplinary process, the following driving forces have been identified for the Lobau: fishery, eco-farming, eco-tourism, drinking water supply, and the maximum potential for ecosystem development (rehabilitation of functional processes and conservation of habitats). Restrictions due to laws and legal regulations as well as the ecological potential of the landscape for various utilizations determine the framework of the different sub-scenarios. For the assessment of the sub-scenarios, various ecological and socioeconomic indicators have been developed by linking hydrological, ecological and socio-economic models.

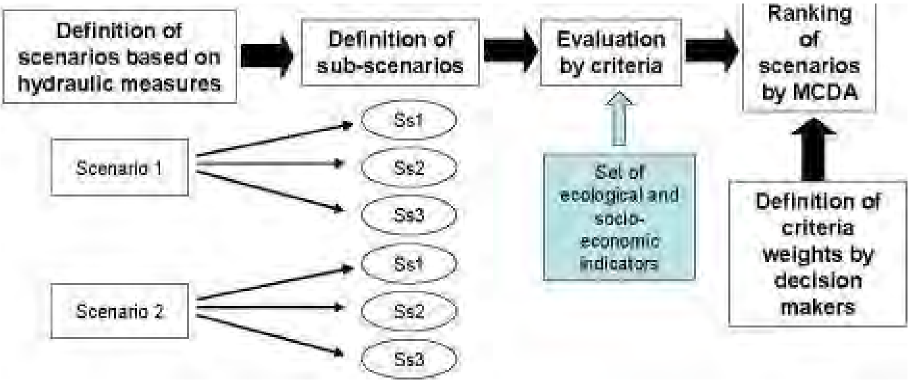

Figure 3 – Work flow diagram, showing the interdisciplinary co-operation. Ss 1-3 = Sub-scenarios 1-3 (modified after Weigelhofer et al. 2006).

To assess the effects of these potential changes, 75 indicators have been selected from the following fields: aquatic ecosystem quality, terrestrial ecosystem quality, drinking water use, potential for recreation, potential for sport fishing and potential for organic farming. The details for the set up of models and the data used can be found in Hein et al. (2006) and Hein et al. (unpubl. report). The results for each indicator and each scenario have been integrated in the MCDA using the PROMETHEE outranking technique (Brans et al., 1986). The basic matrix for the MCDA was a 31 scenarios x 75 indicators table.

4. RESULTS OF THE ANALYSES

The calculation of the multi-criteria decision aid was performed for the unweighted indicator matrix and several matrices based on preferences from several stakeholder. This approach was used to demonstrate the effect on the ranking and the changes due to different preferences sets.

Generally, all rankings resulted in partial rankings as some scenarios remained not completely comparable for all indicators. While the potential solution space was not intended to be identified within the frame of the research project as it depends on a political decision process within the group of stakeholders, our intention was to demonstrate the potential of this method to elucidate reasoning behind trade offs, identify thresholds and sets of measures which could get combined for a more optimized management strategy.

The results of the MCDA clearly showed that, for example, the status-quo is not a preferred status for most of the involved stake-holder institutions. In terms of a sustainable development of the ecosystem any measure of partial reconnection of the area could result in improved ecosystem conditions, while a full reintegration of the area into the riverine flow regime would lead to a decrease of all human-oriented demands like recreation, security of drinking water supply. as well as unclear impacts on endangered species in secondary-developed lentic habitats. Thus, potential directions for future strategies have been identified and the trade-off between e.g. drinking water supply and requirements of increased ecosystem quality are now available on a quantitative basis. This information forms the basis for the next steps in the development of measures for a sustainable development.

5. STRATEGIES FOR URBAN FLOODPLAIN MANAGEMENT IN THE LOBAU

The developed approach aimed to link research tasks and management in a more explicit way and provided a scientifically- sound basis for further planning steps in the management of the Lobau area. Concerning an elaborated planning process, the presented research covered the analyses of the status quo including a detailed description of information gaps (e.g. a more advanced sedimentation model), a detailed description of drivers and demands in the area and, based on the historic analyses, of potential reference conditions (compare to Hohensinner et al. 2005). The MCDA provided a tool to assess potential operational guiding images including a presentation of the trade-offs between different indicators and potential future scenarios which provide a high potential for an integrated sustainable development of these urban floodplain ecosystem.

6. CONCLUSIONS

A multi criteria decision aid approach was used to evaluate the effect of different future scenarios for the urban floodplain Lobau. Within the MCDA, 75 indicators from various fields (from ecology to socio-economy) were integrated to evaluate 31 scenarios and to identify the future scenarios with the highest potential for an integrated sustainable development including ecological, social and economical values.

The process of the MCDA evaluation proved to be a reasonable strategy to start a planning process by setting historical and operational guiding images and considering multiple objectives and drivers for the respective urban floodplain Lobau.

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RESTORATION EFFICIENCY INDEX TO CHARACTERIZE AND PRIORIZE RIVER RESTORATION PROJECTS. APPLICATION TO THE REGION OF CANTABRIA (SPAIN)

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ABSTRACT

In Spain, as in most European countries, the density of hydro-morphological impacts on rivers is considerably high, and rehabilitation or restoration will be increasingly relevant in order to achieve the legal objectives of the Water Framework Directive and other directives. This paper addresses the need to assign priorities to all possible restoration projects in a particular region, and to decide weather they are feasible or not, considering, at the same time, their ecological, sociological and economic dimensions. To this intent, a restoration efficiency index (REI) for each candidate project, is defined as a quotient of benefits (B) and costs derived from the project (C). The benefits are separated into two terms: an objective benefit, linked to the fulfillment of the objectives related to the WFD, and a subjective benefit related with other issues, such as other environmental directives, recreational activities, economical revenues, etc. Both benefits and costs can be estimated from double-entry tables. As a practical application, the paper shows the results obtained following this methodology in the region of Cantabria, in the north of Spain.

Key words: Water Framework Directive, river restoration plans, cost-efficiency analysis

1. INTRODUCTION

Continental aquatic ecosystems have suffered a loss in biodiversity of approximately 50%, in comparison with the 30% pertaining to the marine and terrestrial ecosystems (Naiman, 2007). These are considered to be the most endangered ecosystems on the planet, due to the increase in population (Millennium Ecosystem Assessment, 2005). These data illustrate the multiple services that human beings obtain from these ecosystems, altering fundamental hydrological and ecological processes. Given the actual state of conservation of these ecosystems, different European directives, such as the Water Framework Directive (Directive 2000/60/EC) or WFD, promote the implementation of management strategies that will guarantee the services obtained from these ecosystems, by maintaining their ecological biodiversity and integrity.

Consequently, the WFD gives to the entire European territory an unprecedented opportunity to study, understand and characterize the aquatic ecosystems and the diversity they represent. Its presentation and progressive application has helped to increase the knowledge of its water bodies and the related ecosystems, with the ultimate goal to reach a good environmental state of the water bodies before the year 2015. This date is to some extent becoming a symbolic event in the post-industrial European society, for which it is necessary in most cases, to carry out river restoration projects, which will solve certain dysfunctions in these aquatic ecosystems.

This article aims to establish a methodology to rank, in terms of efficiency, river restoration projects. Its ultimate goal is to prioritize the activities that make up the restoration plans of the river ecosystems in a region or territory, which, due to budgetary issues, can not be simultaneously executed completely, and must therefore be scaled in time. Although the literature on river restoration is becoming increasingly abundant (e.g., Landers, 1997; Palmer et al. 2005), there are hardly any references which discuss these issues (see: Verdonschot and Nijboer, 2002).

Reaching the goals proposed by the WFD for rivers, is in many cases conditioned by water quality and quantity factors, as well as by existing hydromorphological impacts. Consequently, an integral restoration of a river system is not possible without restoring specific discharge (Poff, 1997) and physical-chemical conditions of its waters (Ryder and Miller 2005). After this has been accomplished, the final step to reach a good ecological water quality would be to ensure that the rivers has enough physical space as well as the necessary conditions to support the variety of habitats that should be present.

In many restoration projects, it is impossible to recover each and every normal function of the ecosystem (Giller, 2005; Goodwin, 1997). However, improvements can be introduced which will help contribute to a gradual restoration of the system. To this effect, rivers in which the morphological characteristics which are found to have been altered to a greater extent with respect to their natural conditions, and therefore contribute largely to the deterioration of the river ecosystem’s natural integrity (such as river bed, bank and plain), can be subject to a rehabilitation project. This does not exclude the possibility to carry out other complementary actions such as reforestation, wastewater sewerage or the creation of river paths; however, these measures on their own, however, do not constitute a restoration project as described in this paper.

Therefore, a very important part of the improvement goals of the water bodies is linked to sectorial measures, such as water supply, sewage systems, ecological discharges, etc. If these instruments are developed integrally, that it, considering each one of them as part of the total, and based of the principles and objectives of the WFD, they will become efficient tools to reach the goals set for the year 2015.

Because of these considerations, it seems pertinent to introduce the concept and the need for river restoration projects, at either the national or the regional scale. The main objective of this instrument would be to explore, identify and characterize all the opportunities for improvement of the ecosystem quality, based on the partial or total recovery of the physical space through which the river used to pass. This article present the cases of river restorations aimed at recovering the lateral connectivity with the floodplain and the longitudinal connectivity between different bodies of water, whereas the restoration of quantity and quality of these water bodies should be the object of a different study. The priority relation of two activities that will be equally effective, in terms of ecological objectives, will be solved based on the unit cost of the restoration works. This issue will be further described at in the following paragraphs.

According to these principles, the criteria used to characterize the proposals for restoration will be presented first, to continue on how these tasks were applied in the region of Cantabria (Spain). A brief discussion on the results will close the paper.

2. SELECTION CRITERIA AND TASK PRIORIZATION

First, the analysis and selection of the potential places to carry out restoration works has to be conducted. To do this, it is necessary to combine all the available information (studies and technical analysis of the water bodies, detailed cartography, existing projects, etc.) with field observations, which allows to evaluate the restoration needs of the pertinent area. It is important to note that all the possible data should refer to reaches of similar lengths of the affected river (for example, between 0.5 and 3 km).

Once these data are collected, the practical criteria to rank them according to a measure of the involved benefit must be established. In this case, an efficiency index, called REI (Restoration Efficiency Index), has been used as the prioritizing parameter, based on the ratio between the benefits and the costs derived from the restorations works: REI = Benefits / Costs. The benefits are obtained as the sum of two parameters; one (B1) is obtained form an objective tableand the other (B2) introduces a subjective evaluation made by different experts:

Benefits= B1 (objective evaluation) + B2 (subjective evaluation).

The parameter B1 is obtained from the state of the water body to which the candidate stretch belongs, and that of the water body which is upstream along the river channel. The state is defined, according to the WFD, as the quality of the river ecosystem -estimated from a combination of physical-chemical, biological (macroinvertebrates, macrophytes, diatoms, riparian forests, etc.)- and hydro-morphological variables. The reason to express the benefit component B1 of an intervention not only in terms of the water body in which it is located, but also considering the one above it, is to promote the recovery of long stretches of rivers, instead of acting on isolated patches. Moreover, the factor linked to the "state of the waterbody in which the intervention takes place" is designed in such a way that it promotes an intervention that allows the evolution from a mediocre/average water state to a good state, rather than from a good to very good or from a very poor to poor state, so to foster the accomplishment of the WFD objectives. The B1 parameter assumes values from 1 to 5 (from very low to very high benefits) which are considered independent of the expert's judgment and can be obtained from Tab. 1.

Table 1 – Parameter B1, objective valuation.

	State of the waterbodies in the restoration area		
Upstream water conditions	*Poor or very poor*	*Average*	*Good or very good*
There are no significant pressures upstream regarding water quality or quantity	High (4)	Very high (5)	Intermediate (3)
There are significant pressures upstream, but many of them should be solved in the short term (wastewater systems, ecological discharges, etc.)	Intermediate (3)	High (4)	Low (2)
There are significant pressures upstream whose mitigation cannot be guaranteed in the short term.	Low (2)	Intermediate (3)	Very low (1)

The second component of benefit evaluation, named B2, takes into consideration other benefits of the intervention, of a more subjective nature and less linked to the strictly legal goals of the Water Framework Directive. This parameter can add a maximum of 2 points to the evaluation of the stretch under restoration, due to the factors which are shown in Table 2 and which can be structured into two large sections: ecological criteria and other criteria.

Within the ecological criteria, naturalization responds to the degree of naturalness achieved once the restoration project's objectives have been met. This criterion measures the efficiency of the project related to the state reached upon completion of the project. The second criterion measures the impact of the constructions, as there is a risk that the manipulation of the river system may have harmful effects for the organisms, and the time elapsed until the optimum state is achieved could be excessive. The third ecological criterion takes into consideration the schedule of the restoration project according to the improvement introduced in the river system. For example, the backwards displacement of entrenchment dikes is a very local intervention which nevertheless affects the reach of the intervention as well as the reaches several hundred meters downstream, whereas the demolition of a dam is a local intervention which will affect the entire river basin, both farther up and downstream. Lastly, one must take into consideration that after a construction is completed, it must be able to sustain itself, not needing any further maintenance for it to function.

The following four criteria refer to the benefits which can be obtained from the foreseen intervention, and they are divided into economical (i.e. increase in fishing), aesthetical (landscape improvements), recreational (i.e. possibility to carry out recreational activities), educational (i.e. possibility to increase environmental education and the number of volunteer positions) benefits. These last two are more related with the benefits obtained through the different restoration projects regarding the contribution to the understanding of river systems and the organisms that inhabit them on one hand, and on the other, the increase in the management quality of these river systems.

Since the B2 parameter implies a subjective evaluation of the benefits of a project, accompanied however by the objective parameter B1 (see Table 1), an evaluation by a set of external, independent experts is considered appropriate. This will result in a different evaluation of the global efficiency of the restoration for each one of the experts. Consequently, the evaluation of the benefits not directly associated with the WFD should be carried out following a Delphi type methodology, with the singularities required for each case.

Table 2 – Criteria to assign values to the B2 parameter in a river restoration project (0 to 2)

Ecological criteria
Naturalization
Action impacts - Risks- Recovery time
Scale of the intervention - Ecological improvement
Self-sustainability
Other criteria
Economic benefits
Aesthetical benefits
Recreational benefits
Educational benefits
Scientific contributions
Experience and management improvements

Finally, to obtain the REI of the different projects, it is necessary to evaluate, at least in a preliminary and semi-quantitative way, their associated costs which in this case are reduced to monetary costs, since the other possible costs are covered with a reduction of the benefits, penalizing either B1 or B2. The monetary costs of this type of intervention can be divided into two large chapters:

- Expropriation costs or those associated with changes in the use of the land or private ownership which, after the intervention, are of public domain, or are more prone to flooding
- Construction costs, which depend on the type of channel and valley, and on the technical characteristics of the interventions (materials, technologies and necessary machinery)

Table 3 – Semi-quantitative evaluation of the economical costs per unit of length of the river restoration project.

	Localization of the lots incorporated to the river area		
Type of intervention[(1)]	Public or rural real-estates without perspective of change of use	Rural real-estates with possibility of change of use	Urban areas
Earth banks + bio-engineering techniques	Low cost (1)	Average cost (2)	Average cost(3)
Riprap and gabions	Average cost (2)	Average cost(3)	High cost (4)
Concrete structures	Average cost (3)	High cost (4)	Very high cost (5)

[(1)] Both demolition and construction

Furthermore, several qualitative levels of unitary costs (specifically 1 to 5, from very cheap to very expensive) are proposed, and Tab. 3 can help to define these levels at a first approach. With the three parameters obtained, two of benefits (B1, B2) and one of costs, the efficiency index for each intervention can be obtained. Note that after having introduced the experts' criteria to define B2, there are as many intervention efficiency evaluations as the people consulted. The efficiency indicator does not have any interest in itself, but as a relative value which will allow us to establish a ranking of the interventions based on these indicators. The aim is to classify the proposals according to their efficiency, obtaining a classification from each expert, to calculate afterwards the average position in the classification scale for each of them. Consequently, the average of the efficiencies obtained for each intervention according to the different experts should not be used. It would be more appropriate to ponder their ordinal position in the different evaluations. If several interventions obtain the same efficiency value according to a specific expert, they will be assigned the same order within the classification.

3. EXAMPLE OF IMPLMENTATION IN THE REGION OF CANTABRIA (SPAIN)

The region of Cantabria is located in the north of Spain, belonging to what is usually referred to as the "humid Spain", with an annual rainfall of approximately 1300 mm. Its reduced extension, around 5200 km2, is drained in over 70 % of its territory by numerous rivers of short length and acute gradient, which descend form the Cantabrian Range to the coast, where they form in many cases large estuaries. The rest of the territory belongs mainly to the Ebro river basin, including its source, except for a small section of the Camesa River, which flows towards the Duero River Basin.

The impact and pressures study, carried out by the Government of Cantabria between 2004-2006 and the evaluation of the ecological state of the water bodies (Consejería de Medio Ambiente, 2007) were utilized to select the stretches of the Cantabrian rivers which would be candidates to be included in the National River Restoration Plan. Photographs obtained through the SIGPAC tool provided by the Ministry for Agriculture, Fishing, and Food (MAPA) were also used to study all the main and secondary channels, to detect the areas in which the original river geometry had been altered. Many of these areas were already known thanks to previous field campaigns. Completely urban interventions have not been included in the proposal, although some semi-urban ones are considered; this is due to the fact that in areas where the river is completely surrounded by buildings, a restoration is practically impossible (due to economical reasons). A clear example of a possible intervention, in this last sense, but not included in this proposal would be the improvement of the Samano river, as it passes through Castro Urdiales urban settlement.

Sixteen candidate spots (not shown here for the sake of brevity) were selected for a restoration project. A technical description of each of them was carried out, using a template (see an example in tab. 5). Tab. 4 shows the results obtained for the 16 interventions carried out in Cantabria, according to the classification made by each expert. Using these results, three qualitative levels of efficiency of the restoration project have been established: high, average and low. The thresholds that separate these different levels, and the efficiency evaluation procedures, must be inter-calibrated at the national level. This is necessary because the goals that may seem a priority at the regional scale of Cantabria, could be less important at the national scale. In any case, this proposal is a first attempt to render the decision-making processes objective as to which river channels are more appropriate for a river restoration project.

Table 4 – Importance and average priority obtained for each river restoration intervention suggested for the region of Cantabria.

Priority order	Average of the order of priorities	Importance
1	1.29	High
2	1.43	High
3	2.14	High
4	3.57	High
5	6.14	Medium
6	6.57	Medium
7	6.71	Medium
8	7.00	Medium
9	7.43	Medium
10	8.71	Medium
11	9.71	Medium
12	11.43	Low
13	12.14	Low
14	14.00	Low
15	15.00	Low
16	15.29	Low

4. DISCUSSION

The river restoration projects selected by the proposed methodology seem all to be related to enhancement of longitudinal and lateral fluvial connectivity. These processes are key elements for natural river functioning (Palmer et. al, 2005; Giller et. al, 2005; Boesch 2006).

Most of the selected restoration projects take place in rural areas, where there is not too much human development, and land is much cheaper. This might be seen as a shortcoming, however, we believe this regional discrimination ensures that many more kilometers of rivers and streams can be restored with a given budget, and thus, it guarantees a more effective restoration and protection of aquatic biodiversity. Another variable that might have to be taken into account in following developments of this methodology is public opinion (Merelender, 2007), and this may be use to counterbalance the obtained results, as most people live in urban areas and may prefer to restore stretches of river where they can appreciate the improvement of restoration projects.

Table 5 – Example of a characterization template

ACTIVITY	Restoration of the river Pas in the Toranzo valley. Section between Puente de la Union and Puente del Soto.
KEYWORD:	RESCAN-2
BASIN:	Pas-Pisueña
DISCHARGE:	Pas
BODY/IES OF WATER:	PAPA2
MUNICIPALITY	Corvera de Toranzo, Santiurde de Toranzo
INHABITED AREAS IN THE VICINITY:	Villasevil, Cillero, Iruz, Corvera
STARTING POINT:	Puente de la Unión
FINAL POINT:	Puente del Soto
LENGTH OF THE SECTION	4100 m
INVESTORIED PRESSURES:	Riprap bank-protection along both banks. Grade-control structures every 100 m.
HYDROMORPHOLOGICAL STATE OF THE WATER BODY	Moderate
NATURA 2000 NETWORK SPACE	SAC of the Pas river
TYPE OF ORIGINAL RIVER BASIN:	Braided, with meanders and transversal bars.
TYPE OF DISCHARGE :	Straight with little variety of facies
	− Recovery of the transversal and longitudinal connectivity - Recovery of the habitats associated to the river spaces:

RESTORATION GOALS:	whitewaters, wells, bank forests, etc. − Peak flow reduction and consequent risk reduction in the lower basin. − Increase of the aquifer recharge - Recovery of the river landscape and the recreational possibilities of the river.
RESTORATION TASKS:	− backwards displacement or elimination of entrenchment banks − Removal of grade-control structures - design and construction of controlled river paths
COMMENTS:	The river channel was built at the beginning of the 90's to counteract the flood risks in the valley. However, the social perception associated with the residual risks, along with the existent of tributary creeks which continue to flood the confluence areas o have prevented these areas from being occupied. This makes it easier to carry out a controlled recovery of some of the river stretches, by widening the area which it currently occupies.

The third selected project is the restoration of a rheocrene spring which gives birth to the Ebro river. This case illustrates the importance of direction of river restoration in our methodology, which should go from upstream to downstream stretches (Parkyn, et. al 2003), and also the benefits of small projects that contribute to restore whole river sections.

Overall, we believe the presented methodology may discriminate in a simple way the restoration projects for a given region, although some improvements could be done, as for example including more variables in the criteria such as public opinion, or any other variables from the B2 criteria section.

ACKNOWLEDGEMENTS

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VOLUNTARY RIVER WORK PROGRAMME ORGANISED BY THE WATER DEPARTMENT OF THE MINISTRY OF ENVIRONMENT AND RURAL AND MARINE AREAS

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ABSTRACT

By way of its AGUA (actions for water management and use) programme, the Spanish Government's Ministry of Environment is carrying out a new water policy to restore the ecological conditions of the country's rivers, which have been seriously damaged as a result of changes induced by man.

This policy includes the Conservation programme, the National River Restoration Plan and the Voluntary River Work Programme. The latter encourages the direct participation of the community in volunteer activities for the restoration of Spanish's rivers. The proposal has the following objectives:

- To create awareness about the socio-environmental values of river systems.
- Promote citizen participation.
- Conserve and improve the river's natural and cultural assets.
- Encourage cooperation between all of the parties involved.

To facilitate the participation of organisations, the "Guide for the development of voluntary activities" was drawn up. After the presentation of the guide, during the summer of 2007 the proposal was established, and a total of 65 proposed projects were received, 37 of which were selected. The budget for the 2007 execution of this programme amounted to € 700,000.

Due to this year's successful results, the proposal for 2008-2012 has been set up, with an estimated budget of almost 8 million Euros that also includes an environmental education programme.

Key words: Voluntary work; Ministry of Environment and Rural and Marine Areas; Spain; National River Restoration Strategy.

1. INTRODUCTION

In recent years, the Ministry of Environment and Rural and Marine Areas has made significant efforts in aspects relating to Water Quality and Hydrological Planning, in order to improve river management and the state of river conservation. Despite the very valuable results that have been beneficial to the rivers, there still exist other aspects that must be improved. To this end, new methods of action will have to be defined that allow the recovery of the river system dynamic and an increasing promotion of their restoration and conservation.

One of the actions launched is the National River Restoration Strategy, which proposes a set of measures that will improve river management and the ecological conditions of rivers. The Strategy arose from the collaboration between all of the administrative bodies involved and shall apply to the timeline of the next hydrological planning period from 2008-2015.

Within the framework of the National River Restoration Strategy, the following lines of action are proposed:

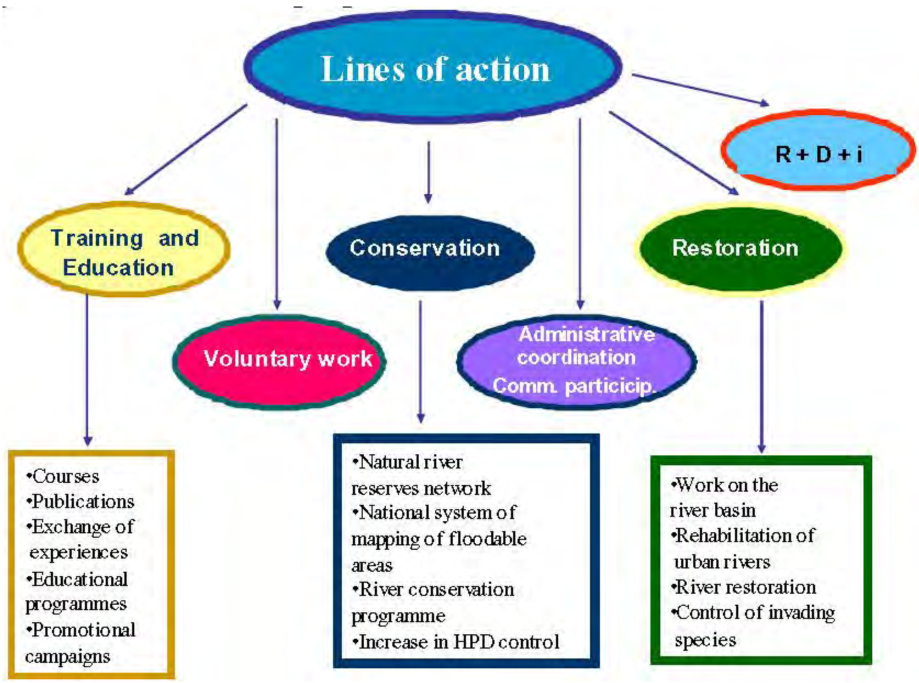

Figure 1 – Proposed lines of action for the development of the National Strategy for the restoration of Spanish rivers.

One of the programmes already put into action by this Strategy is the Voluntary River Work Programme, which is aimed at encouraging the community to participate in river management and also at sharing the responsibility for the ecological condition of the rivers amongst the responsible administrative bodies, the habits and customs of the community, and the interests of the most important economic and social agents in each river basin.

Projects focusing on three main areas of action of the the National Strategy will be carried out within this Programme,:

a) Training and Education

Voluntary work can play an important role in the area of training and education, by organising courses and publications for different technical levels, and promotional campaigns as well as recreational and cultural activities with a greater potential for communication and more widespread coverage in comparison to more official authorities, of a more regulated character.

b) Conservation and Protection of rivers

By helping to carry out maintenance, surveillance and data collection tasks, etc., voluntary work can also play a valuable role in participating and contributing to river conservation projects, projects to increase awareness amongst the riverside populations and projects relating to the protection of the habitat and species. The result is a great opportunity and degree of flexibility for the involvement of physically or mentally impaired people in these tasks, in collaboration with local administrations, financial institutions and foundations, etc.

c) Restoration and Rehabilitation

Lastly, within the framework of the Voluntary River Work Programme, there are projects focusing on participation in the restoration and rehabilitation of riverbeds, always in accordance with the health and security regulations in force, and under no circumstances attempting to do work that should be carried out by professionals, and encouraging, amongst others, the following activities:

- Light cleaning tasks and removal of rubbish and weeds from the river streams.
- Improvement of the habitat to encourage the natural regeneration of native species.
- Control of invasive species and identification of the causes of their spread.
- Adaptation of the infrastructures to enable the use and enjoyment of rivers.
- Work on signs, documentation and highlighting of river landscapes.

- Restoration of small infrastructures of cultural assets and recovery of traditional customs linked to the area of rivers.
- Environmental surveillance, filing reports of infringements and identification of new pressures and impacts.
- Conduct surveys relating to different problems regarding the rivers.

2. BASIC PRINCIPLES

The voluntary river work programme began in July 2006. The public Spanish company, Tragsa, was commissioned to handle it and it started with the drafting of the Methodological Guide for the creation of Voluntary River Work Projects, which was written by WWF/ADENA®, in collaboration with a work group representing all of the parties involved. This work group met on various occasions, and with the collaboration of WWF/Adena®, the first version of the protocol of action was created, which all members of the group agreed upon.

To provide this protocol with a greater degree of quality, a Validation Seminar was held at CENEAM (National Centre of Environmental Education) that was attended by 51 people. Based on the presentations and specific workshops, the protocol contents were then discussed and remarkably improved.

The Methodological Guide for the creation of Voluntary River Work Projects was presented by Cristina Narbona in May 2007, at the same time as the call for proposed activities was opened for the 2007 Proposal, which had a budget of 500,000 Euros.

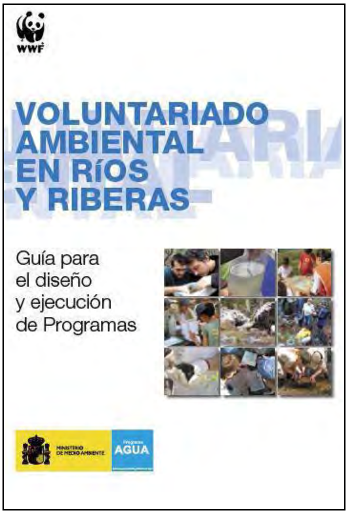

Figure 2 – Front cover of the Guide for the design and creation of Voluntary Environmental Work Programmes on Rivers and Riverbanks.

In total, 65 voluntary work proposals were received, corresponding to 54 organisations. Out of these proposals, in the first phase, the activities of 24 associations were selected. Meanwhile, modifications were made on the commission to Tragsa to deal with a higher number of proposals and later, another 15 projects were selected in a second phase (of these, 2 could not be fulfilled because the entities were lacking in means to carry them out). In the end, therefore, 36 associations participated during 2007. These projects were geographically distributed amongst the 8 intercommunity hydrographic confederations belonging to the Ministry of Environment and Rural and Marine Areas.

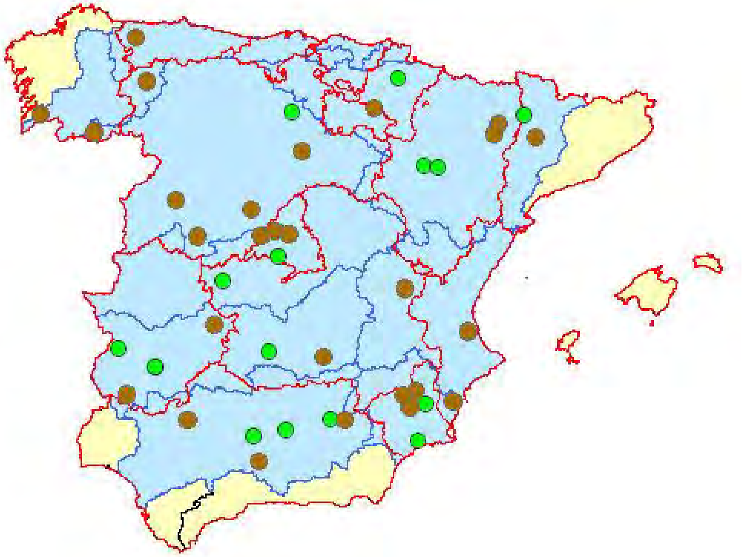

Figure 3 – Geographical locations of the projects carried out. The brown dots mark the projects carried out in the first phase and the green dots mark those carried out in the second phase.

Within the wide variety of projects presented, and to facilitate the study of them, it was decided to organise them by category into four groups, which covered all of the activities carried out:

- Diagnosis and evaluation of the rivers’ state.
- Conservation and improvement of the river ecosystems.
- Information and awareness among the community.
- Restoration of assets and increase in public use.

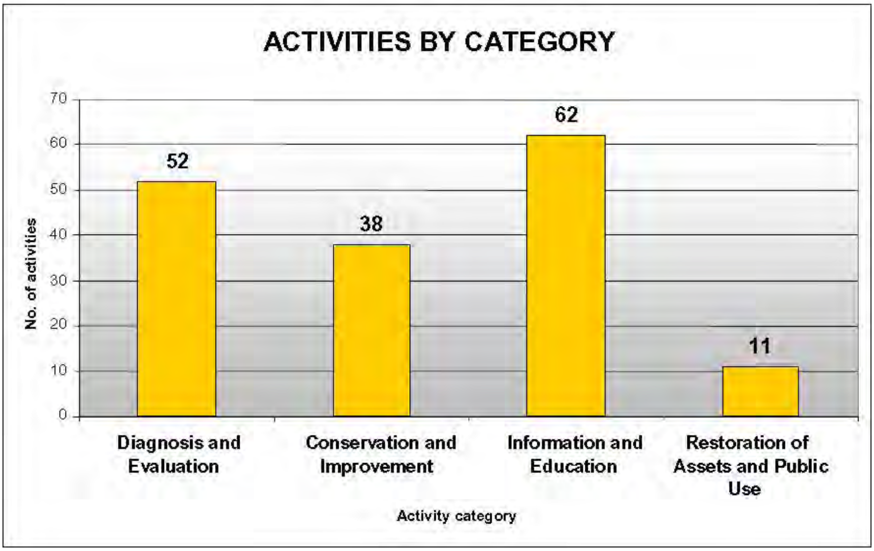

Figure 4 – Number of activities carried out within the Voluntary River Work Programme grouped according to category.

The general results of the 2007 proposal were:

- Invested budget: 913,000 €
- Participating associations: 36
- Projects carried out: 37 (the Spanish Red Cross had 2 projects)
- Average budget provided to the associations: >16,500 €
- Number of volunteers participating: > 15,000

The results of the application of this programme during 2007 were very positive. Although it was the first year it was carried out, the associations were very satisfied with the activities and the volunteers were treated very well.

Nonetheless, given the timeframes of the Proposal and the fact that it is relatively new, improvements in the coordination between all parties involved are planned for 2008.

A new provision has currently been drawn with Tragsa to carry out the voluntary work programme for the next few years, with annual payments of 1 million Euros for 2008, 2 million Euros annually for 2009-2010-2011 and one million Euros for 2013. Within this provision, Tragsa is being provided with more means for the coordination and monitoring of activities, with the creation of the Office of Environmental Education and Voluntary River Work, that will support the participating entities and any other related association or administration.

This order also includes the development of a programme of environmental education that is being designed based on one of the voluntary activities managed by ADECAGUA (Association for the protection of water quality), consisting of Spain's participation in the *World Water Monitoring Day*TM, the success of which in this first year has been significant, given the modest resources it had for its promotion.

The *World Water Monitoring Day*TM consists of volunteers measuring different parameters to assess the quality of the river ecosystem. The volunteers later provide the information to ADECAGUA that then passes it on to the international organisation that produces the reports on the international state of water quality. This activity was carried out during 2007 at different Secondary Schools as a trial to complement the technical subjects of physics and chemistry and was welcomed by the teachers and students. As such, the Water Department intends to provide a regulated offer of participation through the Ministry of Education, Social Sciences and Sport to the Autonomous Communities and Teacher Centers to promote action and to reach the highest number of educational centers. The Ministry of Environment and Rural and Marine Areas provided the Educational Centers with the materials necessary for carrying out the analysis, monitoring, etc… with the option to include, if requested by the centers, conferences held by well-known technicians in the area of sustainable management of river ecosystems.

Lastly, and given that these activities still do not include the "little ones", we are beginning to design material, in collaboration with the Ministry of Education, Social Policy and Sport that will accommodate this sector. In conclusion, this programme promotes the rehabilitation of the river ecosystem, as a clear component in the search for sustainable development within the framework of the implementation of the Water Framework Directive which is in full harmony with that set out by the Law on Natural Assets and Biodiversity and the Law for the Sustainable Development of Rural Areas.

3. EXAMPLES OF ACTIVITIES

Description of the projects run by some organisations participating in the Voluntary River Work Programme.

Asociación Gaia, with the project, "Environmental Sampling Routes in the Guadarrama River and its Environs". This association carried out the diagnosis and evaluation of the state of the rivers, which consisted of 10 field trips, during which samples of water quality were taken and interesting aspects were identified relating to the conservation of the rivers. As a result of these activities, the participating volunteers were educated on the environmental problems that are caused by the pollution of our rivers. A total of 64 volunteers participated in the activities.

Fundación Oxígeno, with the project, “Voluntary Environmental Workin the Rivers of the Municipality of Burgos”. This organisation carried out various activities, including: talks and conferences to inform the community of the current problems of the rivers; analysis and assessment of the state of the rivers and riverbanks of the municipality of Burgos; completion of surveys to find out about the perceptions that the local population had of the rivers; restoration of the cultural assets linked to the water streams; and environmental restoration involving the removal of rubbish, replanting of riverbeds and installation of bird boxes. A total of 725 volunteers participated in the activities.

Asociación Sierra Norte para la Atención al Disminuido Psíquico (Northern Sierra Association for Services to the Mentally Handicapped) with its project, “We can change our water: get involved”. This project involved a series of conferences, and leaflets were distributed on the importance of looking after our rivers and riverbanks while helping mentally handicapped people to integrate. A total of 13 volunteers participated in the activities.

Associació Habitats with its project, “Dynamisation of the volunteer groups in the Land of the Ebro”. This project involved a series of informative talks on the value of the river ecosystems to educate the community. Fixed groups of volunteers were also created, who will go on various excursions each year to determine how healthy the rivers they work with are. A total of 61 volunteers participated in this project.

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IS VISIONING AN EMPTY VISION? VISION GENERATION AND IMPLEMENTATION IN AN URBAN RIVER MANAGEMENT PROJECT

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ABSTRACT

Severe degradation of river ecosystems around the world has been coupled with a loss of social and cultural values. These effects are especially pronounced in urban areas. Increasing concern for these issues is being addressed through ecosystem-centred, adaptive and participatory approaches to environmental management. Unfortunately, many management initiatives lack a clearly defined purpose, with their aims essentially masked within (or behind) motherhood statements. Unless a clear vision statement with which to guide specific goals and objectives is provided, it is not possible to frame priorities in a coherent plan of action. Though the experience of 'Project Twin Streams', a local government and community partnership initiative in Waitakere City, Auckland, New Zealand, this study explores vision generation and application. Semi-structured interviews were conducted with 14 key informants who had differing strategic roles in the project, ranging from positions within regional and local government to community coordinators and consultants. Analyses entailed detailed investigation of project reports and planning documents, and application of discourse analysis to process interview information using nVivo software. Key themes explored included: vision elements, who decides the vision, the institutional, environmental, social, cultural and economic context, and the process and outcomes of the vision application. Emerging messages arising from the experience of Project Twin Streams highlight that concern for process can (and in some settings should) supersede statements that articulate visions as outcomes in themselves. Consequently, the process of vision generation may be more important than the statement itself. It is suggested that in efforts to maximize their effectiveness, visions should be developed inclusively within a flexible institutional setting, promoting and engendering holistic and sustainable actions. Although participatory approaches are recognised to be key to the implementation of the vision, leadership is needed to weave objectives in a coherent and synergistic manner. Key outcomes from management efforts should be fed-back with re-evaluation of the contextual setting, recurrently reframing 'living' visions.

Key words: Vision statement, sustainability, river management, adaptive management, Project Twin Streams

1. INTRODUCTION

It is now widely accepted that river systems around the world have been subjected to severe degradation arising from a plethora of direct and indirect anthropogenic impacts (Nilsson et al., 2007). The realisation of the extent of human impacts to river systems has coincided with a global push for sustainable management of biophysical resources. As we enter an era of ‘river repair’, river ‘restoration’ or ‘rehabilitation’ projects have been developed to improve the biophysical condition rivers in many parts of the world (e.g. Palmer et al., 2005; Brierley et al, 2006). In many instances, these objectives are coupled with goals to simultaneously improve social, cultural and economic associations with river systems within participatory and adaptive approaches (Hillman and Brierley, 2005). Such processes seek to enhance community awareness of the goods and services provided by riverine systems, and of the uncertainty inherent within these systems (Hillman and Brierley, 2008).

Genuine and sustained benefits of river rehabilitation will not be achieved unless we state explicitly what we seek to achieve in these activities (i.e. clear vision statements and target conditions are defined) and we audit the effectiveness of our actions (i.e. pre- and post-project data are used to monitor system responses to treatments; e.g. Palmer et al., 2005). While enormous pressure is often exerted to implement ‘on-the-ground’ river rehabilitation measures, *ad hoc* actions are unlikely to achieve their intended goals and measures should be applied within a strategic plan. A vision statement is an articulation and encapsulation of what the activity seeks to achieve, framing action in a meaningful and coherent manner (Hillman and Brierley, 2005).

Effective river management programmes give due regard to both product and process – the attainment of healthy rivers on the one hand, and the steps we take collectively to get there on the other. To date, relatively few programmes truly link a sense of what is biophysically achievable with due regard for what is socially acceptable and desirable (de Groot and Lenders, 2006). This severely limits prospects that the process of river repair will be undertaken in a just and equitable manner (cf., Golet et al., 2006; Hermans et al., 2007).

As protection is more effective, and cheaper, than cure, conservation of unique, rare and valued attributes requires not only the designation and setting aside of reserves and conservation areas, it also requires the implementation of proactive measures to tackle threatening processes that could bring about biodiversity losses (Hilderbrand et al., 2005). It is in everyone’s interests that actions are undertaken in a strategic, cost-effective manner, targeting key attributes, processes and stressors in efforts to address the underlying causes rather than symptoms of environmental degradation. Big-picture thinking at the 'whole of landscape' scale is required to move our efforts beyond compartmentalized ideas and approaches to environmental repair (Brierley et al., 2006). Critically, resulting actions need collective engagement among practitioners, including managers, stakeholders, researchers and the community itself (Rogers, 2006). Such a conceptualisation not only allows management to give due regard to strategies that 'work with nature', it also enhances prospects to build social resilience and capacity to manage the catchment (Hillman et al., 2008). Ownership begets responsibility, often prompting innovative and practical solutions to environmental repair. In some instances, sustained support from local communities may be compromised unless goals meet aesthetic expectations (e.g. Junker and Buchecker, 2008). Ultimately, the prospect to improve river condition, and sustain a healthier environment, is contingent upon broad-based community support. Building social capital and pooling resources are integral components in developing engagement with the process of environmental repair (e.g. Plummer and Fitzgibbon, 2006). Sharing and potential convergence of perspectives and aspirations provide a basis for collective action (e.g. Everard, 2004; Golet et al., 2006).

By definition, the visioning process entails efforts to scope the future, framing 'visionary' initiatives in light of what is realistically achievable given biophysical, socio-cultural, economic and institutional constraints. Pressures and limiting factors must be appraised, not only in light of prevailing biophysical fluxes and social and institutional trends, but also in relation to uncertain prospects (e.g. population trends, urban growth and forms, climate variability, etc) (Miller and Hobbs, 2007). While it is possible to plan for some changes, and other changes are actually planned, it is inevitable that surprising outcomes will occur. Ability to adjust to such changes has been encapsulated through notions of socio-ecological resilience. This prompts the adoption of adaptive management strategies, striving to promote an institutional capacity to 'hold fast' during threats and periods of stress (Rogers, 2006).

This study explores the visioning process as part of a river management initiative in an urbanising catchment in West Auckland, New Zealand. The development of the vision statement and it's consequent application in this case study are investigated.

2. PROJECT TWIN STREAMS

'Project Twin Streams' officially began in 2002. This local-level government and community partnership aims to develop sustainable management for the Oratia and Opanuku catchments in Waitakere City (Fig. 1). The project covers a total area of approximately 10,000 hectares.

Approximately 100,000 people reside within the catchment, with prospective growth of up to 202,900 by 2021 (Waitakere City Council, 2002). Much of the upper catchment comprises regenerated native bush, with healthy river systems. Mid-catchment reaches are also in good condition, but are being placed under increasing stress by peri-urban land uses. The lower reaches comprise relatively dense urban development, including the town centre of Henderson. The main stimulus for Project Twin Streams arose when the local governing body, Waitakere City Council, was required by regional-level government to improve stormwater management to mitigate the effects of housing development. Concern had also been mounting within the community over the polluted appearance and the increasing flooding to the lower parts of the catchment. Prospective solutions to these issues were fashioned, in part, by Waitakere City Council's commitment to sustainability ideals, exemplified by its declaration as an 'EcoCity' in 1992 (Waitakere City Council, 2002).

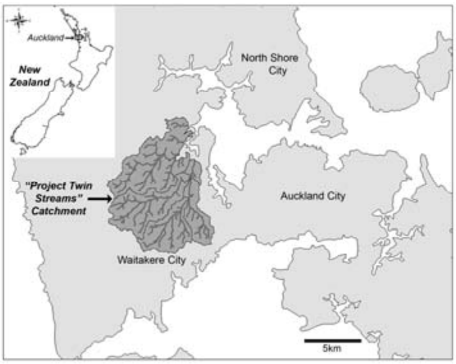

Figure 1 – Location of the 'Project Twin Streams' catchment, Waitakere City, Auckland, New Zealand.

The structure of the Project is two-fold. Waitakere City Council retains part ownership of the project, being legally bound to retaining ecosystem values of waterways through the Resource Management Act (1991). Council staff provide long-term strategic plans for the project and organise sources of funding to carry out actions. Community organisations are responsible for implementing the project. At present, the catchment is divided into five geographically-based 'community groups'. The primary role of these groups is to develop awareness of river management issues and to promote buy-in to the project. Over time, greater commitment to strategic planning will be passed over to the community, once the capacity has been developed to do so.

3. METHODS

A mixed-methods approach was applied to investigate the clarity of the 'vision' for Project Twin Streams, and its subsequent application. This entailed interviews with 14 key informants (strategic and day-to-day practitioners involved in the project past and present) and analysis of policy documents and publications pertaining to Project Twin Streams. Discourse analysis was applied to both interview transcripts and documents, with the aid of nVivo software. This followed a line of questioning centred around the key components of the vision, who decides the vision, the context in which the vision is embedded, and how the vision translates to action on the ground.

4. RESULTS

4.1 The vision for Project Twin Streams

The vision for Project Twin Streams is provided in the statement "Working together for healthy streams and strong communities: creating a sustainable future". Participants interviewed recognised two key themes inherent within this vision. Firstly, while the return of 'healthy' streams is identified as central to the project, long-term sustainable outcomes will not be achieved by concentrating upon environmental objectives alone. As social, cultural and economic stressors acting within (and outside) the catchment influence the physical and ecological condition of the channel and floodplain environments, environmental goals must be supplemented by social, cultural and economic goals at the outset. Secondly, communities must be explicitly involved in the project, developing an ethos of 'environmental stewardship' which seeks to address the consequences of human impacts upon river systems.

4.2 Product and process: A frame for stating what we seek to achieve and how we are going about achieving it

A sustainability paradigm brings to the fore a variety of values which need to be integrated in a coherent manner. These factors need to be constantly re-appraised and re-negotiated, as biophysical, social, cultural and economic values pertaining to the system, and associated governance structures, change through time. Fig. 2 presents a conceptual model of the experience of Project Twin Streams in developing and implementing their vision. Four phases in development and implementation were identified, with learning and feedback between these four phases (also see Tab. 1).

The first phase involves identification of the place-specific contextual base for the management effort. This phase conceptualises biophysical, social, cultural and economic values (and the linkages between these) to be incorporated in the vision. Such a conceptualisation allows an inclusive, holistic appraisal of what values are to be managed for, providing a clear platform that underpins decision making processes. As identified by one of the interview participants, this place-specific grounding ensures that management goals are realistic for the given catchment (Tab. 1).

The second phase involves planning the vision. This process involves pulling the components of the context together to frame the issues the project seeks to address, subsequently generating a place-specific vision for the management effort. Such a statement encapsulates the essence of what the project is to achieve. In the case of Project Twin Streams, this was carried out by three individuals, termed 'visionaries' or 'champions' (being figures in local government), who pulled these values together, and fashioned a statement which encapsulated these ideals. As identified above, the vision statement these 'visionaries' developed for 'Project Twin Streams' is: "Working together for healthy streams and strong communities: creating a sustainable future". Underlying this vision, goals/objectives are identified, framing a 'plan of action' wherein smaller steps guide the eventual fulfilment of the vision. This aids in determining if the vision is achievable. Due to the complex interplay of the broad range of values which the vision encompasses, the vision may appear overwhelming. Setting small, incremental steps assists in efforts to overcome this perception. Activities that will inspire broad-based community action are prioritised (Tab 1).

The third phase entails on-the-ground implementation of the vision. This provides a "space for action" (Participant 9), whereby initiatives are implemented by both the council and the community. The council carries out those actions which require substantial resources (such as the creation of sediment settling ponds), while the community groups have taken ownership of other actions, such as the planting of riparian margins. These actions have been combined within a substantial awareness campaign, ensuring that community involvement moves beyond singular or tokenistic gestures (such as attending a planting day) (Tab. 1). Actions which span the array of objectives have been hampered by the 'silo' structure of the Waitakere City Council, whereby management actions are implemented in a compartmentalised approach (Tab. 1).

Following the implementation of these actions, monitoring towards the achievement of the goals and objectives is carried out (the 'outcomes' phase) (Tab. 1). Adjustments to actions are made as required. This is not simply a linear process. Goals, objectives and actions are redefined as more is learnt about the catchment, recognising that some actions will either prove to be unrealistic, or they may have unintended and/or undesirable outcomes. Key learnings can be derived from all phases of the process, providing goals and actions which are grounded in the reality of the biophysical and community context (Fig 1, Tab. 1).

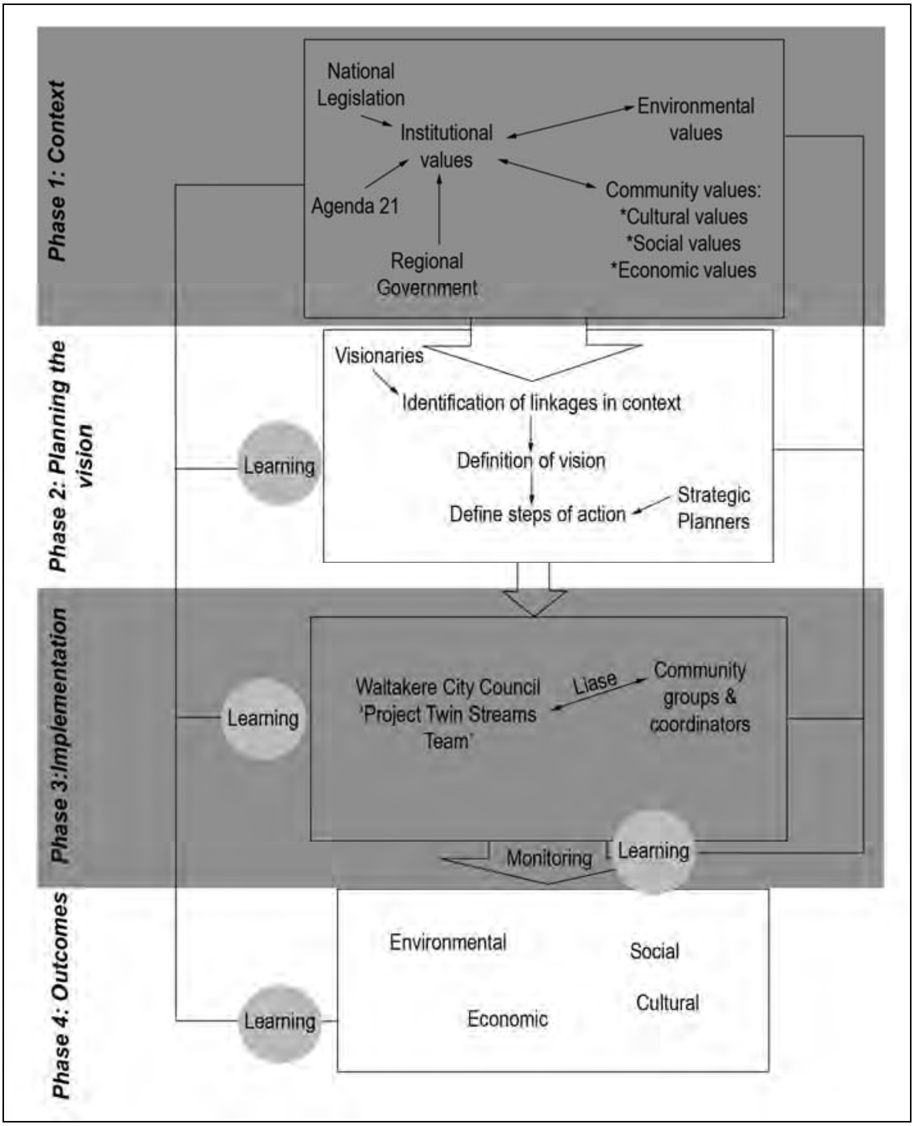

Figure 2 – Process of vision generation and application, as conceptualised through the experience of Project Twin Streams

Table 1 – Interview quotes that support each phase of the vision process

Phase	Supporting evidence
Context	***Importance of place-specific grounding of vision*** “Waitakere (City Council) had 20 years of community capacity building and a council committed to environmental issues… if you picked (the project) up and threw it into (a surrounding local government body)… the community infrastructure isn’t there to

	support it…". (Participant 8)
Planning	***Importance of visionaries*** "…there was strong leadership to begin with, and there was a clear vision… it was articulated and people understood and were able to buy in… you could debate,… get on board, but there was something quite tangible…" (Participant 8) ***Actions to foster community participation – for example, art projects*** "I think that the Arts Coordinator role has been, I've always described that role as being the glue to the whole project, it's what draws the community in and holds everything together" (Participant 6)
Implementation	***Actions tied to greater awareness campaign*** "… [we are] trying to engage people and make it more meaningful for them, so there is an ongoing relationship [with the river] after the initial restoration work has been done" (Participant 8) ***Issues associated with governance structure*** "We are so used to siloing everything, you know we say 'right this is environmental over here, and this is social over here, and they are quite different you know… we need to think about them differently, we need different people working on them'…" (Participant 7)
Monitoring and outcomes	***Development of evaluation framework*** "we have had the strong evaluation frameworks [implemented] around Project Twin Streams, so we've been able to learn along the way" (Participant 8)
Feedback	***Importance of learning and adjusting goals and actions*** "…it's been a learning process for me, you know, I think it is for everyone in this project, we… are creating the path by walking it… you can develop it in a responsive way" (Participant 6)

5. DISCUSSION

Although vision statements are widely used in river management projects, very little work has been dedicated to examine their value in guiding what we seek to achieve through management activities. While idealised vision statements may encapsulate what we seek to achieve, they can be rendered virtually meaningless unless there is a coherent, grounded process with which to guide the steps that must be taken in efforts to achieve such visions. Vision statements have the potential to provide an encompassing statement of what is to be achieved through management, providing a forum for all values to be heard and negotiated. Visions are not merely a statement of the 'end product' of management, they also encompass notions of the processes that must be taken to achieve the vision.

To be effective, visions promote a symbiotic relationship whereby biophysical considerations strengthen, and are strengthened by, community considerations (Fig. 3). In a sense, such efforts endeavour to 'help the system to help itself', engendering a healing process in both biophysical and socio-cultural terms (Higgs, 2005). The process of vision generation offers a focal point for developing inclusive goals for river management aspirations. In this process, genuine efforts are made to address what is biophysically possible (and desirable), while simultaneously respecting the capacity of the community to carry out such actions. Such relationships can strengthen the connection between social and biophysical systems. If the project fails to inspire action across a broad base of the community, prospects to achieve a vision of socio-ecological integrity will be compromised.

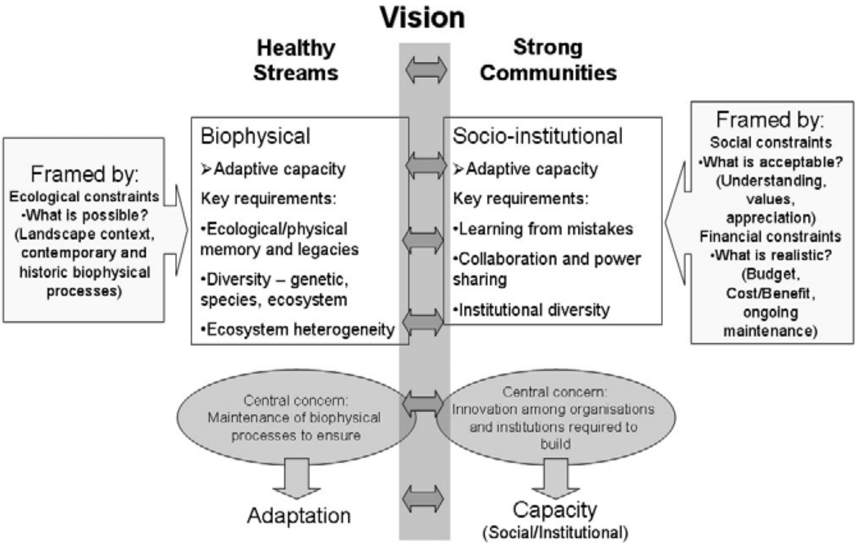

Figure 3 – Conceptualisation of mutual relationships between biophysical and socio-institutional values, which are framed by ecological, social and ecological constraints in the vision of Project Twin Streams. These concerns promote notions of adaptation and capacity. After Armitage (2005) and Miller and Hobbs (2007).

The constant reframing and appraisal of actions allows the instigation of a 'living' vision, providing for notions of adaptive capacity (Fig. 3). Innovation and flexibility are required in efforts to learn to 'live with nature', ensuring that biophysical systems can maintain their resilience (Armitage, 2005). Barriers to management flexibility may inhibit this process. For example, a 'silo' structure within local government, and relationships with the regional council, have led to fragmented approaches to environmental management within Project Twin Streams, prompting calls for institutional flexibility. Adaptive capacity will be enhanced though greater power sharing. Members of community groups have significant knowledge about factors causing degradation and actions that must be taken to change behaviours. Tapping into this information is fundamental in efforts to engender a genuine ‘whole of ecosystem’ approach to environmental management. The experience of Project Twin Streams reinforces the vital role of ‘visionaries’ in such programmes, weaving the myriad of community values within a catchment with biophysical aspirations. This role has allowed the simultaneous integration of biophysical and community values to be managed for, recognizing that actions taken to attain the vision must work within current limits community capacity, thereby strengthening this capacity over time (Fig. 3).

The legacy that we leave for future generations reflects actions that we take today. The application of technological endeavours framed within an ethos of landscape ‘design’ is little different from management practices applied within a developmental ‘command and control’ ethos (Hillman and Brierley, 2005). Such ‘technofix’ solutions not only fail in biophysical terms, they also fail to embrace societal relationships to place that promote community engagement in the process of river repair (e.g. Higgs, 2003).

Visioning is an under-valued tool for implementing river repair. The process of delineating what we seek to achieve through river management provides a focal point for conceptualising the key values to be managed for within a catchment, ensuring that actions are framed in a place-based holistic manner. From this conceptualisation, actions may be framed in a coherent manner, directly targeting the identified issues in a strategic approach. An iterative process to vision generation, implementation and reappraisal is a key component of adaptive management. While maintaining a vision of an improved socio-ecological system, the objectives underlying the vision must be inherently flexible, allowing for change and surprise. With due regard to product and process, a vision is not necessarily an empty vision.

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SUSTAINABLE, SOCIAL ACCEPTABLE AND ECONOMIC SOUND DECISION-MAKING IN WATER RESOURCES PLANNING

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ABSTRACT

Though in the last few decades Integrated Water Resource Management (IWRM) has definitively entered the lexicon of water managers and stakeholders as the mainstream approach to water management, a gap still exists between concept and practice, between idealized IWRM and operational IWRM. Indeed, documented real world applications that produced tangible progress in actual water management are still few, especially in transnational contexts. In the authors' opinion, this can be partly attributed to the lack of a real procedural approach to decision-making: emphasis is usually placed on modelling and toolboxes rather than on the decision making procedure itself, which is often thought of as a mere succession of "what if" questions posed to simulation models, through which the effects of different planning alternatives are assessed. As the number of alternatives and of stakeholders grows, this approach quickly becomes impractical, as it does not provide any guidance to evaluate and compare alternatives, and negotiations thus remain unsupported. To overcome this limitation a procedural approach for Participatory and Integrated Planning (PIP) of water resources systems is presented in this paper.

The procedure has its conceptual basis in the IWRM paradigm, but has been conceived and implemented by formalizing the methodologies developed and tested in a number of real-world planning projects. The procedure is here presented both in its theoretical aspects and as an application to the planning of the Lake Maggiore, a transboundary water system between Italy and Switzerland. This application produced a solution that will probably close a long-standing controversial between the two countries: it is strongly supported by the stakeholders of both sides and the international agreement it requires is presently under consideration of the Foreign Offices of the two countries.

Key words: Integrated Water Resource Management, Regulated lakes, Conflict resolution.

1. INTRODUCTION

Today, water resources planning and management face challenges well beyond those associated with the economically effective allocation of water in time and space as a result of population growth, rising living standards, and a less predictable climate. Integrated Water Resource Management (IWRM) is emerging as an accepted alternative to the sector-by-sector, top-down management style that has disastrously dominated in the past and partly contributed to the current water crisis. IWRM is based on the recognition that the intrinsic complexity of interconnected biophysical, social, economic and political factors can only be addressed by combining and truly integrating social constructivist ideas of participation and empowerment with a cross-disciplinary engineering approach. Water conflicts are value-laden and not neutral in a technical sense, and thus they cannot be resolved in a fully rational decisional context: the combined presence of multiple water uses and strong vested interests in the water resource management, both within and between nations, requires the active involvement of the stakeholders in each stage of the decision-making process, from the identification of their preference structure to the negotiations of the decision(s) to be actually implemented. On the other hand, the existence of many alternative decisions and the uncertainty on their future effects require a systematic and formal approach through which the most interesting (namely Pareto efficient) decisions are singled out and their effects somehow assessed ex ante. To couple effectively technical issues and preference aspects, a procedural guidance must be provided to the decision-making process and an appropriate toolbox designed to "support planning as a systematic, integrative and iterative process" (EU WFD Guidance doc. N. 11).

According to these requirements, a general procedure for Participatory and Integrated Planning (PIP) has been recently conceived and implemented by the authors as a 9 phases procedure that, starting from the identification of the overall objective of the planning exercise, ends with a negotiation process among the stakeholders that produces a set of compromise alternatives to be submitted to the decision maker(s) for the final political decision. The procedure is here presented both in its theoretical aspects and as an application to the planning of Lake Maggiore, a transboundary water system between Italy and Switzerland. The paper is organized as follow: in Sec. 2 the PIP procedure will be briefly described. The planning of Lake Maggiore is outlined in Sec. 3, while in Sec. 4 the application of PIP procedure to Lake Maggiore is described. In the last section some conclusions are drawn. Procedure, in short, has been conceived and devised by formalizing the methodologies developed and experienced in a number of National and International projects. Here, we will quickly go through the main activities included in each phase. A detailed description of the whole procedure is available in Castelletti & Soncini-Sessa (2006) and Soncini-Sessa et al.(2007a).

2. THE PIP PROCEDURE

The procedure for Participatory and Integrated Planning (Fig. 1), PIP procedure in short, has been conceived and devised by formalizing the methodologies developed and experienced in a number of National and International projects. Here, we will quickly go through the main activities included in each phase. A detailed description of the whole procedure is available in Castelletti & Soncini-Sessa (2006) and Soncini-Sessa et al. (2007a)

Phase 0. Reconnaissance. The aim of this phase is the definition of the *project goal*, the temporal and spatial boundaries of the water system, and the normative and planning context where the decision has to be implemented (scoping). All the *stakeholders* and their concerns, needs and expectations are identified, along with the available and missing information on the system. The very PIP procedure is presented and explained to the parties (decision makers (DMs) and stakeholders), and, if necessary, negotiated among them.

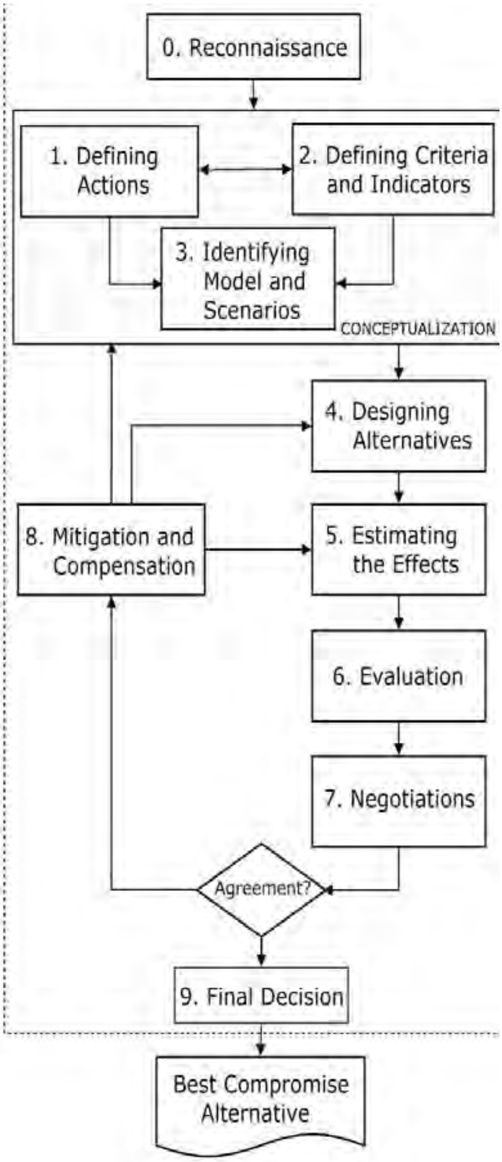

Figure 1 – The PIP procedure.

Phase 1. Defining Actions. The *actions* and measures that are presumed to serve the project goal are identified in strict collaboration with the parties. These may include infrastructural and normative actions as well as regulation policies for reservoirs and diversion dams. An action is said to be instantiated when the parameters through which it is easily and fully identified are specified. An *alternative* is a coordinated mix of instantiated actions.

Phase 2. Defining Criteria and Indicators. The project goal is translated into a hierarchy of operational *criteria* that reflects the stakeholders' viewpoint in evaluating the alternatives and the environmental and sustainability issues. The hierarchy's lower level criteria are associated to quantitative (or even qualitative) *indicators* through which criterion can be verified. Such indicators are functions of the trajectories of the variables describing the system condition.

Phase 3. Identifying the Model and the Scenarios. In order to compute the value of each indicator in correspondence with each alternative, a model of the whole system must be identified. The inputs to the model are the variables describing the alternatives and the variables specifying the *project scenarios*. The latter include the description of all the future events that are not under the control of the DMs, e.g. hydrological and water demand scenarios under climate change. Models are usually mathematical ones, but, when necessary, they can also be substituted by expert judgments.

Phase 4. Designing the Alternatives. The set of alternatives to be presented to the stakeholders for negotiations is designed in this phase. First all the possible combinations of the actions specified in phase 1 are taken into account to obtain a list of alternatives. Then, the ones that are efficient in the Pareto sense are selected for consideration, either by experts, or by solving a Multiobjective Mathematical Programming (or Optimal Control) problem.

Phase 5. Estimating the Effects. The effects produced by the efficient alternatives are assessed by simulating the system behaviour over a given time horizon.

Phase 6. Evaluation. The *value* the stakeholders attribute to an alternative, namely the satisfaction they derive from it, is not always directly proportional to the numerical value of the indicator. It is therefore necessary to translate each indicator (occasionally groups of indicators) into the actual ‘‘value’’ perceived by the stakeholders. This can be done by means of a Partial Value Function that has to be identified through interviews of the stakeholders. From these functions, a dimensionless *index* is obtained for each alternative and for each stakeholder, which expresses the overall satisfaction that stakeholder assigns to that alternative.

Phase 7. Negotiations. The above indexes are used to compare the alternatives and to guide negotiations among stakeholders. Negotiations can be carried out in many ways and terminate with the identification of a set of alternatives to which the majority of the stakeholders agree to.

Phase 8. Mitigation and Compensation
To improve the outcomes for the unsatisfied minority of stakeholders and broaden the approval for the attractive alternatives, mitigation and/or compensation measures are analyzed . Eventually, a set of *reasonable alternatives*, for which consent cannot be broadened any further, is identified.

Phase 9. Final decision
Among the set of reasonable alternatives, the one that provides the *best compromise* is selected by the DMs.

3. LAKE MAGGIORE PLANNING

Lake Maggiore is a natural lake located south of the Alps between Italy and Switzerland. It is the most important water system of the sub-alpine area on account of its multiple – conflicting - socio-economic uses. Its large alpine watershed (6600 Km2) is characterized by extremely variable weather conditions, which cause important flood and drought periods of both the lake and its outflow - the River Ticino - with consequent damages to the socio-economic systems. Miorina dam, built by Italy in 1943 to meet the needs of downstream water users (mainly irrigated agriculture and hydropower generation), regulates the lake outflow. An international agreement signed at that time states a limited range of levels within which the dam can be operated with the aim of reducing risk of flooding on the lake's shores. However, it is common opinion among lake communities, particularly in the Swiss city of Locarno, that lake regulation has increased flood frequency and intensity. Swiss authorities replied to these concerns by devising some proposals, henceforth called *structural actions*, aimed at increasing the outflow capacity by excavating the outlet. Such proposals, however, did not encounter the agreement of the Italian party, as they do not bring any advantage for downstream users, while enhancing the risk of flooding for the populations on the River Ticino. Italian farmer leagues, in their turn, suggested accompanying the Swiss proposal with a modification of the regulation range (*normative action*), which would allow the lake to be regulated up to a level of +1.50 meters even in the summer period, thus reducing the risk of water deficit for the downstream users.

However, such an action, which can be regarded as a second action, complementary to the structural one, is not supported by the lake shoreline population, which fears it will increase the risk of flooding. To overcome this difficulty and avoid an uncontrolled increase of the lake level, the decisional freedom of the lake regulator can be reduced with a suitable regulation policy (*regulatory action*), i.e. a rule that every day specifies the amount of water to be released as a function of the lake level. With the purpose of exploring whether any combination of the aforementioned actions (that henceforth we will denote as an *alternative*) might be suitable for addressing the conflict among the different water uses/users in the Lake Maggiore water system, the PIP procedure was adopted to support the planning process along all its duration. Two issues make this process extremely challenging and significantly more complicated than the common planning tasks: the combined presence of planning and management decisions, due to the highly dynamic nature of the water system, and its transboundary nature, which results in the presence of more than one DMs.

4. PIP PROCEDURE IN LAKE MAGGIORE PLANNING

In this section we will present how the PIP procedure has been successfully applied to the planning of Lake Maggiore, by following phase by phase its logic development as introduced in Sec. 2. More details can be found in Soncini-Sessa et al. (2007b).

Phase 0. Reconnaissance

The information presented in Sec. 3 should have already given an idea of the project goal in Lake Maggiore planning. Formally, this can be formulated as ``to assess and analyse the effects possible measures would produce on the whole system, and to identify the alternatives to be submitted to the DMs for final decision, together with the list of the stakeholders supporting and opposing each one of them". The DMs are the Governments of Italy and Switzerland, who will negotiate the final (political) decision, considering the viewpoint of the stakeholder group they represents. Lake Maggiore stakeholders are numerous: in addition to lacustrine and riverine communities, farmer leagues and hydropower companies, one may consider the navigation company, the fishermen, the tourist operators, one natural reserve located at the top of the lake and two natural parks placed along the downstream River Ticino. Stakeholders that share the same interests are grouped tentatively in a *sector*. A list of the project's stakeholders and sectors is shown in Fig. 2

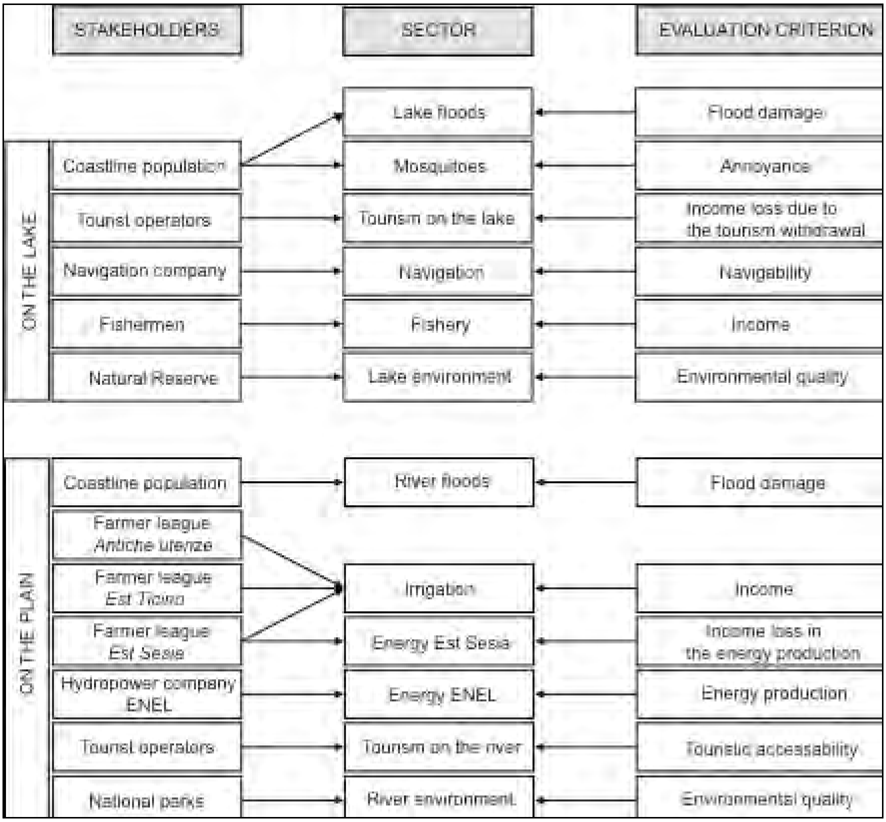

Figure 2 – Stakeholder, sectors and criteria.

Phase 1. Defining Actions

Some of the actions to be evaluated have already been introduced above, i.e. the excavation of the lake outlet, the modification of the regulation range, and the re-design of the regulation policy. However, another significant proposal emerged during the Reconnaissance: the revision of existing Minimum Environmental Flow (MEF) values in the downstream River Ticino, which was proposed by the Environmentalists. All the alternatives obtained by combining in all the possible ways the values that each one of the above actions can assume were considered.

Phase 2. Defining Criteria and Indicators

Once the stakeholders were identified and agreed on the definition of the project goal, they were asked to specify the criterion through which they would judge the performance of an alternative from their own viewpoint. Due to the high number of stakeholders involved, this operation was carried out sector-by-sector, thus obtaining as many evaluation criteria as the sectors individuated in Phase 0 (see Fig. 2). Each criterion was then resolved in a hierarchy and one or more indicators associated to the leaves of each hierarchy. An example of hierarchy is given in Fig. 3. Eventually, 53 indicators were defined for the 11 sectors.

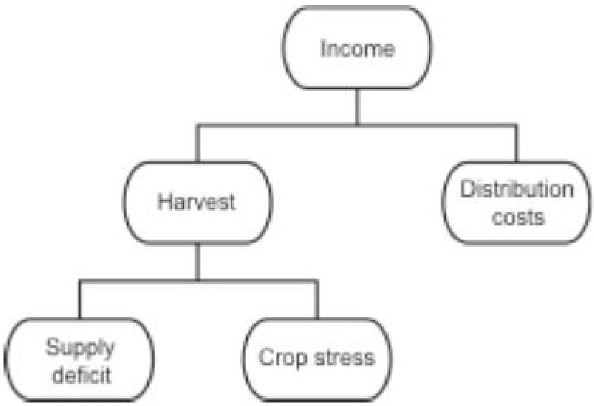

Figure 3 – The hierarchy for the Irrigation sector.

Phase 3. Identifying the Model and the Scenarios

The models of the single system's components (the catchment, the lake, the distribution network, the irrigation district, the power plants, etc.) were aggregated to form a model of the whole system. This model is dynamical and stochastic, its inputs are the alternative, whose effects are being evaluated, and the disturbances (i.e. the inflows to lake), and its outputs are the lake level, the release and the water flows both in the distribution network and in the River Ticino. Different modelling approaches were used to describe the different components, depending both on the type of processes taking place in each of them and on the available data. For instance, the catchment was described by means of an autoregressive mechanistic models, while the flood propagation along the River Ticino with a neural network. The model identification process was carried out in strict collaboration with the stakeholders.

Phase 4. Designing the Alternatives

The actions identified in Phase 1 were combined in all the possible ways to produce the set of alternatives to be evaluated. Given a couple of structural and normative actions, efficient regulation policies were designed by formulating and solving a stochastic multi-objective control problem.
Stochasticity is the effect of lake inflows, which are described as a stochastic process. As a straightforward consequence the indicators identified in Phase 2 are also stochastic variables and therefore a statistic was applied to obtain the objectives of the “control problem”, i.e. the problem of deciding along a

time horizon how much water to release from the regulating dam. Moreover, in order to keep the computing time at a reasonable level, only a subset of the indicators identified in Phase 2 was considered to formalize the problem objectives.

Statistics and indicators were chosen in collaboration with the stakeholders who, stimulated through interviews and decision support tools based on proper communication techniques, proposed to filter stochasticity through the expected value (Laplace criterion) and selected some indicators of the following sectors: Lake Flood, River Environment, Irrigation and Hydropower generation. By considering all the combinations of structural and normative actions, and by discretizing the Pareto frontier, 195 alternatives were designed

Phase 5. Estimating the Effects.

By using the model of the system, the system behaviour was simulated over the entire evaluation horizon for each alternative. The trajectories so obtained allowed computing the values of the 53 indicators for each alternative. The simulations were performed using the historic scenario (catchment inflow and water demands for farming and electricity generation), as suggested by the stakeholders, since they were only able to evaluate the effects of the alternatives under the conditions that had already taken place in the past. The indicators were then validated by checking if their variations were significantly greater than the precision of the model by which they had been computed, and by testing if they were properly describing the phenomenon they were expected to: a couple of indicators did not pass the test. These were the indicators for the River floods sector, whose values were estimated by means of a neural network model of the flood propagation along the River Ticino. Since the precision of the model turned out to be less than the difference among the values of the indicators, the indicators could not be regarded as representative of the effects of the alternatives. For this reason, the sector “River floods was temporarily kept out of the decision-making process; however, detailed analysis of the effects on the River floods sector was accomplished in the Mitigation phase, focusing on the limited group of the reasonable alternatives (more details are available in Soncini-Sessa et al. (2007b)). Thereafter, a correlation analysis between all couples of indicators was carried out to test if the indicators used in Phase 4 were good representatives of the whole set of indicators. The reply was positive. The final product of this phase was a *matrix of effects* with the value assumed by each indicator over each alternative.

Phase 6. Evaluation

The Evaluation of the alternatives was performed according to the strict Multi Attribute Value Theory (Keeney and Raiffa, 1976) with active participation of stakeholders. Physical indicators in the matrix of the effects were translated into dimensionless numbers by specifying *partial value functions* identified though interviews to stakeholders and then linearly aggregated within each sector to form a dimensionless *sector index*, one for each criterion expressed in Phase 2.

Phase 7. Negotiations

A negotiation process among the stakeholders was established with the purpose of identifying the alternatives gaining the largest consent. The procedure adopted was and *ad hoc* modification (see again Soncini-Sessa et al. (2007a)) of Pareto Race (Korhonen, 1988): starting from a sector, the stakeholders belonging to that sector were invited to single out the alternative they consider the best from their point of view. The value of the indexes produced by this alternative in each sector were then compared.
The set of the (Pareto efficient) alternatives was then explored to find out an alternative, if any, that would have incremented the benefit of the `most penalized' stakeholders and, at the same time, lowered the indexes of its supporters only of an `acceptable amount', i.e. of an amount that did not transform them into opponents. If such an alternative existed, it was an *attractive alternative*. By repeating the procedure starting from each sector the set of the attractive alternatives was eventually determined.

Phase 8. Mitigation and Compensation

The attractive alternatives are not yet reasonable alternatives since the agreement on some of them might still be widened by means of mitigation actions. For example, alternative A34 was an attractive alternative and gathered a large agreement among the sectors. However, the sector Lake Environment was not among its supporters, because the value of its sector index was nearly as unsatisfactory (0.26) as the present situation. Mitigation measures were then studied and it was discovered that, by appropriately extending the Natural Reserve's present surface the sector would have became a strong supporter of alternative A34 (the sector index growed up to 0.85). The cost for acquiring this land was estimated in 10,15 millions of Euro, and the stakeholders of the Lake Floods sector, which are strong supporters of A34, declared to be willing to cover it if the stakeholders group would accept A34 as the best compromise alternative. Other types of mitigation measures that induced the relevant stakeholders to turn into supporters of the A34 were identified also for the River Floods sector.

Phase 9. Final Decision

The two Governments have not yet made their final decision. However, a step towards it has been already taken: the Swiss Government proposed to select alternative A34 among the set of reasonable alternatives; the Italian Government has not yet responded, claiming the need for further studies on the compromise alternatives.

5. CONCLUSIONS

An application of the PIP procedure to a real world case study has been presented in this paper. PIP procedure has shown to be able to deal with complex problems, with many decision makers and many stakeholders, where a mixture of planning and management decisions has to be taken. This kind of problems can be considered as the more complex ones in the field of the integrated water resources management.

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CHAPTER 9

Session 8A

Ecohydrology: water quality

Chairperson

P. BAKONYI

Introduction
ECOHYDROLOGY: WATER QUALITY

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Traditionally water quality meant water chemistry. With the launch of the EU Water Framework Directive (WFD) its interpretation became broader and besides chemistry biological aspects came into picture. Moreover the concept of “good ecological status” brought hydrobiology in the forefront of water quality classification. While the chemical classification of water bodies is fairly well defined the biological classification was lagging behind it. Since the launch of the WFD a lot of effort was devoted to define and quantify the “good ecological status of the water bodies”.

The papers of Session 8A all touched upon the ecological status of water bodies. Three of them focused on nutrient reduction possibilities while the forth one attempts to develop a bioindication method based on macrophytes. Two papers that do not appear in this book also dealt with nutrient balance (and uptake by macrophytes and bacterial processes) and nutrient reduction.

The major finding of the Session is that nutrient reduction requires a basin-wide action though local ecohydrological strategies can substantially contribute to the improvement of ecological conditions. Preliminary research results show that the classification of river bodies using macrophytes depends on the geographical area and the use of macrophyte indexes cannot be generalised.

4th ECRR Conference on River Restoration
Italy, Venice S. Servolo Island
16-21 June 2008

PROFOR (AUSTRIA): INTEGRATING THE EFFECTS OF STREAM STRUCTURE ON NUTRIENT LOADING PATTERNS IN MANAGEMENT OPTIONS FOR HEAVILY MODIFIED STREAMS

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ABSTRACT

Due to the high agricultural land use, most stream reaches in the northern part of Lower Austria are heavily modified and carry high amounts of nutrients. Together with the low precipitation in the region, this leads to a marked reduction of the streams integrity and to a bad ecological status.

The aim of the proposed project PROFOR (2008-2011) is to identify those management options for such heavily modified low order streams which can potentially improve water self-purification and thus restore the good water quality. The project focuses on the biogeochemical processes which significantly increase the nutrient retention within these streams and can be managed through the restoration of the stream morphology. In a preliminary study in 2007 we investigated 16 stream reaches of different hydro-morphology and degrees of degradation, ranging from semi-natural to restored to heavily degraded reaches. We performed short term NH4 and PO4 addition experiments develop an understanding of the factors influencing nutrient uptake in those small agricultural streams.

Our first results show that nutrient uptake in those streams is influenced by the spatial heterogeneity of the active channel, the extension of the transient storage zone and, partly, by nutrient background concentrations. Nutrient uptake could not be related to the degree of degradation.

Key words: restoration, agricultural streams, nutrient uptake, transient storage

1. INTRODUCTION

In many European and North American countries, agriculture has been identified as the largest non-point source of nutrients to streams and rivers (e.g. Böhlke et al., 2004; Bernot etal,. 2006). High amounts of nitrogen and phosphorous not only lead to the eutrophication of the freshwater systems, but are discharged into estuaries and coastal waters where they cause enhanced primary productivity and hypoxia. To reduce nutrient export to these sensitive ecosystems, management options have to primarily focus on headwater streams, as they account for most of the length of the drainage network and are tightly connected with the terrestrial environment (Craig et al. 2008).

The northern part of Lower Austria is characterized by intensive agriculture, which produces multiple pressures on the headwaters in the area. Drainage practices conducted in the past together with low precipitation, led to low discharges and increasing intermittency during the dry seasons (summer and winter). Besides receiving high loads of nutrients from the surrounding agriculture, the streams have been heavily regulated, showing straightened and incised channels with scarce bank vegetation (Fig. 1).

For an effective management of nutrient loads in such streams, a comprehensive understanding of the underlying processes of nutrient uptake, transformation and, eventually, release, and their linkages to stream morphology is needed. The aim of the three-year research project ProFor (*Process-oriented research about the self-purification potential of heavily impacted small streams in the Weinviertel and in South-Moravia: Development of a guideline for sustainable management measures to improve the water quality*; 2008-2011) is to identify management options for small, heavily impacted agricultural streams which have the potential to improve their self-purification capacity and thus to restore a good water quality. The project focuses on biogeochemical processes which significantly increase the nutrient retention within these streams either by removal or by long-term storages, and which can be managed either by the restoration or by changes of the stream morphology.

In a preliminary study in 2007, we performed short-term nutrient additions experiments in 16 morphologically different stream reaches in the project area. Scope of the experiments was to analyze the range of potential nutrient uptake, link these results to structural properties and, by that, develop a conceptual scheme of the driving factors that control nutrient retention in those small agricultural streams.

2. PROJECT AREA

The project area Weinviertel is located in the north-east of Lower Austria. The western part of the catchment of the investigated streams belongs to the molasses zone, the eastern regions are part of the Northern Vienna Basin, characterized by gravel, sand and clay sediments with highly fertile soils. The Weinviertel is a flat to hilly country with the highest elevation at 491 m a.s.l.. Mean annual precipitation is about 500 – 600 mm (dry pannonic climate). Intensive agriculture dominates the catchment with cultivation of grain (wheat, barley, rye), sugar beet, and grapes (Tab. 1).

Figure 1 – A typical degraded headwater stream in the project area in Lower Austria

3. METHODS

3.1 Sampling design

We selected 16 stream reaches with different hydro-morphology and degrees of degradation to investigate nutrient uptake (Tab.1; reach length: 500 m). The reaches ranged from semi-natural, to restored, to heavily degraded ones. Semi-natural reaches either flowed through forested catchments (Ho, P2) or through remains of a pristine floodplain (Hi), but still showed high pollution and a low to moderate water quality. The experiments were conducted once for each stream between July and October 2007.

3.2 Characterization of the investigation areas

Using GIS (ArcGis), we located the investigated stream reaches and calculated the distance to the source of the streams as well as the catchment area. To analyze land use conditions, land use types were identified within a 500 m broad buffer strip along each stream side. The quantification of the percentage of each land use class helped to characterize and classify the surrounding area with regard to intensity and patterns of land use. Agricultural land was defined as arable land plus cultivated grassland.

Channel characteristics were measured every 100 m along each 500 m stream reach, including water depth, current velocity, channel width and bank inclination over cross sectional profiles.

Table 1 – Land use characteristics of the study sites and hydromorphological and chemical parameters measured during the experiments

Site	Catchment area (km^2)	Agriculture (%)	Condition	Discharge (ls^{-1})	NNH_4 (μgl^{-1})	NNO_3 (mgl^{-1})	$P\text{-}PO_4$ (μgl^{-1})
Su1	28.1	94.4	degraded	8.6	300.2	4.4	110.5
Su2	22.2	82.2	degraded	2.2	64.5	7.2	217.4
He	31.2	97.1	degraded	3.6	26.1	2.3	178.5
Te	6.5	84.9	degraded	1.2	46.4	3.6	391.8
Mü	26.6	65.4	degraded	5.6	66.4	4.0	61.0
St1	6.4	84.7	restructured	0.7	6.4	0.2	157.9
St2	7.6	88.2	restructured	0.8	76.4	0.8	709.1
St3	9.0	81.7	degraded	1.3	117.8	3.7	723.8
W1	89.6	43.2	degraded	60.3	120.3	1.9	405.7
W2	110.3	95.7	restructured	60.3	90.2	2.0	403.2
W3	175.9	76.7	restructured	123.5	555.0	2.0	1841.0
Fe	12.1	90.5	degraded	0.8	6.5	0.1	40.8
Hi	1.0	90.2	semi-natural	2.9	94.6	5.1	68.1
Ho	3.1	0.0	semi-natural	0.9	75.6	0.7	146.4
P1	2.4	71.6	degraded	3.9	56.5	10.7	55.8
P2	9.7	1.1	semi-natural	16.0	48.9	7.7	51.2

3.3 Nutrient additions experiments

To measure overall biogeochemical nutrient uptake at the reach scale, we performed short-term nutrient additions with NH_4, PO_4 and NaCl as a conservative tracer as described elsewhere (Stream Solute Workshop, 1990). In short, nutrients and sodium chloride were injected simultaneously into each stream reach for about 1 hour. We recorded conductivity with an electrical conductivity meter to measure change in relative ions concentration with time. After ions concentrations reached plateau conditions, we collected water samples every 50 m along a longitudinal transect located between 100 and 300 m downstream of the injection point. Filtered water samples were analyzed for $N\text{-}NH_4$, $N\text{-}NO_3$ and $P\text{-}PO_4$ concentrations using standard colorimetric methods (APHA, 1995).

Nutrient uptake parameters (uptake length Sw, uptake rate U, mass transfer coefficient Vf and uptake coefficient Kc) were calculated from the longitudinal decline of the nutrients during plateau conditions corrected against the chloride via a first order uptake regression curve (Stream Solute Workshop, 1990). Transient storage zone As and transient storage exchange coefficient α were estimated for each injection by fitting a one-dimensional advection, dispersion, transient storage model OTIS-P to the time-series data of the conductivity curve (Runkel, 1998).

3.4 Calculations and statistics

We used univariate and multiple linear regression models to analyze the relationship of nutrient uptake and transient storage parameters with hydro-morphological features and nutrient background concentrations. In those cases where the linear model did not yield a significant relation, we used Pearson's correlation to test whether any relationship existed between the respective variables. All statistical analyses were performed using SPSS 7.5 for Windows.

4. RESULTS

4.1 Transient storage

The relative proportion of the transient storage *As* to the stream surface cross sectional area *A* was between 0.04 and 0.5 in our study streams (Fig. 2). These values lie within the range reported from other headwater streams with a low water exchange with groundwater (Hall et al., 2002). In general, the semi-natural and restored reaches showed a larger transient storage zone than the degraded ones. We could not detect any significant correlation between transient storage and any of the hydro-morphological parameters derived from the cross-sectional profiles in our study streams. Transient storage seems to be mainly a function of the longitudinal heterogeneity caused by pools and debris dams which frequently occur in the semi-natural and restored reaches.

4.2 Nutrient uptake

Based on the first statistical analyses, the mass transfer coefficient was used as the explaining parameter for the nutrient uptake. Because it is independent of discharge, this parameter can be used to compare different streams. The mass transfer coefficient represents the uptake velocity and, thus, shows the demand of nutrients relative to their supply in the water column. Nutrient uptake in this paper always refers to the overall biological as well as geochemical uptake of nutrients on the reach scale.

Mass transfer coefficients ranged between 0 and 0.05 mm s^{-1} for both NH_4 and PO_4 (for NH_4 see Fig. 2). 40 % of the stream reaches showed either no or only low nutrient uptake. Nutrient uptake was not related to the degree of degradation. While some of the degraded reaches yielded similar uptake velocities as the semi-natural ones, two of the restructured reaches, again, showed extremely low values (St1, W2).

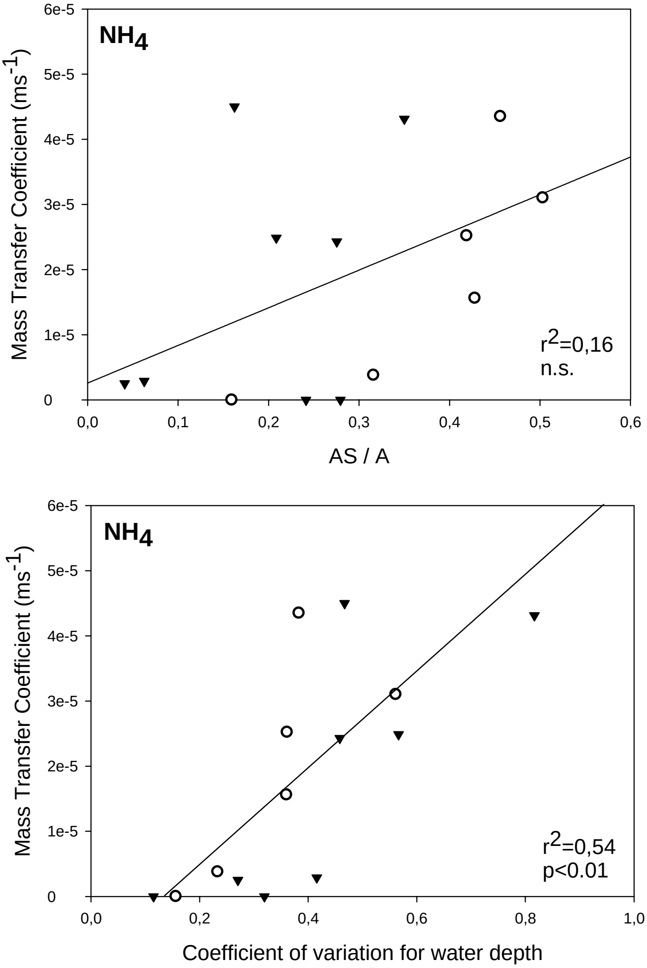

Figure 2 – NH_4 uptake in relation to the proportion of the transient storage zone (AS / A) and the coefficient of variation for water depth. Triangles = degraded reaches, circles = semi-natural and restored reaches.

4.3 Factors influencing nutrient uptake

Nutrient uptake tended to increase with the proportion of the transient storage zone relative to the surface cross-sectional area (*AS/A*; Fig. 2). However, due to the high variability existing among different stream reaches, the correlation was not significant for both NH_4 and PO_4.

The spatial heterogeneity of the active channel also influenced the nutrient uptake. We found a significant correlation between NH_4 uptake and the coefficient of variation for water depth and stream width (Fig. 2). PO_4 uptake also increased with increasing variability in depth and width but correlations were not significant.

PO_4 showed an almost exponential, but not significant, decline in the mass transfer coefficient with increasing background conditions in the streams. Above a threshold of approximately 300 µg P-PO_4 in the water column, phosphate uptake was low. In contrast to that, NH_4 uptake was not correlated to either ammonium or total nitrogen background concentrations.

5. CONCLUSIONS

The preliminary study gave us a first insight into the nutrient uptake capacity of small heavily impacted agricultural streams and its controlling factors. Even some of the degraded reaches in the study area still showed a potential for nutrient uptake. However, a high proportion of the streams seemed to be already near or above nutrient uptake saturation (Bernot et al. 2006). Such streams have lost their natural function in controlling the export of nutrients to downstream reaches and act mainly as drainage systems for the agricultural catchment. In these cases, management concepts have to focus on reducing the nutrient input from the adjacent terrestrial habitats before restructuring the channel morphology.

The nutrient retention in the streams was influenced by the longitudinal and cross-sectional heterogeneity of the channel. However, a great part of the variability among reaches remained unexplained, showing the complex biogeochemical processes underlying nutrient retention. For an effective management of nutrient concentrations in such small agricultural streams, a comprehensive understanding of these processes as well as their linkage to each other is needed. This knowledge can then form the base for the development of restoration strategies to enhance self-purification and improve water quality.

Examples of restructured reaches with a low potential for nutrient uptake show that restoration concepts improving spatial heterogeneity and species diversity also have to include the functional aspects of the respective stream. Hydro-morphological changes in the stream may alter the conditions at the water-sediment-interface and within the sediments and, thus, lead to secondary eutrophication. Therefore, restoration concepts should focus on channel conditions that are favorable to biogeochemical nutrient uptake.

6. FURTHER STEPS

In order to determine key pathways and mechanisms of nutrient uptake in our project streams, our next steps will include investigations at the catchment, reach and micro scales to identify

.(1) dominant nutrient sources and input pathways (point vs. non-point sources, groundwater vs. overland flow input),

.(2) effective nutrient uptake mechanisms (permanent removal vs. temporary storage, e.g. denitrification, microbial or algal assimilation) and

.(3) morphological structures with the potential of high nutrient turnover rates

Nutrient loads and transformation patterns will be studied via long-term additions with stable isotopes (^{15}N) and laboratory experiments, and will be linked within models. Based on these results, we will create a guideline for small water bodies in agricultural landscapes which will provide management options for the long-term improvement of the water quality by raising the in-stream nutrient uptake and by optimizing restoration measures to avoid negative feed-back loops resulting in secondary eutrophication events. The guidelines will be applied to pre- and post restoration sites for the verification and comparison of this process-based approach to the stream evaluation by the biotic components of the WFD.

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APPLICATION AND DEVELOPMENT OF RIVER QUALITY BIOINDICATION METHODS BASED ON MACROPHYTES.

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ABSTRACT

The present study, which is still in progress, aims to develop a macrophyte-based method to assess the trophic level of rivers. Data were collected on 27 sites, belonging to different river types. 19 sites are located in the Trentino region, and 8 sites in the Veneto region. At each sampling site macrophytes were mapped, nutrients concentration was measured and flow velocity and shading were recorded together with other site characteristics. Aquatic vegetation was surveyed between June and September 2007. All helophytic and hydrophytic vascular plants, including bryophytes, charophytes and filamentous algae were recorded. The survey was carried out on 50 m long sections with uniform morphology and shading conditions, substrate characteristics, flowing velocity and vegetation patterns. The abundance of each species was estimated according to a five levels scale (1 = very rare, 2 infrequent, 3 common, 4 frequent, 5 abundant, predominant). Plant abundance was estimated separately for submerged and emergent growth forms, in those cases where the taxon occurred in both growth forms. The surveyed sites were divided into groups, on the basis of hydrological and morphological features (flow velocity, substrate, etc.) through a Cluster Analysis. The correlation between macrophyte species composition and nutrients was assessed for every group.

Key words: macrophytes, nutrients, fluvial ecosystem

1. INTRODUCTION

In many European Countries, research on the relationships between aquatic vegetation and running waters has a long tradition (Kohler, 1976; Holmes Whitton, 1977; Haslam, 1982; Carbiener et al., 1990; Robach et al., 1996) and, it often resulted in methods that use macrophytes as bioindicators, especially at the community level (Haury et al. 1996; Newman et al., 1997; Schneider, 2000).

On the contrary in Italy, systematic studies on macrophytes of running waters, with a macrophyte-based index as output, do not exist so far. Macrophytes are principally studied from the phytosociological point of view (Sburlino et al., 1995; Prosser Sarzo, 2003; Buchwald et al., 2000; Sburlino et al., 2004) and the studies are in general not addressed to bioindication, with the exception of some isolated cases (Minciardi et al., 2003; Gomarasca et al., 2004).

The European Water Framework Directive (WFD) requires the ecological assessment of running waters based on various biotic elements, one of them being the macrophyte community (EU 2000). Therefore there is the need to set bioindication methods based on macrophytes as well. This can be very difficult without an adequate knowledge of the aquatic vegetation of rivers of our Country.

This study, still in progress, wants to be first step towards the definition of a macrophyte-based index for Italian rivers.

2. STUDY AREA

Forty-seven sampling sites were selected on different water courses. 37 sites are located in Trentino (Trento province), the remaining 10 in Vicenza province. These last ten sites were added to the initial group to have a representative sample from a lowplain river, a typology totally lacking in Trentino.

The 47 sites were chosen on rivers and streams very different from each other, and with various levels of chemical and morphological impacts.

Since the macrophytes have to be mapped during the main vegetation period (that in our study area lasts from June to September), 27 sites were mapped during summer 2007, the remaining 20 sites will be sampled in the next growing season (summer 2008).

3. METHODS

Most of the sampling sites (35) belong to the monitoring network of the Environmental Protection Agencies of Trento or Vicenza. Therefore, a time-series of chemical data is available. Two sites of the province of Vicenza (one on the Tesina River and the other on the Bacchiglione River) are located next to other monitoring sites of ARPAV-Vicenza to which they will be correlated, after a control analysis. For ten sites in Trentino, on the other hand, there were no previous data available. In these sites we performed chemical analyses, once a month, from May to September, in coincidence with the growing and sampling season, to characterize the sites from the chemical point of view.

The following parameters were analyzed, according to the IRSA methods (IRSA, 1994): water temperature (field measurement), dissolved oxygen (field measurement), conductivity, pH, alcalinity, COD, BOD5, ammonia, nitrite, nitrate, total nitrogen, SRP (soluble reactive phosphorus), total phosphorus.

3.1 Macrophyte mapping

The survey was carried out into 50 m long sections with uniform morphology and shading conditions, substrate characteristics, flowing velocity and vegetation patterns (Haury 1996, Haury et al. 1996, Robach et al. 1996, Sabbatini and Murphy 1996, Ali et al. 1999, Thiébaut Muller 1999, Flynn et al. 2002, AFNOR 2003, Schneider and Melzer 2003). For the macrophyte mapping we recorded all the macroalgae, briophyte, pteridophyte and phanerogam species that we found in the considered river section. The filamentous algae were recorded as well and were determined to genus level, to find a compromise between scientific information and time required for the determination. This choice is supported by many authors (Haury et al., 1996; Newman et al., 1997; AFNOR, 2003). In the river section we assessed the total cover of the macrophyte community and the cover of each species or blanket weed aggregate. The abundance of the different genera of algae composing the blanket weed were determined in the laboratory with the help of a microscope (Minciardi et al., 2003). The coverage of macrophytes excluding the filamentous algae, and the coverage of algae alone, were recorded in the field as well. For each species we distinguished between cover of submerged form and emerged form, if the taxon is present with both growing forms (Schaumburg et al., 2004; LfU 2005). Vegetation cover is estimated through a five degree scale, according to the Kohler's method (Kohler, 1978; Melzer, 1992), similarly to the phytosociologic approach. Some morphological and hydrological parameters were recorded together with the macrophyte map, especially those that strongly influence the macrophyte community, i.e. flow velocity, shading, water depth, substrate composition (Minciardi et al., 2003; LfU, 2005), as well as all aspects which could be useful to interpret data (presence of weirs, dams, flow swings etc.). All these parameters were recorded in a semi-quantitative way, using different degree scales reported in the field data sheet[1].

[1] The field data sheet that was used for this study was created *ad hoc*, paying particular attention to those characteristics which strongly determine the macrophyte community development.

Table 1 - Macrophyte cover evaluation scale

COEFFICIENT	DESCRIPTION
1	Very rare
2	Infrequent
3	Common
4	Frequent
5	Abundant, predominant

Cluster Analysis (STATISTICA, 2005) was run to establish clusters of stations on the basis of hydrological and morphological characteristics: mean width, mean depth, flow velocity and composition of substrate. For each of the groups defined by clustering, the correlations between each species and phosphorus and nitrogen concentration in water was calculated with a Spearman's nonparametric rank order test (STATISTICA, 2005). This test was run using only ammonia nitrogen and total phosphorus, because the data about nitrite, nitrate and SRP are at the moment still lacking for some sampling sites. Once the data are complete, the test will be run using also the other forms of phosphorus and nitrogen.

4. RESULTS

As already mentioned, the results are still partial. We will present here only some results of the first part of the study. During summer 2007 27 sites were surveyed , belonging to 21 water courses and 3 different hydrological basins: the Po, Adige and Brenta-Bacchiglione basins. 91 macrophyte taxa were recorded in these water courses, among them 11 genera of filamentous algae belonging to Chlorophyceae, Bacillariophyceae, Cyanophyceae and Xanthophyceae, one species of Characeae, 6 species of mosses, 1 species of Hepaticae and 2 species of Pterydophytes. The most common species, in term of number of sections in which they were present, are reported in Tab. 3, while the species with the largest coverage, calculated as median, are listed in Tab. 4.

Table 2 - Taxa recorded in 9 sites at least

Species or genus	**Number of sites**
Agrostis stolonifera	13
Berula erecta	9
Cladophora spp.	9
Nasturtium officinale	14
Phalaris arundinacea	20
Ranunculus trichophyllus	14
Sparganium erectum	9
Vaucheria spp.	12
Veronica anagallis-aquatica	12
Veronica beccabunga	10

Table 3 - Taxa with coverage median value ≥ 3,5

Species or genus	**Coverage** (median)
Amblystegium riparium	4,0
Callitriche stagnalis	3,5
Ceratophyllum demersum	3,5
Elodea nuttallii	5,0
Glyceria maxima	4,0
Hippuris vulgaris	5,0
Lemna trisulca	4,0
Oscillatoria spp.	4,0
Phormidium spp.	4,0
Potamogeton pectinatus	4,0
Ranunculus trichophyllus	4,0
Vallisneria spiralis	5,0

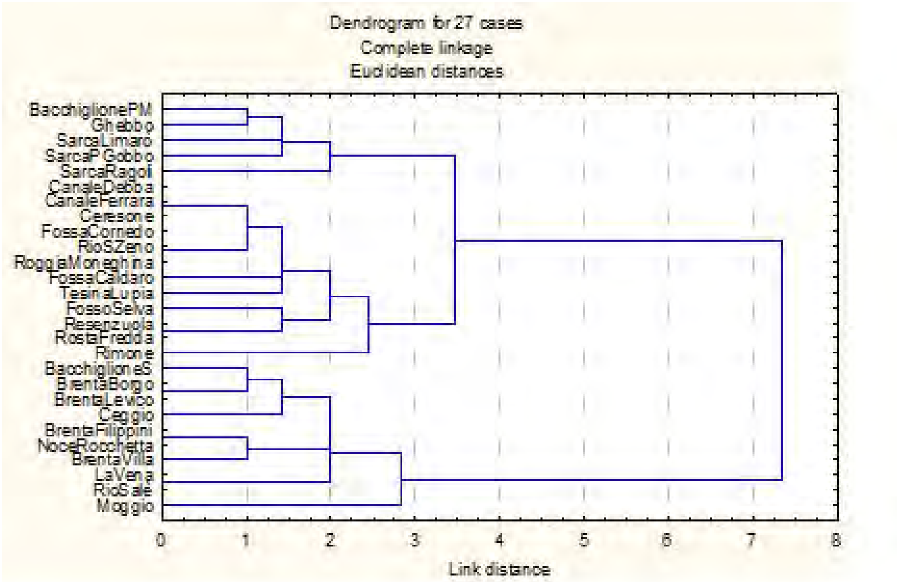

Figure 1- Single linkage Cluster Analysis (Euclidean distance) of the surveyed sites on the basis of their morphological features

The 27 sampling site were clearly divided into 3 groups by the Cluster Analysis (Fig. 1), the 3 groups are listed in Tab. 4. The Spearman's rank order test showed that some species are related, positively or negatively, to nutrients concentration. The significant results are listed in Tab. 5.

Table 4 - Results of the Cluster Analysis

Cluster N°	Sampling sites	Physical features	Macrophytes
1	Bacchiglione Ponte Marchese, Sarca Limarò, Sarca Ponte Gobbo, Sarca Ragoli, Torente Ghebbo	Medium water flow velocity, laminar or with limited turbulence, substrate medium to coarse	*Agrostis stolonifera, Berula erecta, Phalaris arundinacea, Ranunculus trichophyllus, Vaucheria* spp.
2	Bacchiglione Sorgente, Brenta Borgo, Brenta Filippini, Brenta Levico, Brenta Villa, Ceggio, La Vena, Moggio, Noce Rocchetta, Rio Salè	High water flow velocity, coarse substrate	*Cladophora* spp., *Fontinalis antpyretica, Glyceria fluitans, Myriophyllum spicatum, Nasturtium officinale, Ranunculus trichophyllus, Sparganium erectum, Vaucheria* spp.

3	Canale Debba, Canale Ferrara, Ceresone, Fossa Caldaro, Fossa Cornedo, Fosso Selva, Resenzuola, Rimone, Rio S. Zeno, Roggia Moneghina, Rosta Fredda, Tesina Lupia	Low or very low flow velocity, medium-fine to fine substrate	*Berula erecta, Callitriche stagnalis, Carex* spp., *Ceratophyllum demersum, Elodea nuttallii, Hippuris vulgaris, Lemna minor, Lemna trisulca, Potamogeton pectinatus, Ranunculus trichophyllus, Sparganium erctum, Vallisneria spiralis*

Table 5 - Spearman's rank correlations (significance level $p < 0,05$)

Species	N_NH4	P_Ptot
Agrostis stolonifera		0,68
Berula erecta	-0,72	
Fontinalis antipyretica		-0,76
Lemna minor		0,69
Mentha aquatica		-0,67
Ranunculus trichophyllus	0,85	0,64
Veronica anagallis-aquatica		0,69

5. DISCUSSION

The clustering divides the 27 sampling stations into 3 groups that correspond to different river typologies, especially according to flow velocity and substrate granulometry. These two factors strongly influence the species composition of macrophyte biocenoses (Barendregt Bio, 2003; Dawson & Krysztof, 1999; Heegard et al., 2001). The first group is composed by water courses with medium flow velocity, laminar flow or limited turbulence and medium to coarse granulometry. The sites of the second group present high flow velocity and coarse substrate, and the third group is formed by canals, with low or very low flow and fine sediment. The first two groups are quite similar and are in fact partly characterized by the same macrophyte species; on the contrary, the water courses of the third group are very different from those of group 1 and 2 and, coherently, different macrophyte species are present and prevailing.

The correlation between species and nutrients were investigated inside each group. This fact allowed to define if the absence of some species from a site was due to morphological conditions or from high concentrations of phosphorus and nitrogen. The result will be sounder with the increase of the number of sampling station and with the inclusion of other phosphorus and nitrogen species.

Nonetheless, some interesting and consistent results were obtained. Berula erecta and Mentha aquatica have negative correlation with ammonia and total phosphorus concentrations respectively. These species could be used as indicator of low nutrient content in water. Fontinalis antpyretica as well had negative correlation with total phosphorus concentration. These three species are generally described by many authors (Haury et al. 1996; Holmes, 1996) as mesotrophic, whereas other authors give especially to Berula erecta and Mentha aquatica a meso-oligotrophic indicator value (AFNOR, 2003).

On the other side, Agrostis stolonifera, Lemna minor, Ranunculus trichophyllus and Veronica anagallisaquatica have positive correlation with total phosphorus (R. trichophyllus with ammonium as well) and could be investigated as possible indicators of high nutrients conentration. Once again, literature reports discordant results about the cited species (Haury et al., 1996; Holmes, 1996; Schneider, 2000).

To test the tolerance or sensibility of species to nutrients enrichment the sediment should be analyzed as well, since many rooted macrophyte species get nitrogen and phosphorus from sediment (Demars & Harper, 1998; Madsen & Cedergreen, 2002; Robach et al., 1995).

6. CONCLUSIONS

The first results support the use of macrophytes as bioindicators, but the comparison with literature data about the species considered here shows that classification of macrophyte species, according to their ecological trophic range is not univocal. The basic idea of this study is that differences in macrophyte distribution, and therefore their trophic classification, are also dependent on the geographical area in which macrophyte species are studied. As a consequence, the application of English, French and German macrophyte indexes to Italian rivers give results that are rarely satisfying (Fabris, unpublished).

The aim of this work is thus to attribute to some macrophyte species an indicator value based on data collected on Italian water courses.

The study will continue on summer 2008 with the mapping of other sites and with the investigation of sediment nutrients content in some sampling stations, to confirm the first data about correlation between species and phosphorus and nitrogen.

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THE USE OF HYDRO-ECOLOGICAL MODELS IN PREDICTING PHYTOPLANKTON DEVELOPMENT IN URBAN FLOODPLAINS

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ABSTRACT

Predicting basic ecosystem properties like primary production proved to be useful to estimate the effects of restoration measures in river-floodplain systems, for example by developing predictions of the trophic development of phytoplankton and the impact of a floodplain on the river. The main focus of this work was to describe the relevance of hydrological connectivity to aquatic primary production patterns in the context of the project ‘Optima Lobau’, a study aimed to develop and compare future management alternatives for the Lobau, a significantly altered floodplain of the River Danube (Austria). Seven hydrologically determined scenarios ranging from disconnected backwaters to a fully integrated side-arm system were developed and compared for a variety of socio-economic and eco-hydrological aspects. To calculate potential primary production and differentiate the scenarios, a biomass model was developed. We analysed statistically the basic information on habitat structure, surface and groundwater dynamics, and estimates of light availability and combined them with biomass measurements of phytoplankton and macrophytes.

Based on the results of modeling, the different hydrological changes implied different interactions between macrophytes and phytoplankton compared with the present state of the floodplain. Macrophytes dominated in the most isolated segments of the floodplain and were well abundant in areas with reduced flow velocity, for example at low connectivity levels and in shallow areas. The biomass of pelagic algae was highest in segments with high connectivity, due to a stimulated primary production enhanced by frequent nutrient pulses and lower competitive pressure of macrophytes. Scenarios with an integrated side-arm in the Lobau and

therefore, increased area of highly connected parts of the floodplain, induced higher overall phytoplankton biomass in the system.

Key words: river/floodplain systems, aquatic primary production, River Danube.

1. INTRODUCTION

Floodplains include a mosaic of connected, highly productive patches and play a decisive role in nutrient retention and organic matter dynamics of riverine landscapes (Robertson et al., 1999). Water quality in floodplains and its net effect on downstream water quality in terms of nutrient retention and of development of phytoplankton as autochthonous carbon source for the foodweb in river-floodplain systems, depend upon the hydrologic interaction with river water (Preiner et al., 2008). Resources availability and the distribution of algae and macrophytes, and therefore the potential productivity in floodplain waters, are determined by the frequency and intensity of surface water connectivity (Hein *et al.* 2004), which depends on the main channel water levels and, in urban areas, on the management scheme. Within the scope of the project 'Optima Lobau', which is aimed to develop potential future management alternatives (scenarios) for the Lobau, a significantly altered floodplain of the River Danube (Austria), we analysed quantitatively the effects of surface water connectivity on aquatic primary production. Seven hydrologically-determined management alternatives, ranging from disconnected backwaters to a fully integrated side-arm system, resulting in variable patterns of hydrological conditions, were modeled and the effects on various socio-economic and ecohydrological aspects were analysed.

Main objective of the study was to analyse the impact of surface water connectivity on the interaction between algae and macrophytes. We focused on modeling and predicting the algal biomass development, for different connectivity and macrophyte coverage scenarios created by the different management alternatives of 'Optima Lobau'. Scope of this analysis was to create indicators associated with the functional integrity of the ecosystem. We analysed basic information on habitat structure, surface and groundwater dynamics, and estimates of light availability statistically and combined them with biomass measurements of phytoplankton and macrophytes to develop an algal biomass model.

2. METHODS

2.1 Study area

The Lobau is a large floodplain area at the eastern border of the city of Vienna. During the regulation of the Danube in the late 19th century, this former dynamic floodplain was disconnected from the main channel by the construction of a dike for flood protection. Lateral embankments along the main river channel severely altered the geomorphic and hydrologic dynamics and hindered the natural sequence of erosion and sedimentation (Hohensinner et al., 2004). During the last decades, vertical erosion in the main river bed (incision), together with ongoing aggradation in the floodplain, have further disconnected hydrologically and ecologically the wetland from the river (Reckendorfer et al., 2005). Today, the Lobau represents a groundwater-fed and back-flooded former side-arm, arranged in pools with varying hydrological connectivity (Schiemer, 1999) and surrounding isolated pools, where sedimentation and terrestrialisation processes prevail. Thus, within the scope of the research project “OptimaLobau”, multiple future management scenarios were discussed in order to identify potential management strategies for a sustainable development of this floodplain ecosystem.

2.2 Modeling of algal biomass

Present data of the Lobau (978 data-sets measured at 33 sampling stations from 1995 – 2006) was analysed to identify interactions between several abiotic and biotic habitat factors and phytoplankton biomass (mean Chlorophyll-a-concentration for the vegetative period from March to October) in hydromorphologically homogeneous segments of the floodplain. By means of a statistically evaluation (Multiple Linear Regression) three main factors were selected. The first factor, hydrological connectivity, which is defined as the mean number of days per year (calculated with water level data from 1995 – 2006) where surface water connection of a segment and the Danube is established. Hydrological connectivity is used as a substitute parameter for mean hydrologic conditions and the mean nutrient availability of an area. River water compared with floodplain water can be characterized with higher nutrient and particulate matter concentration. Therefore, surface water connectivity results in nutrient import on the one hand and hydrological changes on the other. Second factor was the coverage of submersed macrophytes, which is related to nutrient and light competition in the ecosystem and third, the proportion of shallow areas within a segment. Hydromorphological conditions and the three main factors were calculated for the developed scenarios to provide the basis for biomass modeling. Using the given correlations of factors and Chl-a-concentration, the mean biomass of phytoplankton was modeled for each of the investigated scenarios.

Model results were evaluated in 2007, i.e. when monthly measurements of Chla- concentration and associated abiotic conditions at 15 sampling stations, varying in hydrological connectivity and pool morphology, were conducted.

3. RESULTS AND DISCUSSION

In the back-flooded floodplain Lobau the degree of surface water connectivity depends on the Danube water levels and the distance to the inflow area. Mean connectivity is about 137 days per year in the lower parts and decreases with the distance to the inflow area to 1 day per year in the former side-channel of the Danube. In isolated waters, surface water connectivity is limited to major flood events. In scenario ‘Isolated’ surface water connectivity is restricted; scenario ‘Reconnected’ is characterized by a fully integrated side-arm system with multiple inflow areas and a surface water connectivity of up to 345 days per year.

Present state mean Chl-a-concentrations are high in water bodies near the inflow area (15 - 20 µg l^{-1}) and in ponds near the main channel (30 µg l^{-1}), which are fed by infiltrating Danube water and are not connected to the river. The lowest Chl-a-concentrations (5 - 10 µg l^{-1}) were observed in isolated, shaded water bodies distant from the flood-protection dike. Increased connectivity of floodplain segments with the river (scenario ‘Reconnected’) resulted in higher nutrient concentrations which are carried by the river. The better nutrient availability combined with the disadvantage for macrophytes of the decreased light availability and of the physical strain of higher flow velocities, stimulates phytoplankton productivity and leads to higher Chl-a-concentrations (20 – 28 µg l^{-1}) in dynamic areas. Decreased connectivity, as in scenario ‘Isolated’, results in lower mean Chl-a-concentrations (< 10 µg l^{-1}) and an extension of emergent macrophytes which in turn increase the terrestrialization processes in the floodplain. The higher was the coverage of submersed macrophytes, the lower was phytoplankton productivity due to the decreased availability of nutrients and light, resulting in low Chlorophyll-a-concentrations. High proportions of shallow areas showed different effects on phytoplankton development: in segments with a connectivity of more then 150 days per year, shallow areas are habitats with decreased flow velocity and increased light availability enabling higher primary production, whereas in poorly-connected segments the competition with macrophytes caused a decrease in Chl-a concentration (Riis and Biggs, 2003).

Chl-a-concentrations measured during field assessments were in accordance with the model results. Concentrations were consistent with the model results in isolated waters and the lower parts of the Lobau near the inflow area. Highest variation was found in water bodies distant from the inflow area and in high connected waters, which were evaluated in a restored side-arm system of the Danube near the Lobau.

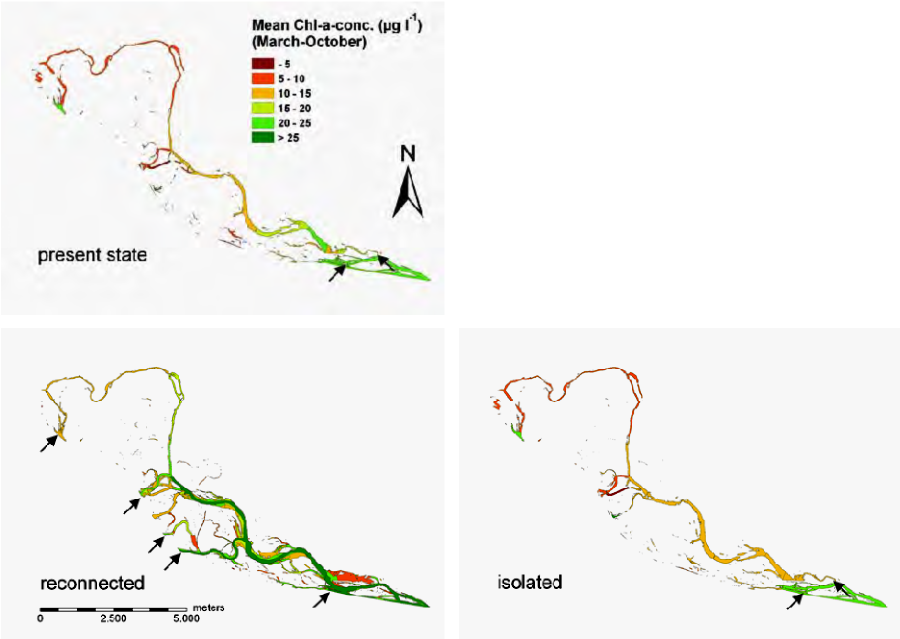

Figure 1 – Mean annual Chl-a-concentrations for the present state, an isolated and a high connected simulation of the Lobau. Inflow areas are marked with arrows.

The model results underline that the hydrological reconnection of floodplains and the increasing duration of lotic conditions in the system, as in scenario 'Reconnected', would potentially induce higher primary productivity of phytoplankton, resulting in high Chl-a-concentrations and high nutrient uptake capacity. The ecological integrity of the floodplain Lobau would be improved, with positive effects on downstream water quality due to increased nutrient retention and the contribution of autochthonous carbon to the foodweb of the main channel – key features in river-floodplain systems. Decreased hydrological connectivity, as in scenario 'Isolated' would enhance terrestrialization processes and the development of a terrestrial ecosystem.

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ECOHYDROLOGY FOR WETLAND REVITALISATION: LESSONS LEARNED DURING TWO EUROPEAN UNION PROJECTS

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ABSTRACT

Two international projects, the Tisza River Project (www.tiszariver.com) and the LIFE-Szigetköz Project (www.szigetkoz.info), have been completed fairly recently. Both projects had, among the major objectives, the revitalisation of wetlands. In these projects ecohydrological monitoring, modelling and actual water engineering tools were used.

The lesson we learned in the Tisza River Basin case (area 157,000 km^2, shared by 5 countries) was that we have proven, first by intensive field studies on 16 wetlands (oxbow lakes) and adjoining ecohydrological lake-wetland models, that the only chance to save these wetlands is the substantial reduction of nutrient loads into these mostly hypertrophic waters. Subsequently, with a careful analysis of all available data and by carrying out a whole-Tisza-Basin nutrient budget catchment model analysis with a model of our own development (SENSMOD), we found that only basin-scale total clean-up programmes can achieve the required load reduction for these wetlands.

In the braided river arm system of Danube in Szigetköz (a kind of inland delta water system with dozens of river arms, canals, lakes and islands), the main focus of revitalisation activities was the provision of supplementary flows and water depths in the river arms and wetland lakes, that had practically been left dry after the diversion of the River Danube to the Hydropower station of Bős/Gabcikovo (Slovakia) in 1992. We, the VITUKI team, carried out detailed field surveys at 35-50 sampling points of this water system aimed at assessing the success of earlier flow-supplementing revitalisation efforts. After that, we assessed the likely outcome of the newly opened revitalising canal system through modelling and field studies. We forecasted an improvement of the system but identified a risk of hypertrophication due to the still high nutrient input. Field studies carried out later, showed that our forecast was correct because the system had improved to a very

diverse aquatic ecosystem, but very low and very high oxygen concentrations mark the existing danger of high levels of eutrophication. The final lesson is the same as in the Tisza case:- full cleanup of nutrient sources is needed in the river basin upstream of the area and also in the direct catchment of this region, and the establishment of ecohydrological reservoirs could further improve the ecological state of this wetland system.

Key words: Wetland revitalisation, oxbow lakes, Danube and Tisza rivers, braided river arm system, Szigetköz

1. INTRODUCTION

Wetland ecosystems are land-and-water ecotones, and thus have an outstanding role in controlling plant nutrient fluxes of river basins and with this function can or could be one of the major tools in fulfilling the main objective of the Water Framework Directive (WFD), i.e. the reaching of the good ecological status. However, these ecosystems can only fulfil their controlling role when their structure, function and biodiversity are preserved and maintained and for this reason the appropriate control of their water quantity and and nutrient budget is needed. Such control can or could be resolved with appropriate 'ecohydrological' strategies, that is by adhering to the basic objectives of the ecohydrological projects of UNESCO-IHP (Phase V, 1996), i.e.: "*to develop a methodological framework to describe and quantify flow paths of water, sediments, nutrients and pollutants through surficial ecohydrological system, the catchment and the system of recipient water bodies, with their biotic and abiotic, man-made and natural constituents and to develop an integrated approach for managing the surficial eco-hydrological environment.*"

This was the leading principle we followed when selecting the ecohydrological objectives of the two international European Union supported projects, the Tisza River Project and the LIFE-Szigetköz Project, which were completed in 2004 and 2007, respectively. In this paper we summarise the major ecohydrological results of these projects, calling the attention of the readers to the project websites where many more details are presented.

2. WETLAND STUDIES OF THE "TISZA RIVER PROJECT"

The Tisza River Basin, with a 157,000 km^2 catchment area, is located exactly in the geographic centre of Europe (Figure 1). One of the major objectives of the international EU supported "Tisza River Project" (www.tiszariver.com) was the review of the knowledge on the actual conditions and problems (critical issues) and the revitalisation options of the high number of unique wetlands along the lower reaches of the River Tisza and its tributaries. In Hungary we investigated 16 out of the hundreds oxbow lakes for macrophytes and we regularly measured several ecological and chemical parameters in 5 wetlands. The analysis of the regular network monitoring data of the rivers allowed us to identify the major problems of these wetlands: drying, silting-up and hypertrophication. The major cause of the highly eutrophic, and in some cases hypertrophic, conditions is the high nutrient concentrations and loads in the rivers, which feed these wetlands. The ten major tributaries of the Tisza reached, the Hungarian border in the period of the investigations (2002-2005) with multi-annual mean total phosphorus (TP) concentration of 365.8 mg/m^3 and PO_4-P concentration of 237.9 mg/m^3; these are extremely high, hypertrophication-inducing values according to the OECD classification (OECD, 1982). Calibration of catchment model SENSMOD which we developed (Jolánkai et.al., 1989; Jolánkai, 1992) against the TP concentration, flow, and load data of the entire river system of the catchment (Fig. 1) resulted in shocking diffuse or non-point source unit area load rates of phosphorus. All the areas identified in Fig. 1 with values higher than 10 kg/ha/year fall out of realistic literature ranges, thus indicating unidentified hot spots or point sources.

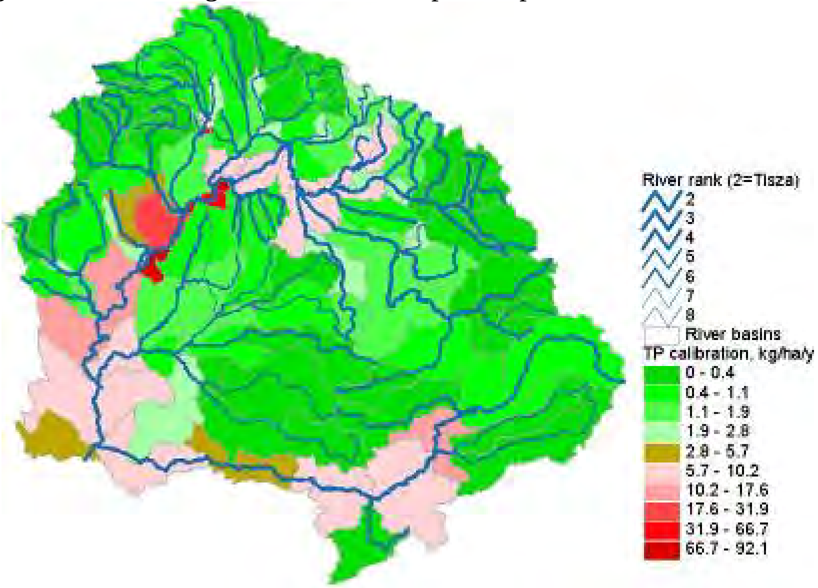

Figure 1 – Catchment model calibration results of the Tisza Basin for total non-point source phosphorus load, in kg ha^{-1}year^{-1} dimension

By comparing in-stream nutrient loads to the loads from point sources as obtained from the international database created for the Project, it was found that only about 20% of the total observed TP load was explained by point sources. The eutrophication control strategy applicable in such case should be the most efficient removal of all nutrient loads. This corresponds, according to practical experiences, to 90% removal of point- and 50% removal of non-point loads. Model runs with this load reduction (Fig. 2) forecasted a tolerable but still eutrophic status.

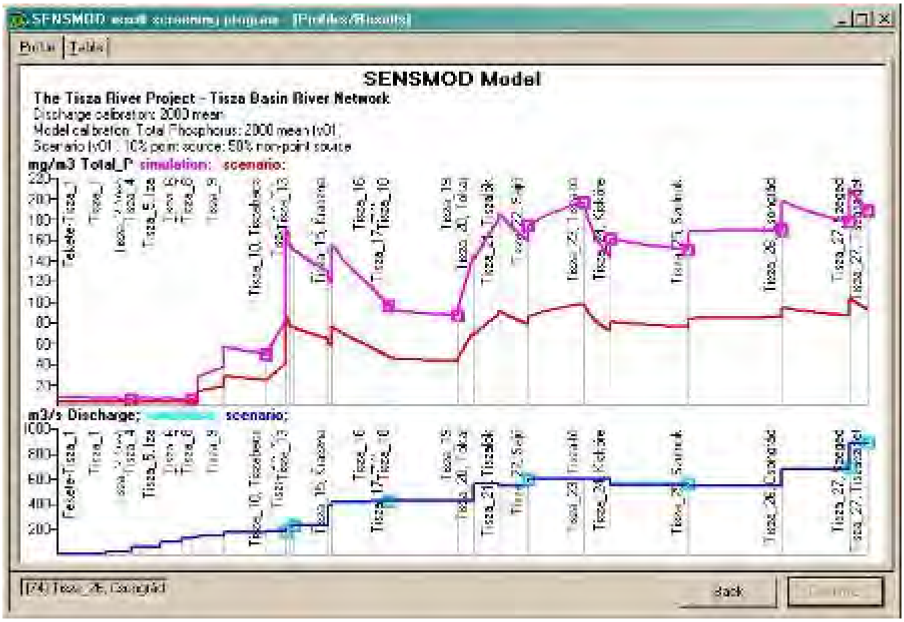

Figure 2 – Calibrated phosphorus and flow profile of the River Tisza from the junction of the Black and White Tisza (in Ukraine) to Tiszasziget (in Hungary), for the mean flow and load conditions of the year 2000, showing also the most optimistic full clean-up scenario

The result of this full phosphorus clean up would still leave the major part of the basin in eutrophic conditions, but hypertrophy will be successfully avoided.

The final step of this ecohydrological modelling exercise was the forecasting of the effect of pollution clean-up strategies on the ecological conditions of the flood-plain wetlands. Figure 3 shows the results of the simulation of the chlorophyll-a concentration of the Lake Mártély, an important oxbow lake of the Hungarian lower Tisza floodplain, used mainly for recreation and fishery. Several ecohydrological models developed by the authors (Jolánkai & Bíró, 2001) were tested and a relatively simple phosphorus-water-biomass budget model was selected. This model was equipped with rather sophisticated hydrological component for simulating flood-time inflows and nutrient inputs from the River Tisza, and was re-named EcohydSim. Simulated chlorophyll-a mean and maximum concentrations (green lines in the lower part of the figure) indicated a substantial improvement from the observed values, although maximum concentrations would still run up to 75-80 mg/m^3, a eutrophic value. Nevertheless, in comparison to the hypertrophic conditions presently experienced, this would be a valuable step-forward in preserving this wetland.

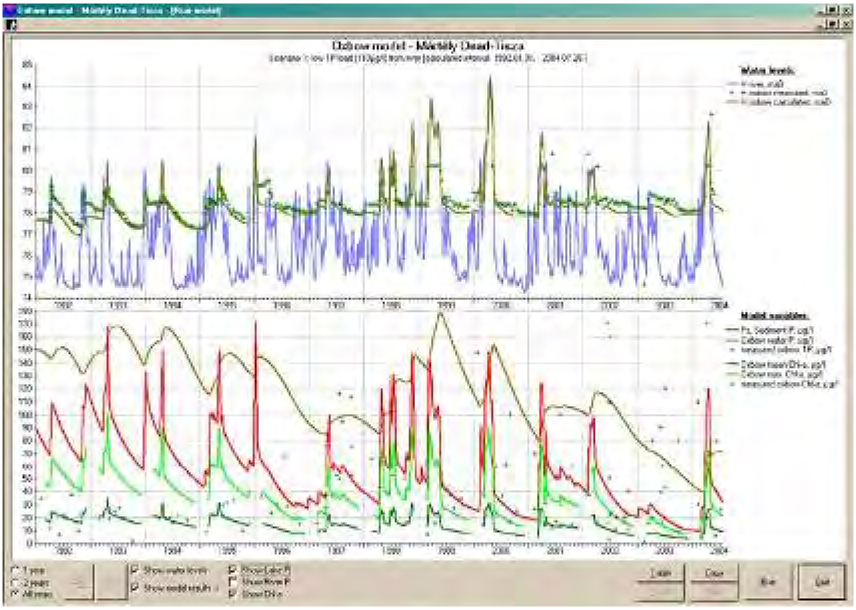

Figure 3 – Simulation results of Mártély Oxbow Lake with model EcohydSim for the maximum possible cleanup strategy of phosphorus loads over the whole Tisza River Basin

We also analysed several other possible revitalisation strategies, among them the dredging of phosphorus-rich sediments. It was found that no local strategies alone could help on the long run. For example, the build up of P-rich sediments would occur within a few years due to the high input of P loads.

The final conclusion was that only an all-basin international cleanup strategy could be efficient, which requires first to identify and monitor all sources of pollution. Next, a careful cleanup strategy must be defined for point and non-point sources, and this would require the upgrading and annual maintenance of the catchment model system that was developed during the project. This complete ecohydrological revitalisation strategy also means an integrated catchment management approach with multiple objectives, including pollution and flood control, recreation and fishery enhancement, etc.

3. WETLAND STUDIES OF THE "LIFE-SZIGETKÖZ" PROJECT

Szigetköz (Inter-island in a free translation) is an inland delta of braided river arms and lakes of the Danube River, located at the common Hungarian/Slovak border, formed by the river channel (Fig. 4).

Figure 4 - Location of Szigetköz, with the sampling sites of the VITUKI team and the aerial view of Dunakiliti dam and the bottom sill (green arrow), built to enhance flow supplementation

The main objective of the LIFE SZIGETKÖZ Project (LIFE04ENV/H/000382) was the implementation of an innovative decision-support tool for sustainable water and land-use management and planning of flow supplementation of the Hungarian-Slovakian transboundary Danube wetland area. The main focus of revitalisation plans was the provision of supplementary flows and the increase of water depths for the river arms and wetland lakes that were practically left dry after the diversion of the River Danube to the hydropower station of Bős/Gabcikovo (Slovakia) in 1992. The very brief explanation of why the river was diverted without practically any ecological or water management counter measures was the following: the flag of the Hungarian environmentalists opposing the Project Bős-Gabcikovo-Nagymaros-Hydropower-Sytem (BGNHS) was used, with a vitally important success, as the main flag of the anti-Soviet movements leading the Hungarian nation (and later whole Eastern Europe) to freedom. An auxiliary consequence of this globally deterministic and nationally vital (but at the same time unprofessional with regard to water and environment) political-environmental movement, was the single-sided termination by the Hungarian partner of the international treaty on the construction of BGNHS. Unfortunately, however, this action also meant that the possible worst solution for Hungary was implemented, when the Slovak partner constructed the dam unilaterally on its own territory (called the “Variant C”). It was the worst solution for Hungary from the viewpoint of both the environment and of the economy, resulting in catastrophic impact on the aquatic and terrestrial ecosystems of the braided river system of Szigetköz, one of the last remnants of the once vast floodplain ecosystems of Europe. Successful remedial strategies were implemented by Partner 2 of the Project, the local water authority ÉDUKÖVIZIG, after some very unfortunate trials, forced upon them by non-professional green activists in power. The successful strategy consisted of a bottom dike (a sill) built at the Dunakiliti dam (see Figure 4) and a series of adjoining closure and diversion structures. The resulting improvement of the ecosystem conditions, was fast and very effective, with the optimal utilization of the marginal river discharge released from Slovakia to the old Danube channel used to increase water depths and to supplement flows.

Main activities of VITUKI within the Project were focused at Task 3 ‘Assessment of the State of the Water-Environment in the Szigetköz and evaluation of former and currently planned water-environmental management strategies and interventions’. First our team carried out a detailed sampling program at 35-50 sampling points of this water system, in order to assess the success of earlier flow supplementing revitalisation efforts to supplement flow. We demonstrated with a wide range of data that in addition to the fast and general upgrading of the wetlands of the Upper Szigetköz, the remedial strategies much enhanced the status of some of the communities (macroinvertebrates and fish), while others responded less favourably (phyto- and zooplankton). We also concluded that with the proper governing of water levels and flows, and with further engineering means it could be possible to create conditions that will provide different habitats (both for limnophylic and reophylic species). Nevertheless, we also found that due to the still high nutrient concentrations (TP_{mean}>100 mg/m^3) of the in-flowing Danube water, the danger of eutrophication (hypertrophication) still exists, and the occasionally measured low dissolved oxygen levels also indicate this (DO frequently lower than 4 mg/l).

Next, we assessed with modelling and field studies the likely outcome of the new revitalising canal system of the Lower Szigetköz, i.e. the Parlagnyilas canal opened during the Project as demonstrative part of the program. We forecasted the improvement of the system but warned about the danger of hypertrophication due to the still high nutrient input. Field studies carried out later showed that our forecast was correct and the system had improved into very diverse aquatic ecosystem, but still very low and very high oxygen concentrations mark the existing danger of high level eutrophication (Fig. 5). The pictures below show the improvement at the downstream end of the water supplementation system of Lower Szigetköz, the canal Szavai at Kisbajcs *before and after the flow supplementation*. The flow supplementation turned a dying weed-covered canal into a biologically diverse one (although still in danger of becoming a macrophyte-monoculture).

Photo 1 - Canal Szavai, the lower end of the water supplementation system, before and after starting the release of additional flows to Lower Szigetköz

The repeatedly very low oxygen values (near to 1.00 mg/l) recorded in the summer period June-August mark an already highly vulnerable ecological status. If we add to this that samples are always taken in daytime the picture becomes more worrisome.

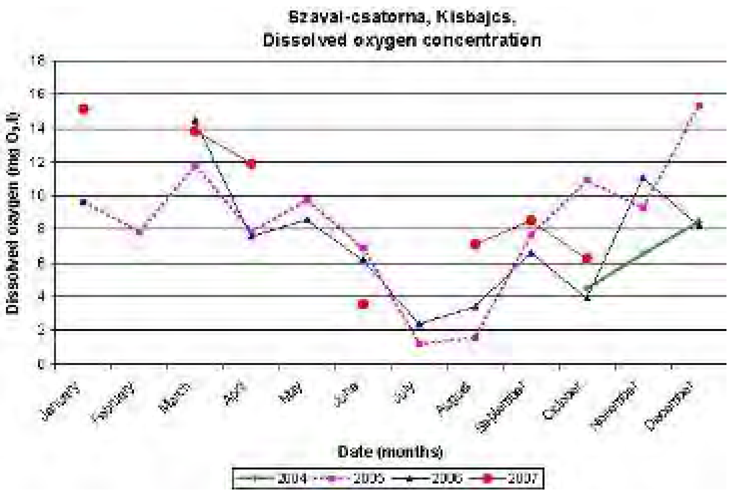

Figure 5 – Measured oxygen concentrations at the end of the new water supplementation system of Lower Szigetköz

We have investigated feasible solutions to this improved but still vulnerable state and found that, apart from the evident whole Danube basin nutrients cleanup, the local solution is the ecohydrological one. Namely, to improve the situation one would need more water and fewer nutrients. Consequently an ecohydrological solution presents itself: to store water in flood release periods and to clean up the nutrients it contains by existing and/or artificial wetlands. In Figure 6 a potential site for such an ecohydrological reservoir is shown for the Lower Szigetköz, near the town Ásványráró, where additional water could be released from the flood-plain side (green arrow) to the newly opened water system (Szavai Canal) and stored and cleaned-up in a reservoir.

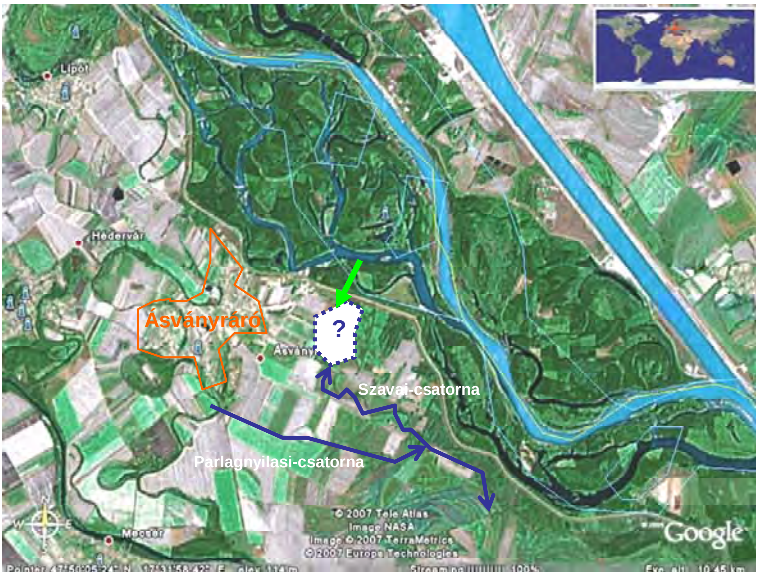

Figure 6 - Space-view of a potential site for an ecohydrological reservoir that could moderate flows and nutrients in the new water supplementation system of Lower Szigetköz

We have also analysed the potential effect of such an ecohydrological reservoir with the model discussed in the previous section and found that roughly up to 30% of the phosphorus could be retained and in dry periods a 20-30 % increase of flow could be provided for considerable time. This strategy would thus be sufficient for improving re-aeration and for rising dissolved oxygen levels. Nevertheless, the final selection of a site is subject to several technical, legal, administrative, financial etc. considerations to be made during the follow up activities of this project.

Summarising: The catastrophic ecological conditions created by the diversion of Danube in Szigetköz have been successfully mitigated by the hydraulic structures and flow governing strategies applied by the water engineers of the local water authority. Similarly successful was the flow supplementation strategy of Lower Szigetköz launched during this project. Nevertheless it became also apparent that different flow conditions are needed by the different elements of the diverse biota of this region and controlling of the nutrients is also needed to reduce the danger of eutrophication. The latter could be done by ecohydrological strategies, making use of both the flow control and nutrient reduction capabilities of existing and potentially built new wetlands, i.e. ecohydrological reservoirs.

4. CONCLUSIONS

Based on six years of detailed field studies of the Hungarian floodplain wetlands of the rivers Danube and Tisza, associated with extensive ecosystem and catchment model studies the following conclusions for the upgrading and revitalising of these vulnerable ecosystems can be drawn: (a) No local strategy alone can lead to the appropriate protection against eutrophication of these wetlands and whole-basin, international cleanup action is needed. (b) Local ecohydrological strategies, that is the joint governing of flows and nutrients by the existing and man-made wetlands could substantially contribute to the improvement of the ecological conditions. (c) Much more detailed monitoring of the hydroecological status of these unique wetlands is needed in order to be able to govern water and mass fluxes in the way needed for improvement. (d) Basin-wide identification of all point- and non-point sources of nutrients is needed in conjunction with the continuous upgrading and maintenance (i.e., recalibration and verification) of the catchment models of the river basins.

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4th ECRR Conference on River Restoration
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RIVER RESTORATION INTEGRATED ACTIONS TO REDUCE RIVER ZERO NITRATE INPUT TO VENICE LAGOON

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ABSTRACT

The contamination of surface and ground water by nitrates is still one of the major factors determining the ready-to-use water resources available within Europe, despite the Directive 676 of 1991. Since there appears to be an urgent requirement for action to control nitrate concentration in freshwaters, there is a need to utilize existing knowledge in the development of management strategies to reduce the risk of such pollution impacts on the environment.

The Consorzio di Bonifica Dese Sile is located within the pumped drainage landscape of the Venice Lagoon. The Consorzio was involved in a big project aimed at developing a catchment strategy to reduce nutrient loads entering the Venice Lagoon from its rivers. To achieve this goal, the Consorzio planned a major river restoration project for the Zero River, which drains into the lagoon.

The main restoration actions carried out regarded: banks widening, increase of aquatic vegetation on river terraces, creation of lateral and inflow wetlands (ponds and lakes) and creation of a wooded riparian area irrigated by the river water.

Within this project a pilot experimental system was built along the Zero River, to evaluate in particular the buffering efficiency of the wooded areas on non-point pollution sources of nitrogen.

The results of this study provided interesting suggestions for improving the management of buffer zones.

Key words: Zero River, Nitrogen reduction, buffer zone, non point pollution

1. INTRODUCTION

Venice Lagoon is a wide, shallow coastal basin extending for about 50 km along the north-western coast of the Adriatic Sea. The lagoon has been substantially modified by human activities over the last century through the artificial control of the hydraulic dynamics of the lagoon, including the construction of channels to facilitate navigation.

Over the past decades nutrient loads delivered to the Venice Lagoon have attracted considerable concern. The local government (Regional Authority) established in 1995 a series of targets to reduce the level of nitrogen and phosphorus entering the Lagoon. The targets were set to establish eutrophication protection measures as well as to improve the overall quality of the water entering the lagoon.

The Dese Sile Consortium, that manages three key-rivers which contribute 40% of the freshwater flowing into the Lagoon, was involved in a large project aimed at developing a catchment-scale strategy to reduce nutrient loads into the Lagoon. In particular, for two of the main rives managed by the Dese Sile Consortium (which developed the project) Dese and Zero (tributary to the former) rivers, the following values of nutrient loads reduction were established:

CATCHMENT	Ntot reduction (Tons/Year)	Ptot reduction (tons/year)
Dese and Zero rivers	150	40

The value of 150 tons/year of Ntot represents a reduction of 12% of the total loads of the Zero and Dese rivers (1271.4 tons/year), whereas for Ptot a reduction of 17% (229.1 tons/year) is the target.
To achieve these results, the Consortium planned a major river restoration project for the Zero River.

Figure 1 – The area managed by Consorzio di Bonifica Dese Sile and the section of the Zero River interested by the restoration project

2. THE PROJECT

The last 11 km of the river Zero (Fig. 1), before it flows into the river Dese, was scheduled to be re-engineered as part of the long-term flood defence works along the Zero. Since this work was planned, the Consortium saw this as an opportunity to develop a new channel section that could increase the ecological value of the river as well as increase the nutrient retention capacity of the riverine environment.

In order to reach the project aims, the Consorzio di Bonifica Dese Sile identified a series of natural key habitats (Fig. 2) to create or to restore:

2.1 Freshwater lake "Lago Pojan"

This is a riverine lake, with the same function of an instream wetland, with an approximate surface of 2 ha, and 4 m depth.

2.2 Freshwater pond at the gate "Nodo Carmason"

One of the objectives of the project was to reduce the length of saline water intrusion within the Zero river thus increasing instream nitrogen removal capacity. To achieve this goal, a gate was built 3.2 km upstream from the confluence of the Zero and Dese rivers. The height of the gate can be regulated in order to prevent tidal water to flow upstream, but at the same time to permit the discharge of freshwater to the tidal section of the river. The final effect of the gate is the creation of a 6.7 km long section of freshwater that behaves like a pond characterized by near static water height and slow-moving water from the majority of the time.

2.3 wetland next the tidal gate

It is a small wetland created next the "Nodo Carmason" tidal gate. The wetland consists of a sedimentation pool followed by 0.7 ha of Phragmites thicket. This system receives the river low flows and acts as small but significant filter for freshwater before it passes into the tidal section.

2.4 Terrace in freshwater section

Within the freshwater section of the Lower River Zero, the proposal was to let *Phragmites* grow spontaneously thicket of 1.5 m minimum width to limit bank erosion and to facilitate nutrient retention.

2.6 A series of rainwater- and groundwater-fed shallow lakes, called "Cave Cavalli"

Created in an area previously used for the extraction of clay. The lakes are 1-4 meters deep, with a water surface of over 30 ha. Some of the River Zero water passes through the quarry and utilises the potential nutrient retention capacity of the lakes.

2.7 Riparian woodland

A cultivated area of about 30 ha was converted in a forested buffer strip, irrigated with freshwater from the Zero river, so that the wet woodland could operate similarly to a natural riparian woodlands (see also paragraph 4.1).

Figure 2 - location of the key habitat: 1) the riverine lake "Lago Pojan"; 2) freshwater pond with the gate "Nodo Carmason"; 3) Terrace in freshwater section 4) a series of rainwater- and groundwater- fed shallow lakes, called "Cave Cavalli"; 5) wetland next the tidal gate 6) riparian woodland.

3. MODELED EFFECTS IN TERM OF NUTRIENT REDUCTION

In order to allow estimating the nutrient retention capacity of different geometries and hydrodynamic conditions of the buffer key habitats, the nutrients mass balance was investigated for each habitat (research conducted by Quest Environmental) with the commercial numerical model STELLATM 5.0, which has been tested and widely used in this kind of investigation (Haycock, unpublished data).

As regards nitrogen, the mean value of N-NO_3 introduced in the system (obtained from several simulations conducted for years with different meteorological conditions) was 187 tons/year with total reduction ability for the entire system restored of 31.7 tons/year (17%) (Haycock, 1997).

According to the model, the most efficient buffer system is represented by a 60 ha forested buffer strip (30 ha of which have been developed so far) which should remove 18.6 tons/year of N-NO3 (59% of the total reduction). Total reduction of Ntot (NO3-N+TKN) is estimated in 44.17 tons/year, i.e. 22% more than the amount of Ntot introduced into the system (Haycock, 1997). Therefore, even for Ntot the most efficient buffer system is represented by the forested buffer strip with an estimated reduction of 30 tons/year of Ntot. Values obtained from modeling are, at least for forested buffer strips, overestimated compared to those measured during the monitoring campaign conducted in the years following the model implementation (see paragraph 4.3), which assessed a real reduction ability (for 15 m wide buffer strips) of about 75 Kg/ha of $N\text{-}NO_3$ and thus (for the 30 ha of strip developed so far) of 2.25 tons/year of $N\text{-}NO_3$ removed instead of the 9.3 tons/year (for 30 ha) forecasted by the model. As shown by experimentation, the "potential" buffer ability of these areas (with higher nitrogen loads) is definitely higher: the initial overestimate given by the model is mainly due to the partial reduction of the irrigation volumes which flow through the system, and to a lower concentration of nitrogen in the water of Zero River than the one forecasted initially.

4. EFFICIENCY OF RIPARIAN FOREST BUFFER STRIPS IN REDUCING NITROGEN LOAD: MONITORING AND EXPERIMENTATION

The monitoring activity of one of the key habitats restored, i.e. the forested buffer strip, was also included in the Zero river restoration project. The scopes of the monitoring (carried out from 1999 to 2005) of the experimental site, were:

a. to increase knowledge on the processes which allow the riparian forest to act as buffers strips and thus reduce the concentration of the main nitrogen compounds which are carried by the water flow running through them;
b. quantify the amount of the reduction in nitrogen load, and the trend of the reduction during the maturation phase of the riparian forest system;
c. identify the most appropriate management strategies of the buffer strips and water flow in order to choose those typologies, planting techniques and maintenance operations which would maximize the efficiency of the buffer systems.

4.1 The structure of the experimental site

The experimental site is a part of the 30 ha wide forested buffer strip. It was built in 1999 on an area previously used for arable crops and it covers a total area of around 0.85 ha, divided in three plots structures as follows:

Plots A and B (0.35 ha each) (Fig. 3) : two adjacent plots, symmetrical with respect to a draining ditch which divides them, each one 15 m large and about 200 m long. One-thousand forested saplings of trees and shrubs were planted in each plot 4 (tree rows each).

Plot C (0.15 ha): similar to the previous ones and adjacent to plot B, but only 5 m large and with only one row of trees.

The structure of the experimental field is characterized by ridges and furrows facilitating sub-superficial water flow throughout the entire field from the inlet point, represented by water pumped through the ridges to the parallel network of furrows localized at lower elevation (Fig. 3). Quality of incoming water is checked with a conductivity-meter and an automatic sampler.

The monitoring station has 3 “5 m x 3 m” grids of piezometers, for a total of 36 piezometers which are used to measure the sub-superficial water level, and to collect water samples. Analyses carried out before starting to monitor allowed classifying the soils texture category as “silty clay loam” (USDA classification "Soil Survey"), characterized by horizontal and vertical homogeneity until a calcareous layer at around 80 cm depth. A total volume of about 50.000 m^3/ha/y of water was pumped into the experimental site in 1999-2003. After 2003, due to widening of the buffer strip to a surface of about 30 hectares, irrigation volumes were reduced by 55%.

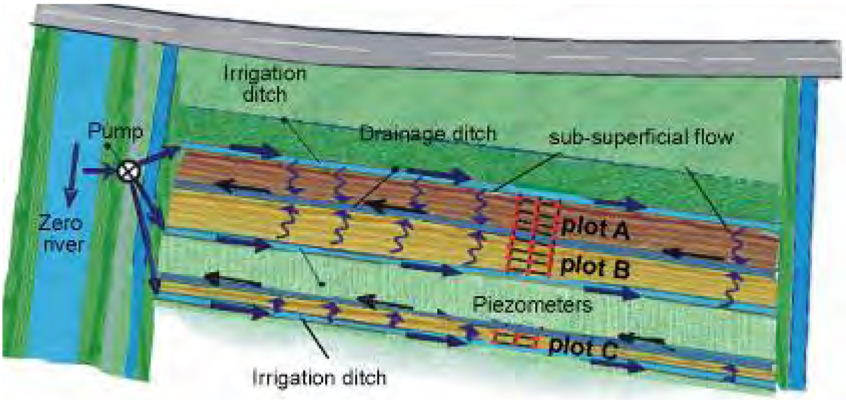


Figure 3 - Plan of the experimental site: each of the 3 strips is watered through an irrigation ditch carrying water from the Zero river. Soil setting allows having a difference in elevation among the irrigation ditches and the drainage ditches, resulting in a sub-superficial flow of water running through the entire buffer strips.

4.2 Monitoring plane

Monitoring was carried out monthly in October 1999-Octobre 2002; a subset of measurement aimed to evaluate the main parameters after changes in the sites structure occurred were taken in October 2003, October 2004, May and July 2005.

The monitoring plan, followed the Europen Recearch Project NICOLAS (DGXII: ENV4-CT97-039), consisted of the measurement of the following parameters:

Meteorological: daily recording of air temperature, rainfall, relative humidity, sun radiation, wind speed and velocity, and soil temperature.

Hydrological: measurements of sub-superficial water flow were taken continuously at the beginning of the monitoring plan, and monthly (using phreatimeters) later on; measurements of volume of irrigation water introduced were taken continuously.

Water quality: daily water sampling (using an automatic sampler) of Zero river; monthly sampling of water from piezometers and from irrigation and drainage ditches. The parameters measured in water samples were: pH, temperature, electrical conductivity, all different nitrogen forms, organic carbon, dissolved total phosphorus, orthophosphate and chloride (used as a biologically inert tracer to monitor dilution and dispersion).

Soil quality: besides the initial pedological analysis (texture, permeability...), seasonal soil samples were collected from plots A and B according to the following protocol: for each plot and for each of the three zones (distal [1], median [2], and proximal [3] to the draining ditch) 3 areas of 1 m^2 each (replicates) were selected (Fig. 4). For each station, zone, and replicate, soil samples were collected at three different depths (0-20 cm; 35-60 cm; 80-100 cm). Soil samples were analysed for the following parameters: humidity, texture, $N\text{-}NH_4$, $N\text{-}NO_3$, $N\text{-}NO_2$, DON, Ntot, nitrogen immobilized/bacterial, organic matter, organic carbon, mineralization rate.

Denitrification: the same soil samples described above were analysed for the following parameters:

- *in situ* denitrification rate (DNT), which measures the real denitrification process under way;
- denitrification enzymatic activity (DEA), which measures the potential ability of bacterial communities present in the soil sample to denitrify if they anoxic conditions occur and if a non-limiting amount of nitric nitrogen or/and carbon are added.

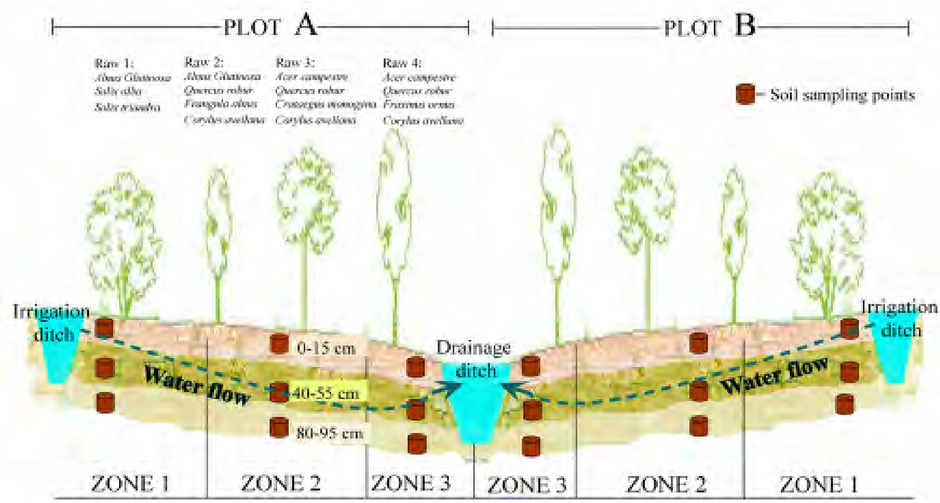
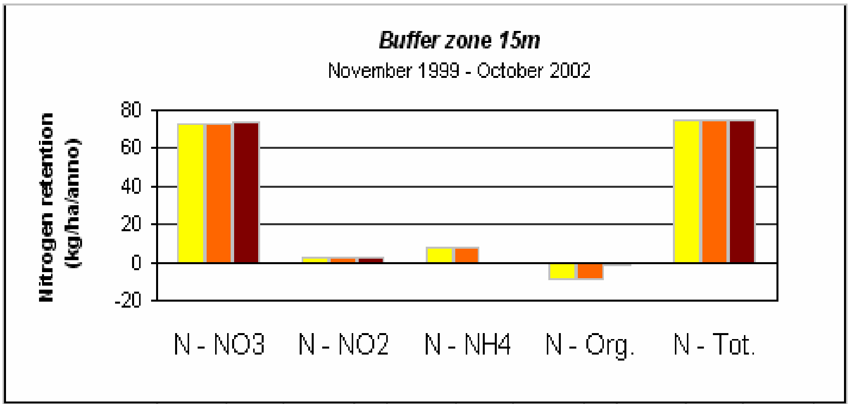


Figure 4 - Experimental site: each of the 3 strips is watered through an irrigation ditch carrying water from the Zero river. Soil setting allows having a difference in elevation among the irrigation ditches and the drainage ditches, resulting in a sub-superficial flow of water running through the entire buffer strips.

4.3 Results

Water quality: as regards the different nitrogen compounds, the nitrates retention capacity increased strongly from about 40 to 85% from the first to the third year, at both site FT15 and FT5 (Fig.5). Ammonia on the other hand had a higher annual variability, with the output sometimes exceeding the input but with the trend of reaching, on the third year in both sites, output values corresponding to input levels. Organic nitrogen output was always higher than the input, but with a progressive reduction of the output, decreasing from the first to the third year. Overall, total nitrogen retention increased from 23-28% in the first year to 61-63% in the third year (Gumiero et al. 2008).



	RITENZIONE 1° year			RITENZIONE 2° year			RITENZIONE 3° year		
N - NO_3	41,6	kg/ha	**39%**	72,7	kg/ha	**86%**	73,6	kg/ha	**86%**
N - NO_2	1,5	kg/ha	**76%**	2,3	kg/ha	**88%**	2,2	kg/ha	**87%**
N - NH_4	5,1	kg/ha	**35%**	7,9	kg/ha	**42%**	0,0	kg/ha	**0%**
N - Org.	-17,0	kg/ha	**-152%**	-8,4	kg/ha	**-87%**	-1,3	kg/ha	**-11%**
N - Tot.	**31,2**	**kg/ha**	**23%**	**74,5**	**kg/ha**	**64%**	**74,4**	**kg/ha**	**63%**

Figure 5 - Graph represent the nitrogen kg/ha/y (as total, and as each compound) removed from the 15m buffer strips in the three sampling years. Removal percentages are presented as well; they show a net increase in removal during the 2^{nd} and 3^{rd} sampling year.

***In situ* denitrification (DNT):** the average annual value (based on seasonal data) of denitrification rates measured in the two plots reached 0.31 µgN g-1 soil-1 in 2000, 0.15 µgN g-1 soil gg-1 in 2001, and 0.53 µgN g-1 soil gg-1 in 2002. The average value recorded for 2005 was only 0.07 µgN g-1. In both plots and in all the sampling years, the highest values were recorded in the intermediate layer (40-60 cm depth) which was always saturated by irrigation water. The upper level, which usually in natural buffer strips has the highest denitrification rates, in this case had more limited activity because it was saturated occasionally, following natural events (rainfall, aquifer level oscillation). The decrease in denitrification rate recorded for the second sampling year was due to the reduced nitrogen availability caused by the strong increase of vegetation uptake.
Denitrification processes showed a clear seasonality, with high rates recorded in summer and autumn, and lower rates in winter and spring.
If we take into account only the 20 cm of intermediate layer, and a soil density of 1200 Kg/m3, denitrification rates reached values of 258 kgN/ha/y in 2000, 113 kgN/ha/y in 2001 and 391 kgN/ha/y in 2002. These data

underline the significant contribution of the denitrification process to the global nitrogen removal (Gumiero et al., 2008; Gumiero et al., in press).
In 2005, the average abatement rate was only 54 kgN/ha/y, to confirm how the process depends on the irrigation flow; in fact during that year the inflow discharge, and the dissolved nitrogen input, were reduced to 55% of the values of the first 3 years.

Denitrification enzymatic activity - DEA: measurements of denitrification enzymatic activity show the potential denitrification of soil in absence of limiting factors: the same soil samples where the *in situ* denitrification was measured, were incubated in saturation conditions (DEA), in saturation with the addition of nitrates (DEA+N), in saturation with the addition of carbon (DEA+C), in saturation with the addition of nitrates and carbon (DEA+N+C). Denitrification values in saturation conditions, but without nitrogen and carbon addition (DEA) were not higher than in situ denitrification values (DNT); this result showed clearly that without the addition of further nitrate and/or without an increase in organic carbon, the denitrification capacity of the buffer strip remains constant. On the other hand DEA+C or DEA+N caused an increase in the denitrification rate which becomes 2-3 times higher. The most striking information was given by saturation condition and non-limiting amounts of both carbon and nitrogen (DEA+C+N): the corresponding denitrification rates became 5-7 times higher.

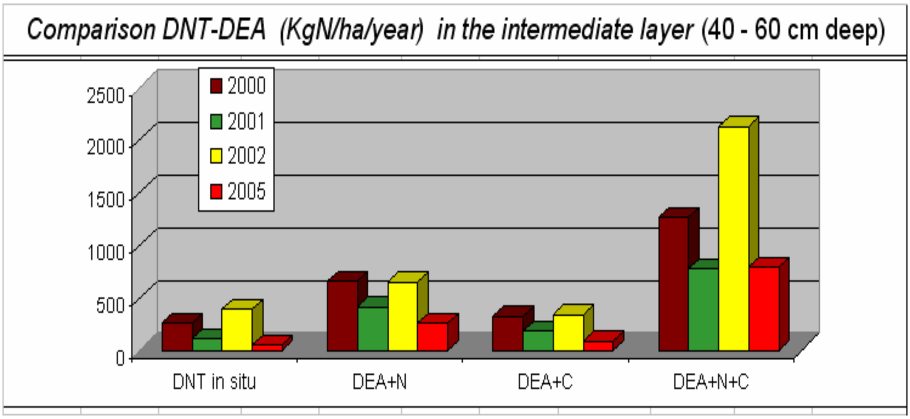


Figure 6 - Graph comparing the annual denitrification rates (Kg/ha/anno) measured in 2000-2005 and the potential denitrification rates (if C and N are not limiting factors), calculated for the same soil samples.

4.4 Conclusions of the monitoring activity

- Young forested buffer strips, two years after implanting (4-5 years old plants), reduced the total dissolved nitrogen load which run through them by sub-superficial flow more than 60%, to a maximum value of 168 kg/ha/y (the surface unit refers to the width of the buffer strip) (Gumiero et al. 2008);
- significant differences in percentage nitrogen retention between the buffer strips 15 m wide and those 5 m wide: narrower strips, with one row of plants, were more efficient than those with multiple rows (same nitrogen reduction but less surface required);
- an increase in the retention time of nitric nitrogen ($N\text{-}NO_3$) was recorded for both 15 m large buffer strips and 5 m large ones, with reduction of 39-43 % one year after planting the buffer strips, to 84-86 % after three years;
- denitrification processes can contribute significantly to total nitrogen reduction (average annual rates 100-300kgN/ha/y);
- measurements of potential denitrification, taken in soils without limiting factors (nitrogen and carbon), showed a strong potential increase in denitrification rates (up to 2000 kgN/ha/y) (Haycock et al., 2005;Gumiero et al., 2008; Gumiero et al., in press).

5. CONCLUSIONS

The river restoration, as in the case of Zero river, can be a very important way to reduce nutrient input to other “sensitive” ecosystems like lakes, lagoons or seas. In the same time, this project demonstrates that it can also contribute to reach other important objectives, such as:

- reduction of hydraulic risk, as a consequence of the widening of sections of the river;
- improvement of the nature value, due to the high naturality of the restored habitats, which have became important humid ecosystems;
- improvement of the multiple uses of banks and adjacent areas and of their landscape value.

ACKNOWLEDGEMENTS

Paolo Cornelio, Raffaella Scaggiante, Federico Fontana and all the Institutes and Authorities involved in the projects: A.R.P.A.V., Haycock Associates St. Albans UK, Bologna University - Department of Evolutionary and Experimental Biology, Padova University - Department of Agricultural Biotechnology, Veneto Agricoltura - Sector for Forestry Research and Experimentation

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CHAPTER 10

Session 8B

Ecohydrology: environmental flow/hydropower

Chairpersons

B. MAIOLINI, G. ZOLEZZI

Introduction
ECOHYDROLOGY: ENVIRONMENTAL FLOW/HYDROPOWER

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Flow regime is considered a primary driving force of riverine communities and processes and five major components are commonly identified: extreme low flows, low flows, high flow pulses, small floods, and large floods.
Most of these components have been modified world wide by human activities and today few river systems befit from a natural flow regime. In Europe such alterations mainly regard interventions in mountain headwaters, through the construction of dams, abstraction pipelines and reservoirs. The most relevant use of these artificial systems is for hydropower use, especially in the Alps, where high precipitation and steep slopes are perfect pre-conditions for hydropower generation. It is also a free domestic energy production that reduces CO^2 releases in the atmosphere, a very important economic factor at regional scale, it offers a quick response to energy demand and finally can be, via pump storage, an ideal partner for excess energy production from other sources as wind, solar, oil, coal and nuclear plants that can not be regulated to follow energy request peaks.
Furthermore, hydropower is strategic to meet EU obligations to Kioto targets and EU energy targets (20% renewables, 20 % increase in energy efficiency, 20% cut in green house gases by 2020) and finally to promote independence from imports.
But traditional hydropower production schemes have severe impacts on freshwater ecosystems and related benefits and goods, which have considerable environmental, social and economic relevance.
These pros and cons represent a challenge for the future, in particular for a proper implementation of the Alpine Convention protocols (Energy and other) and of the EU WFD 2000/60 EC.
As regards River Restoration, the expected ecosystem benefits and services from planned projects may be severely reduced by the overwhelming effects of altered flow and temperature regimes due to hydropeaking and other phases of hydropower production.

For all this, restoration science should also focus on the impacts of hydropower production in order to maintain and possibly increase production while meeting ecological demands.
Finally holistic ecohydrological and basin based approaches are considered paramount in the planning of river restoration projects.

The session hosted six oral presentations and ten posters and six papers were presented for publication.

Several contributions focused on modelling of different aspects of flow or associated parameters as temperature and solid transport. Analyses of long term flow data was also presented by different authors, in the aim of assessing changes of flow regimes before and after disturbances as dam construction and hydropower generation. Longitudinal interruption of rivers was particularly studied for fish migration.

The general outcome from the presentation was rather broad, and links between hydrology and ecology appear to become more and more diffused.

4th ECRR Conference on River Restoration
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USING A TWO DIMENSIONAL APPROACH TO EVALUATE CHANNEL REHABILITATION IN A MEDITERRANEAN STREAM (SOUTHERN PORTUGAL)

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ABSTRACT

Concern about ecological, social and economic losses caused by stream degradation has recently stimulated major conservation and managements efforts worldwide. In Mediterranean rivers, the problem is exacerbated by the higher demand for freshwater. A rehabilitation program was undertaken in a Mediterranean river segment affected by intensive agriculture, unstable banks and degradation of the riparian gallery. Moreover, it will be further impacted by a water supply dam, which is presently under construction. To assess potential habitat enhancement for the different life stages of two critically endangered cyprinid species – the Iberian nase *Iberochondrostoma almacai* and the Iberian chub *Squalius aradensis* – five different restoration scenarios were considered, simulated and compared with the unmodified segment (control), in terms of Weighted Usable Area (WUA), by means of a two dimensional hydraulic model, the River2D. Results showed that habitat improvement was best achieved for both species life-stages, when considering the introduction of islands in the middle of the channel (mean % increase of WUA: nase, 37.7%; chub, 39.6%). The introduction of lateral bays was found to be beneficial for nase (mean % increase of WUA *c*. 2.7%) but not for chub where a decrease in the mean amount of area suitable for habitat, *c*. 3.6%, was noted. The other restoration scenarios, particularly the meandering of the river channel with a submerged weir or with islands in the middle of the channel, revealed a considerable decrease in the WUA for all species life-stages, especially for nase. The results of this study could be useful elsewhere, particularly in other Mediterranean-type rivers where fish species conservation and management are a priority.

Key words: rehabilitation, Mediterranean stream, River2D, nase, chub, WUA

1. INTRODUCTION

River restoration tests the possibility of recreating complex ecosystems, based on simpler and degraded streams, which is a great ecological challenge (Woolsey et al., 2007). Restoration projects have become a powerful tool in river conservation (Smith et al., 2002; Lacey and Millar, 2004; Wheaton et al., 2004; Woolsey et al., 2007). These projects aimed to restore the ecological conditions of natural rivers, create upstream and downstream fish passes, implement instream flows, improve longitudinal and lateral connectivity, and protect habitat and ecosystem (Katopodis, 2006; Brunke et al., 2001). Introducing habitat structures in the stream may restore an impacted river, allowing fish to meet their biological requirements.

The amount of fish habitat that these structures provide can be assessed with computer modelling (Lacey and Millar, 2004; Pasternack et al., 2004). More effective fish habitat structures can be built by improving the tools used to assess habitat availability (Smith et al., 2002). Hydrodynamic models evaluate the influence of flow and morphology changes on biological diversity (Ghanem et al., 1996).

Two-dimensional models have recently been used to assess river habitat conditions since they accurately represent complex mosaics of depth and velocity distributions (Crowder and Diplas, 2000). They can predict habitat changes resulting from flow alterations and channel morphology (Lacey e Millar, 2004) and are, therefore, useful for river restoration projects (Ghanem et al., 1996; Crowder and Diplas, 2000; Waddle et al., 1996; Leclerc et al., 1995).

The goal of this study is to evaluate potential habitat improvement within a river segment of a Mediterranean-type river, the Odelouca River (SW Portugal), by simulating the establishment of five distinct stream habitat enhancement options, in a two-dimensional hydraulic model, the River2D (Steffler, 2000). This model is a depth-averaged 2D hydrodynamic and fish habitat model designed for use in natural streams. This model can accurately represent the usually complex flow of natural rivers. In every hydrodynamic solution, it shows the local velocity and depth along the stream. By combining this information with habitat suitability curves (HSC) developed for target species, the Iberian nase *Iberochondrostoma almacai* and Iberian chub *Squalius aradensis*, two critically endangered cyprinid species, the weighted usable area is computed. Restoration scenarios to be simulated include river meandering along with introduction of submerged weirs or small islands, placement of islands in the river channel and introduction of lateral bays and deflectors. Therefore, quantifying species habitat enhancement under different morphological scenarios is extremely important for an adequate strategy of species conservation and management and can have a wider application in other Mediterranean rivers.

2. MATERIAL AND METHODS

This study was conducted in the Odelouca river, the largest tributary (total length = 92 km) of the Arade basin (987 km^2). It is a medium-sized Mediterranean-type river located in the Algarve region of southwest Portugal. Geology includes schistose rocks in the upper parts, with alluvial deposits in the lower river reaches. The climate is typical Mediterranean, with more than 80% of the rainfall occurring from October to March and with virtually no flow from July to September.

A 250 m length study reach which best represented the river segment was selected in the lower part of the main river course, 4 km downstream from a partially constructed water-supply dam, which is scheduled to begin operating by 2010. Catchment area at the study site is 466 km^2 with a mean annual flow of 4.05 m^3/s. In this reach, the cross section range from 7 to 30 m wide, with a 0.0035 m/m slope.

The river bed topographic was surveyed with a combined association of a total station with a Global Position System, GPS. Overall, 4 129 spots were surveyed. Collected information included the X and Y coordinates, bed elevation and substrate composition according to a modified Wentworth scale (Bovee, 1986) [(1) organic cover; (2) silt (1-2 mm); (3) sand (2-5 mm); (4) gravel (5-25 mm); (5) pebble (25-50 mm); (6) cobble (50-150 mm); (7) boulder (>150 mm) and (8) bedrock]. To calibrate the model, a series of points were located along Y cross-sections where significant alterations in depth, water velocity, substrate composition and slope were noted. Depths were measured with a graduated stick. Water velocities were measured with a water flow probe (model FP101, Global Water Instrumentation, USA) at 60% of the distance from the surface to the riverbed (Bovee and Milhous, 1978). The bed roughness was registered from observations of bed material and bedform size to establish the effective roughness height.

Habitat suitability curves (HSC) had been previously developed for depth, water velocity and substrate according to the procedure outlined in Bovee (1986). The target species considered were the Iberian nase *Iberochondrostoma almacai* and Iberian chub *Squalius aradensis*, two critically endangered cyprinid species. HSC were determined for two size-classes 5-7, > 7 cm for nase and 4-6, > 6 cm for chub, roughly corresponding to life stages of juveniles and adults, respectively – in two periods – spring/summer and autumn/winter. Sampling was performed by means of electrofishing with low voltage to reduce the effect of positive galvanotaxis. A detailed description of the sampling procedure is given in Santos et al. (in press).

The amount of Weighted Usable Area (WUA = quantity of area suitable for habitat) was then computed to evaluate the performance of five potential habitat enhancement measures, relatively to the stream reach under unmodified conditions: (i) meandering of the river channel with submerged weirs (Fig. 1); (ii) meandering of the river channel with two islands in the mid-section of the channel (Fig. 2); (iii) introduction of three islands in the mid-section of the channel (Fig. 3); (iv) introduction of two lateral bays on opposite banks (Fig. 4); and (v) introduction of four alternate triangular deflectors (Fig. 5). These scenarios were designed with a CAD and GIS program and then exported to the River2D model. The WUA was calculated as the product of depth, velocity and substrate suitability indexes. The values of discharge used for the simulations varied between 0.1 and 8.0 m^3/s, which represent the range of the ecological flow regime to be released by the dam.

In order to quantify and compare the habitat improvement, considering the ecological flows to be released by the dam, the WUA was calculated for each month, as well as the increase and decrease of such habitat availability. The HSC Spring-Summer was used for discharges between October to March, and the HSC Autumn-Winter was used for discharges between April-September.

3. RESULTS AND DISCUSSION

The results for depth and for each habitat enhancement measures are display in Fig. 1, Fig. 2, Fig. 3, Fig. 4 and Fig. 5.

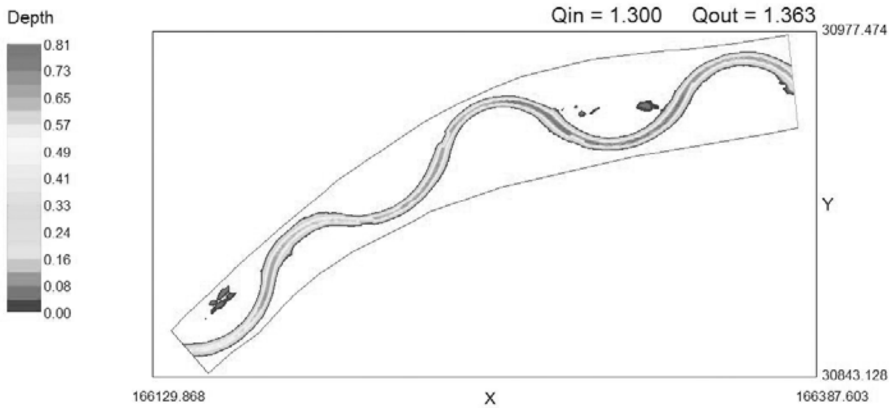

Figure 1 – Meandering of the river channel with submerged weirs. Flow depth for a discharge of 1.3 m^3/s.

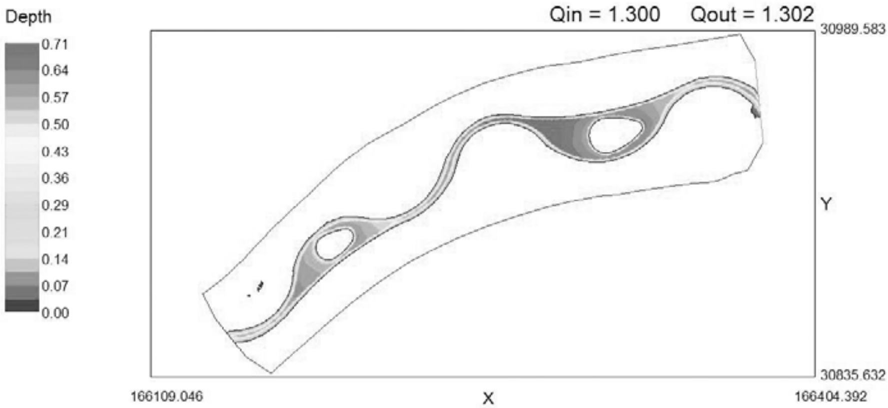

Figure 2 – Meandering of the river channel with islands in the centre of the channel. Flow depth for a discharge of 1.3 m^3/s.

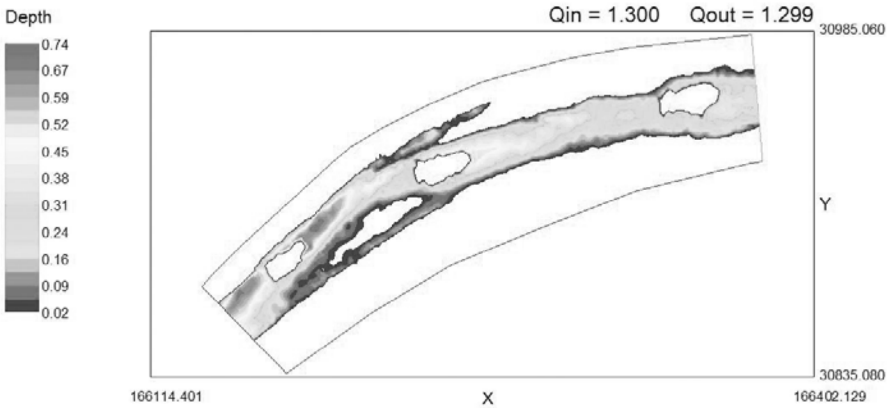

Figure 3 – Islands in the middle of the channel. Flow depth for a discharge of 1.3 m^3/s.

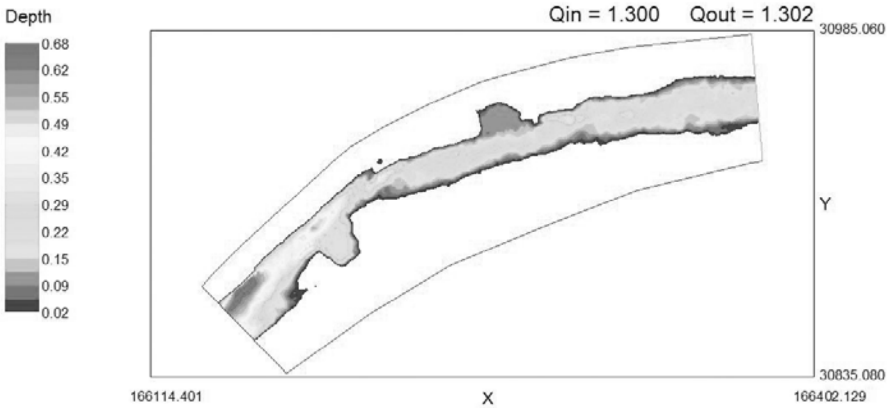

Figure 4 – Lateral bays. Flow depth for a discharge of 1.3 m3/s.

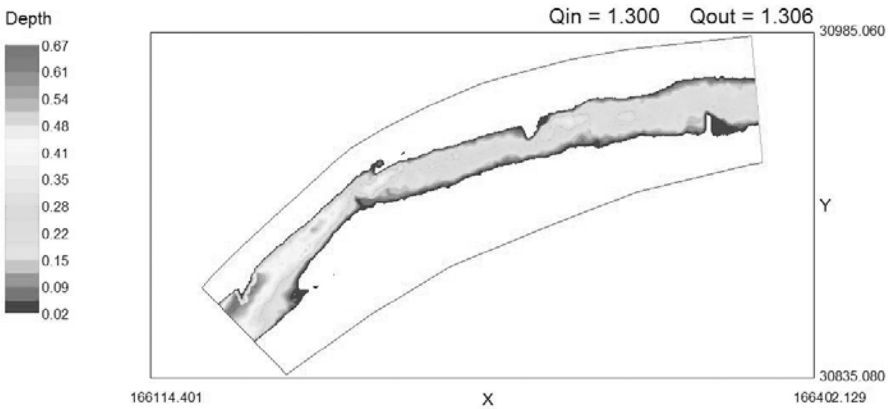

Figure 5 – Lateral deflectors. Flow depth for a discharge of 1.3 m^3/s.

Habitat simulations carried out on the five improvement measures under the ecological flow regime, produced distinct results relatively to the control conditions (Tab. 1). The introduction of three islands in the middle of the channel and of the two lateral bays were the only restoration scenarios that represented an effective habitat gain, particularly the former, with a mean monthly increase of WUA for both life stages of the target species. Although both adult and juvenile nase habitat experienced an improvement *c*. 2-3%, when introducing lateral bays, a concurrent decrease of WUA was found for chub (1.2% for adults and 6.1% for juveniles).

Table 1 – Mean monthly increase and decrease of WUA for target fish species (%).

Restoration scenarios	Nase		Chub	
	Adults	Juveniles	Adults	Juveniles
Meandering of the river channel with submerged weirs	-94.6	-90.8	-43.5	-77.4
Meandering of the river channel with islands in the centre of the channel	-85.3	-69.7	-10.0	-60.2
Islands in the middle of the channel	28.9	46.5	46.5	32.7
Lateral bays	2.4	2.9	-1.2	-6.1
Lateral deflectors	-24.8	-28.2	-5.7	-12.6

Both channel meandering scenarios represented the worst restoration technique, since a considerable decrease in the amount of WUA was found. This is due to the fact that the decrease of the cross section for low flows implies the decrease of wet surface area. For these two meandering scenarios, a smaller decrease on the mean monthly WUA was computed in the case of the two islands in the middle of the channel relatively to the submerged weir scenario. For the nase, the mean monthly WUA decrease is 92.7% considering the submerged weirs and 77.5% for the islands in the middle of the channel; for the chub these reductions are 60.4% and 35.1%, respectively.

Figure 6 and Figure 7 illustrate the monthly WUA obtained for the control conditions and for the five restoration scenarios, when considering the ecological flow regime. It confirmed that the best restoration scenario for this stream is the construction of three longitudinal islands in the centre of the channel. These physical structures increase the amount of habitat shelters downstream the islands and the reproductive habitats for the target species.

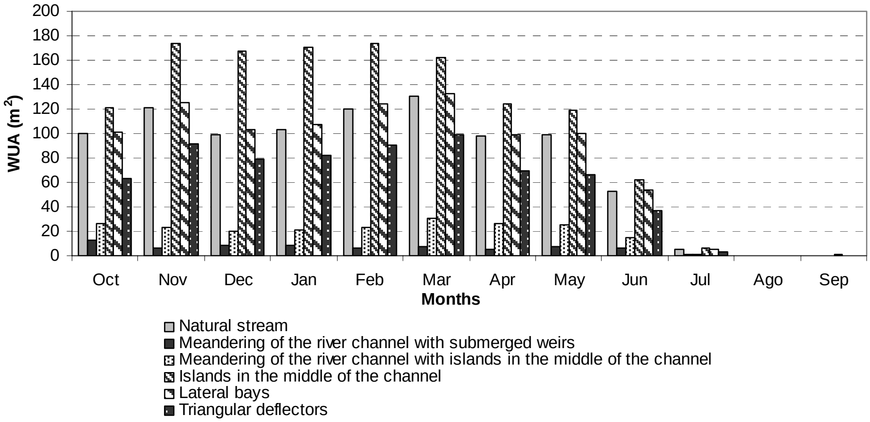

Figure 6 – Weighted usable area (WUA) for Nase and ecological flow regime

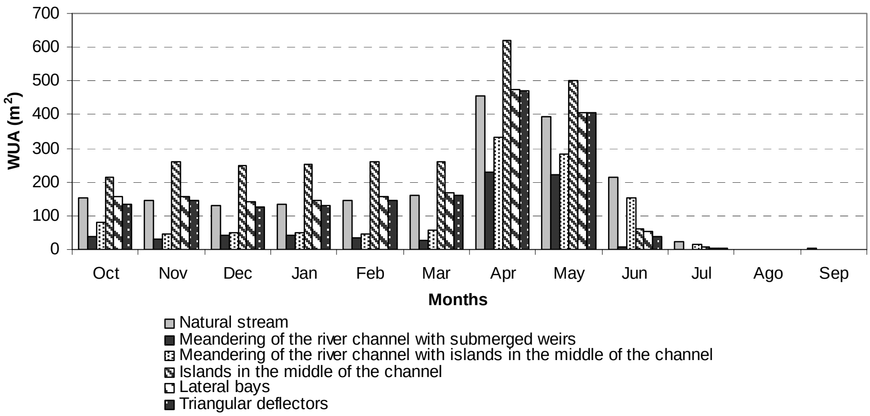

Figure 7 – Weighted usable area (WUA) for Chub and ecological flow regime.

5. CONCLUSIONS

This study highlights the importance of the habitat simulations in analysing the performance of different restoration scenarios, prior to their construction. By applying the habitat modelling to a specific river segment, it is possible to assess if a given set of concrete scenarios will significantly improve fish habitat, quantify their improvement and choose among the best ones, the one that potentially will be worth to be executed. The River2D model provides a useful tool to simulate and compare alternative restoration scenarios for improving fish habitat in a Mediterranean stream.

The methods outlined in this study for a river segment presenting low habitat heterogeneity could also prove extremely useful elsewhere, namely in other Mediterranean-type rivers, where fish species conservation and management are a priority.

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Using a two dimensional approach to evaluate channel rehabilitation in a Mediterranean stream.

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RIVER RESTORATION AND ECOHYDROLOGY: DEVELOPING A GEOMORPHOLOGICALLY-DERIVED FLUSHING FLOW THRESHOLD FOR APPLICATION IN ECOLOGICAL FLOW MANAGEMENT

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ABSTRACT

While numerous biologically-based methods are available for assessing the impacts of water-taking on a system (e.g. variable flow method), the development of methods for evaluating such impacts from a geomorphic perspective remains in a state of growth. Recognizing the role and importance of "extreme" flows within the context of an ecological flow regime, it has become necessary to go beyond achieving one minimum flow target, or a subdued replica of the natural hydrograph. The frequency, timing and duration of flows of various magnitudes also need to be considered.

Flushing flows are typically defined as those frequent flows, well below a two-year return period, which flush fines from the coarse matrix that comprises a riffle. As these flows likely limit the degree of seasonal or periodic embeddedness (filling of interstitial spaces with fine sediments), they are important for maintaining aquatic habitat, particularly during lower flow periods. While the entrainment of exposed fine materials positioned along the margins of the matrix are effectively modeled by a basic shear stress equation, a proportion of these fines settle into the interstitial spaces between the larger particles. In order to account for the entrainment of these 'hidden' fines, some form of correction is required. This paper presents a review of flushing flow equations and evaluates their applicability to the unique challenges of alluvial rivers in Southern Ontario, where surficial till geology supplies a wide range of substrate size (from clay/silts to cobble and larger). Finally, a hybrid equation based on regional data is presented.

Key words: instream flows, flushing flow, fluvial geomorphology, water-taking

1. INTRODUCTION

With ever-growing demands being placed on Ontario's fresh water resources, watershed managers are constantly striving to strike a balance between supply and demand within their system. On a daily basis, water is extracted from a watershed for uses such as drinking water consumption, agricultural irrigation, industrial and commercial supply. At the same time, in-stream demands for water exist in the form of wastewater dilution, aquatic habitat requirements, sediment transport, etc. (Fig.1). Complicating this issue is the fact that none of these variables remain constant. Instead, they fluctuate within a wide range of conditions such that managers are continually 'hedging their bets' to ensure that water demands are met, both by the surrounding population and the river itself. Inevitably, these demands are felt the strongest during periods where water is in short supply. As a result, attempts are being made by the Province of Ontario to develop and implement better, more comprehensive In-stream Flow Management Targets. Essentially, these targets are meant to minimize any negative impacts associated with altering natural flow regimes, thereby maintaining proper channel function and in-stream habitat.

While targets associated with discharges from stormwater ponds are fairly rigorous (MOE, 1999), those associated with water-taking are less robust; targets developed to date have emphasized minimum flow depths required to maintain fish passage. In an effort to improve the water-taking approvals process, research has been undertaken to identify a suite of tools or targets which can better the range of flows required by a system to sustain its ecological integrity. Through this work, flushing flows were identified as one such target. The purpose of this paper is to review different methods for deriving flushing flow parameters and then evaluating their performance within the context of data from Southern Ontario streams.

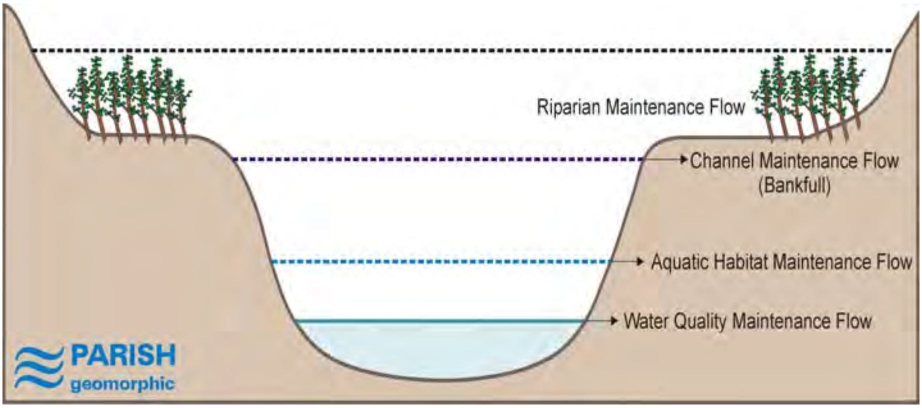

Figure 1 - Cross-sectional profile indicating various in-stream flow requirements.

Flushing flows are conceptually defined as those frequent flows, well below a two-year return period, which flush fines from the coarse matrix that comprises a riffle. As these flows likely limit the degree of seasonal or periodic embeddedness (filling of interstitial spaces with fine sediments), they are important for maintaining both the quality and quantity of available aquatic habitat, particularly during lower flow periods. The concept of flushing flows generally originated through research into the impacts of dams on sediment transport, where reduced flows can result in excessive sedimentation in downstream riffles (Fassnacht et al., 2003; Gaeuman et al., 2003; Osmundson et al., 2002). Typically this results in in-stream habitat degradation, since coarse sediments are required for the spawning of many fish species. In response, strategic dam releases of a specific discharge over a discrete time period have been implemented to flush these fine sediments from the system (Wu and Chou, 2004) (Fig. 2). The case of water-taking presents a slightly different challenge, in that no reservoir is available to create an artificial peak event within the system. Consequently, resource managers are utilizing the flushing flow targets as a level below which no water-taking may occur during key (seasonal) time frames within a year. This prevents intake structures from removing too much water from the system, causing riffles to become embedded and the quality of in-stream habitat to be reduced.

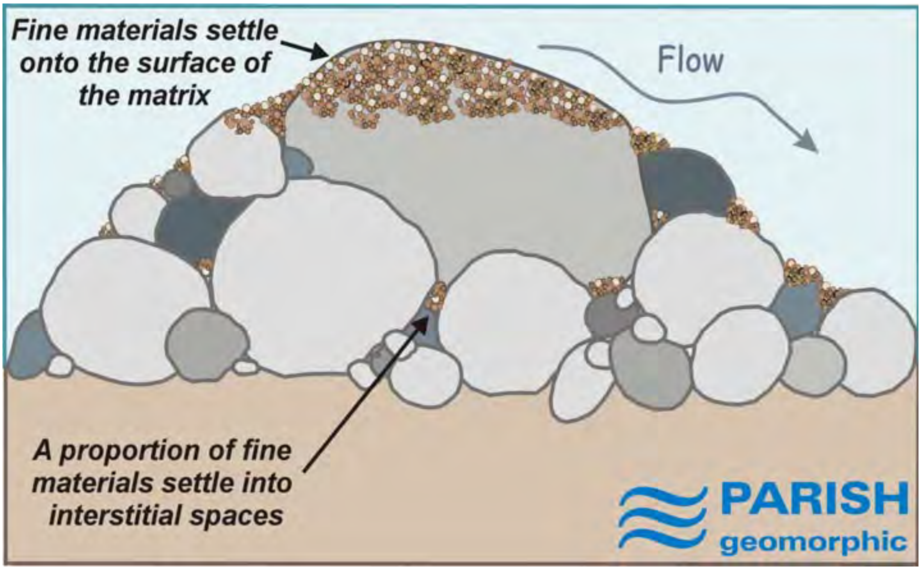

Figure 2 - Conceptual illustration of fine materials removed by a flushing flow.

The difficulty with determining an appropriate flushing flow is that traditional methods of estimating critical shear stress for the smaller size fraction of a sediment distribution are ineffective. These initial experiments to determine critical values were conducted in flumes using uniform sediments, not sediment mixtures, and are inappropriate for determining the critical shear stress of the smaller particles. In graded sediments, the exposure to a flow's energy will vary with particle size. However, larger particles tend to reduce and dampen the amount of energy being dissipated on finer sediments. Therefore, it becomes more difficult to mobilize finer sediments in graded streams. Consequently, attempts have been made to develop correction factors to account for sheltering effects.

2. GENERAL SETTING

A total of 11 streams within 8 sub-watersheds throughout Southern Ontario were chosen to evaluate the performance of hiding functions as part of this study (Fig. 3). While the majority of these sites were considered low gradient, they varied vastly with respect to upstream drainage area (14.8 km^2 - 2,592 km^2), channel dimensions, substrate composition and land use (from predominantly urban, to rural, to natural). The substrate composition is driven by the glaciated terrain characteristic of Southern Ontario, which ranges from till plains, to moraines, to outwash plains; which results in substrate ranging from cohesive fines, to sand, gravel, cobble and boulders. This diversity in geomorphic controls was incorporated intentionally in order to clearly illustrate the range of conditions over which each of the functions can be applied. The selection of these sites was also driven by the availability of detailed geomorphic information collected through previous studies where flushing flows have been developed using a software package that relies on hydrograph data. Unfortunately, hydrologic data is rarely available for the majority of streams in Southern Ontario. Therefore, hiding function performance will be assessed based on how well they agree with these previous studies. Additional criteria such as how the critical flushing shear stress compares to the D_{50} mobilization value will be included as part of this assessment.

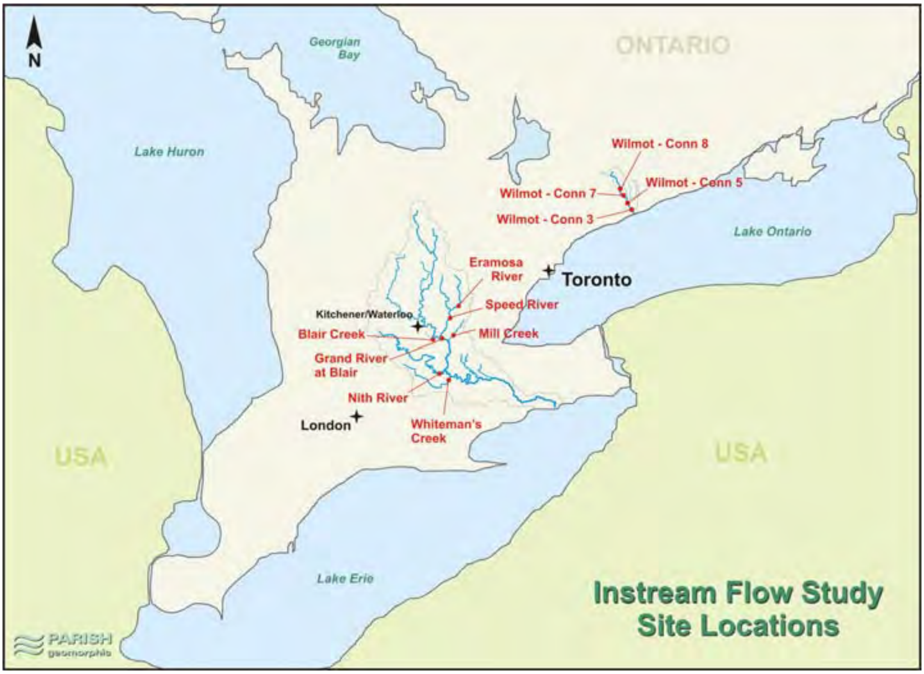

Figure 3 – Flushing flow parameter detailed site locations.

3. RIVER ASSESSMENT

The need to develop a correction factor to account for the degree to which a particle is either hidden or exposed to the flow was first recognized by Egiazaroff (1965), who derived a hiding function to correct Reynolds shear stress values. Subsequently, a whole range of hiding factors have been developed, most of which were calibrated to the results of specific sediment transport models rather than incipient motion equations. As a result, not only do they correct for hiding factors in their critical shear stress values, but they may also be taking into account factors other than the effects of sediment gradation. However, most sediment transport equations incorporate a series of basic assumptions and particle size constraints that may negatively impact the calibration of these hiding functions (van der Scheer et al., 2002).

3.1 Geomorphic analysis and problems

Data from the 11 selected streams throughout Southern Ontario were applied to each of the hiding factors in order to assess their relative performance. Tab.1 summarizes the basic geomorphic parameters for each of the 11 sites. Bankfull widths within the data set ranged from 5.17 – 153.0 m, slopes ranged from 0.04%-1.55%, while the median grain size ranged from 0.18 – 32.5 mm. For the purposes of this study, the flushing particle of interest of interest was identified as the D_{16} (16th percentile). This fraction was selected in order to reflect a relatively fine particle size, but was also sufficiently large to eliminate the need to account for the cohesive properties of a finer fraction. Each flushing parameter was then plotted to determine how each factor responded to varying ratios in particle size. These results were then compared to the D_{50} mobilizing threshold, as well as the expected outcome, based on the relative sheltering effect.

Table 1 - Summary of channel dimensions and particle sizes used in assessment.

Site	Bankfull Width (m)	Bankfull Depth (m)	Slope (%)	D16 (mm)	D50 (mm)	D84 (mm)
Wilmot C3	9.58	0.42	0.39	0.82	17.9	52.0
Wilmot C5	7.27	0.60	0.41	0.36	15.2	51.6
Wilmot C7	8.02	0.59	0.65	0.14	11.2	39.8
Wilmot C8	6.77	0.40	1.55	0.10	5.83	28.9
Speed (Bedrock)	58.6	0.91	0.12	0.92	32.5	195.6
Nith Creek	36.6	1.14	0.15	1.16	29.4	123.6
Whitemans Creek	16.8	0.89	0.31	0.33	20.0	77.2
Blair-Bechtel	5.17	0.41	0.41	0.01	0.18	14.2
Eramosa River	23.7	0.81	0.04	0.01	21.2	185.0
Grand River at Blair Creek	153.0	1.45	0.13	1.56	27.9	207.5
Mill Creek	11.2	0.55	0.19	0.01	0.05	5.64

3.2 Ecological analysis and problems

The results presented in Fig. 4 and Tab.2 indicated that the Egiazaroff (1965) hiding factor often resulted in critical flushing shear stresses that were well above the D_{50} mobilizing value due to the range in particle size between the D_{16} and D_{50}. Several other methods (Hunziker, 1995; Day, 1976; and Proffitt and Sutherland, 1983) fell outside of the acceptable range of results for several of the sites, which may reflect the assumptions inherent in the associated sediment transport equations. While the Ashida and Michiue (1971) model produced trends that were consistent with those expected, the resultant shear stress is consistently 84% of the D_{50} shear value, and does not account for the increasing role of sheltering as the D_{16} decreases in size. Many of these models were developed for sand-based systems that assume equal mobility of all particles in sediment mixtures. Given that, for the purposes of hydro-electric projects, flushing flows have successfully been used to remove only the fines from a channel bed, the concept of equal mobility in the context of establishing a flushing flow may be fundamentally flawed.

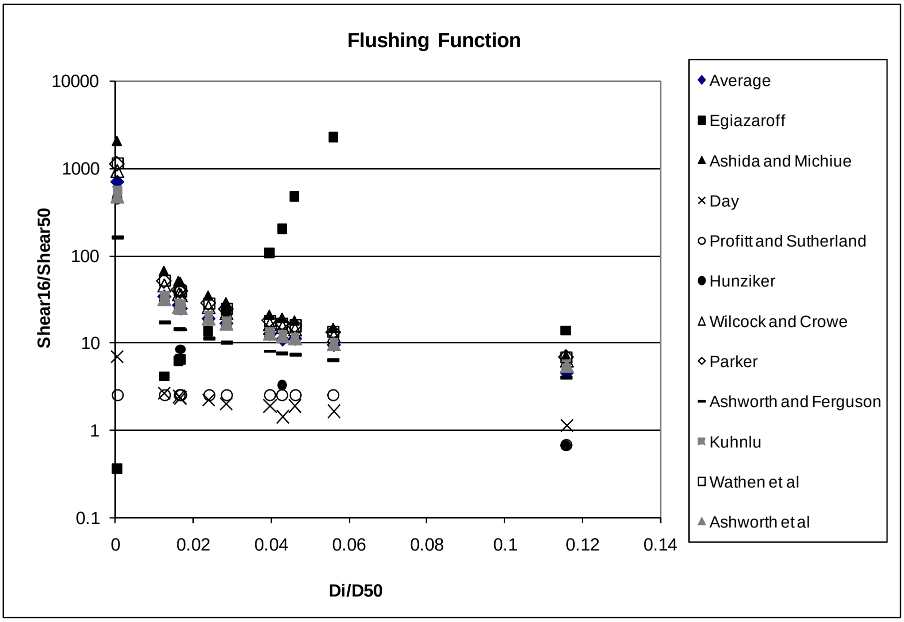

Figure 4 – Plot of flushing flow correction factors.

Table 2 - Summary of preliminary results using different hiding factors.

Site:	D16 Critical Stress (N/m2):	Egiazaroff	Ashida and Michiue	Day	Proffitt and Sutherland	Hunziker	Sohngen	Wilcock and Crowe	D50 Critical Stress (N/m2):
Wilmont C3	0.63	302.26	11.58	1.20	1.57	6.91	8.23	4.50	13.62
Wilmont C5	0.28	3.80	9.81	0.62	0.69	5.07	9.27	4.05	11.54
Wilmont C7	0.11	0.44	7.24	0.28	0.27	3.24	14.87	2.33	8.52
Wilmont C8	0.07	0.49	3.77	0.18	0.19	1.80	13.45	2.22	4.44
Speed (Bedrock)	0.70	16.03	21.03	1.42	1.76	11.28	14.59	4.81	24.74
Nith Creek	0.89	94.20	19.02	1.70	2.21	10.98	12.66	8.88	22.38
Whiteman's Creek	0.25	1.55	12.97	0.61	0.62	6.15	12.95	4.63	15.26
Blair-Bechtel	0.01	1.20	0.12	0.01	0.01	0.07	0.45	0.03	0.14
Eramosa River	0.01	0.00	13.73	0.04	0.02	2.89	59.01	1.26	16.15
Grand River at Blair	1.19	2721.12	18.04	1.99	2.97	11.24	11.53	5.90	21.23
Mill Creek	0.00	0.06	0.03	0.00	0.01	0.02	0.10	0.02	0.04

The remaining models all produce values for each of the sites that were well above the D_{16} shear stress, but below the D_{50} mobilizing shear stress, along with relationships that were inversely proportional to the ratio between the D_{16} and D_{50}. In order to produce a more robust regional model, all of the model results which produced results that were within reasonable range of the actual critical stress values were averaged and a power equation trend line was applied. This included all of the models indicated in Tab. 2, although Egiazaroff (1965) was only relevant for the Mill Creek site. To ensure a level of conservatism in the results, a factor of safety in the form of one standard deviation was then incorporated into this averaged model (Fig. 5). Since this result compared well with the maximum range of critical values derived for each site, it was considered a sufficiently conservative approach. This formula took the typical power function form as follows:

$$\frac{\tau^*_{ci}}{\tau^*_{cD50}} = \beta * \frac{D_i}{D_{50}}^{-\alpha} \quad \text{Where} \quad \alpha = 0.9046 \qquad \text{[Equation \#1]}$$

$$\beta = 1.0667$$

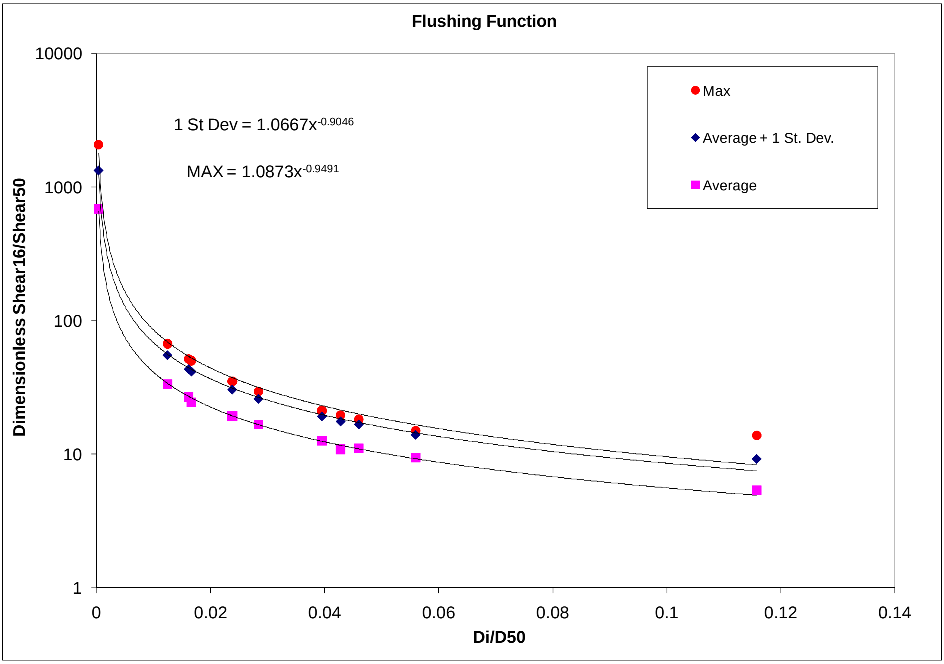

Figure 5 – Plot of dimensionless flushing flow robust model.

It should be noted, however, that while the newly derived power function provided conservative results within the expected range, a further correction factor was required in order to achieve a formula that would approach unity as the D_i approached the D_{50}. The resultant formula has been provided below (Equation 2).

4. CONCLUSIONS

A total of 11 hiding factors were applied to data developed from 11 streams within Southern Ontario in order to evaluate their ability to produce relevant results. A comparison of these models identified several hiding parameters which produced results within the acceptable range. These models were then averaged to produce a more robust regional model which then incorporated a factor of safety in order to ensure a degree of conservatism. This regional model has direct application in the field of water resource management by providing regulatory agencies with a target flow required to flush fine materials from a system and can be used as a minimum flow target, below which water-taking may not be permitted during key seasonal periods.

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RIPARIAN SPECIES AND FLOW REGIME: ECOLOGICAL STUDIES FOR APPLICATION IN ENVIRONMENTAL FLOW ASSESSMENTS AND RIVER RESTORATION (MIJARES RIVER, SPAIN)

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ABSTRACT

Currently, environmental flow assessment is taking place in the Júcar River Basin (Eastern Spain). In the Mijares River, the riparian vegetation was studied in relation to flow regime, in order to incorporate more ecological criteria in water management and river restoration.

The study sites were located in three different reaches (water bodies), where the river is regulated by a large dam and several hydropower plants. An ecological study and a hydraulic simulation were conducted for each site and the time-series of flow and water level were calculated for the period 1990-2007. The discharge-level curves were calculated in the channel cross-sections, based on field data (low flows) and hydraulic simulation of large floods. Geo-referenced data of six target species of riparian vegetation were aquired in such cross-section. We identified some differences in species' distribution in terms of distance and elevation above the channel thalweg.

The hydraulic simulation also allowed us to estimate the discharge required to cover most of the riparian forest area and to spread the seeds in the dissemination period. As a result, we recommended a suitable flood frequency to maintain morphology maintenance and improve the riparian conditions.

The recommendations of this study can be used by the water administration for technical studies of environmental flow regime taking place in the Júcar River Basin. The results could also be applied in river restoration projects involving the design of plantation plots and management of riparian zones.

Key words: Mijares River, riparian vegetation, environmental flow, recruitment.

1. INTRODUCTION

In Spain, different types of environmental flow studies (EFS) have been carried out, which took into account hydrological analysis and also fish habitat simulation. Others studies have shown the effects of altered flow regime on zoobenthos, macrophytes and riparian communities but with low applicability in EFS. These studies are very interesting due to the high number of large dams existing in Spain (García de Jalón, 1987), one of the countries with more dams per citizen in the world.

The relation between riparian species and stream hydrology has been largely studied (Stromberg, 1993; Shafroth et al., 1998; Mahoney and Rood, 1998). But despite their importance for the water management, eco-hydraulic studies relating riparian species and flow regime are just starting to be developed in the context of Mediterranean rivers, where the riparian vegetation is highly influenced by factors such as flow regime, soil moisture and groundwater availability (Tabacchi et al., 1996).

In coherence with these ideas, the general aim of this study was apply some concepts and techniques to study riparian vegetation and flow regime in the Mijares River, in order to address these questions:

1. Which are the distribution patterns of the most relevant riparian species in terms of distance and elevation above the channel thalweg?
2. Is the flow regime suitable for the recruitment of the riparian forest (main plant species)?

2. GENERAL SETTING

The Mijares River is one of the most important rivers of the Júcar River basin (Eastern Spain), which is one of the pilot basins for the implementation of the WFD. The catchment area is approximately 4028 km^2, and the main stem has a total length of 156 km. The altitude in the study area is in the range of 172-418 m a.s.l. and average temperature is between 22.7 and 23.4ºC. The mean annual precipitation is 400-600 mm, with maximum in autumn (Roselló, 1994). There are 3 water bodies in the study area, upstream flow is regulated by Arenós large dam, and along the river there are two hydropower plants (Cirat and Vallat plants). Upstream from each plant there is a small dam (Cirat and Vallat dams) which stores water for electricity production and irrigation.

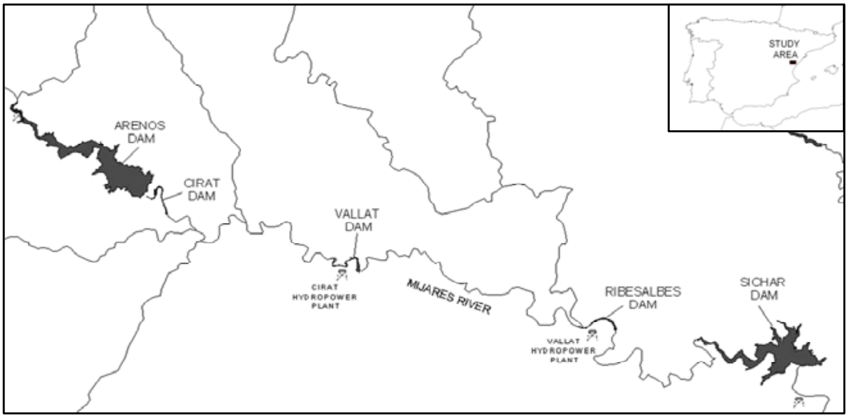

Figure 1 – General view of the study area in Spain, and detail of the Mijares River, where the position of dams and hydropower plants is indicated.

Cirat dam stores all the water released from Arenós dam, and from there it is lead to some irrigation channels and to the hydropower plant. Immediately downstream of Cirat dam the flow is reduced to 0.1 m^3/s (minimum flow). Flow begins to increase downstream thanks to several springs and sporadic flows of a tributary (Montán river). For this reason, the flow regime in the study area is quite similar throughout the year; it is only conditioned by the constant contribution of springs and temporary flows from tributaries. The area where the study was carried out does not suffer hydro-peaking effects because most of the water is diverted.

3. METHODS

The first part of this study was an inventory of the riparian plant species, therefore trees and shrubs were recorded in the study area. Every plant was identified with an abundance rank (1-5) according to its cover (Braun-Blanquet, 1979). A general characterization was made using the following methods: Ferreira and Aguiar (2005), QBR index (Muneé et al., 1998) for the riparian ecological status, and the IHF index (Pardo et al., 2002) for river habitats quality.

In the second part of this study different tasks were carried out, including an eco-hydraulic analysis. Data were collected in 3 reaches 200 meters long, with different valley morphology, valley width and mean annual flow.

3.1 Hydraulic simulation (1dim)

Cross sections were surveyed in the three sites of the study area. Discharge-elevation curves for each cross section were calculated with an hydraulic model calibrated with the program RHYHABSIM (Jowett, 1997), based on field data (low flows) and water elevation cartography (50, 100 and 500 years floods).

Time series of flow were translated into water elevation series, for the period 1990-2007, based on the transects rating curves. At the time of the study, flow data were obtained from the programme AQUATOOL (Andreu et al., 1996); this DSS manages monthly averages, which were converted to water surface elevation in each cross section.

3.2 Geo-referenced survey of the plants related to water level

Among the species present, six target species were selected to study the relation between vegetation and flow regime. These were:

1. Black poplar (*Populus nigra* L.)
2. Large gray willow (*Salix atrocinerea* Brot.)
3. Rosemary willow (*Salix eleagnos* Scop.)
4. Purple willow (*Salix purpurea* L.)
5. Oleander (*Nerium oleander* L.)
6. Tamarisk (*Tamarix* spp.)

Geo-referenced data of these plants were obtained in the selected cross-section using survey level, total station and GPS. The vegetation sampling using linear transects (cross sections) has been described by other authors as the “line intercept method” (FIREMON, 2003). In each transect, every vegetation unit intercepted was surveyed, formed by an individual plant or by a shrub, at the start and the end of the vertical projection of the whole plant on the cross section. The vegetation data (X, Y, Z) and the rating curves of the hydraulic model were adjusted to the same geographic datum. Subsequently, the water level time-series (deduced from the rating curves) above the lower point (start/end) of every plant on the transect was analyzed.

3.3 Diameter-age (growth) curves

Core samples of the target species were collected with pruning shears and a Pressler drill, in order to count the annual rings and to estimate the age. Also the height and DBH were measured in the same plants. The samples were sanded down and dyed to increase the visibility of the growing rings. They were dyed using fluoroglucine in 96% alcohol and clorhidric acid (HCl) as developer. Finally, diameter-age (growth) curves for each species were calculated and were used to assign an age to every plant sampled, in order to analyse the water level during each plant life-time.

3.4 Distance and elevation above the thalweg

The position of the target species in the riparian area was characterized in terms of distance and elevation above the channel thalweg, variables that were selected to represent a ranking of the plant’s tolerance to inundation. The comparative analyses by species were carried out by grouping the results of all the cross sections.

3.5 Considerations about the regulated flow regime and recruitment

April and May are the months when dispersion of the seeds happens. The poplar seeds quickly lose their germination capacity, although this depends on temperature and environmental humidity. In normal conditions, the willow seeds can not be preserved for more than 2-4 weeks (McLeod and McPherson, 1973; Kapustka, 1972). The period with maximum probability of poplar and willow germination in this study was estimated to be between the 1st and 30th of May. In such period, the profile of the hydrograph was observed, in order to evaluate the general trends of the flow during the seedling establishment period (from May to September).

4. RESULTS AND DISCUSSION

4.1 Location of the plants related to water level

The results indicated that poplar and oleander were distributed in stripes near the average water level. The tamarisk covers a slightly higher range of elevation, although there is clear overlap among the three species (poplar, oleander and tamarisk). These results are coherent with those obtained in terms of distance from the thalweg, as these three species are farther from the water than the other ones.

Salix purpurea is the species most exposed to the flow. It had a small sampling size but it was always in the same strip of the floodplain, next to the mean water level. This situation was also confirmed in the analysis of the distance from the thalweg. In general, the three *Salix* species had a similar median, but *Salix atrocinerea* was usually at lower elevations and inundated for longer periods than the other two species.

4.2 Diameter-age (growth) curves

Growth curves were obtained for each target species: *Populus nigra* (N=27), *Salix atrocinerea* (N=13), *Salix eleagnos* (N=26), *Salix purpurea* (N=11), *Nerium oleander* (N=24) and *Tamarix* spp. (N=9). The curves were calculated counting the annual rings (ages) of each core sample and finding the mathematical relation with the diameter (cm) of each sample. These relationships were applied to each plant surveyed in order to estimate their age. Fig.2 and 3 show the growth curve for the large gray willow and the oleander.

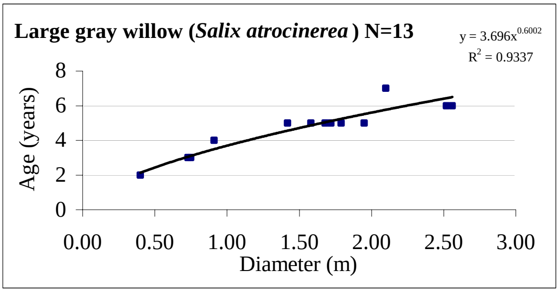

Figure 2 – Diameter-age curve for the large gray willow *(Salix atrocinerea)*.

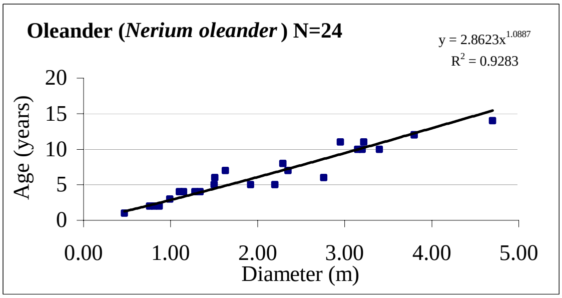

Figure 3 – Diameter-age curve for the oleander *(Nerium oleander)*.

4.3 Distance and elevation above the thalweg

Populus nigra and *Salix eleagnos* showed a similar distance and elevation above the thalweg. They were usually found at a higher level than other willows. In previous studies, *Salix* species have been described as obligate phreatophytes that require permanently available shallow groundwater (Busch et al., 1992; Horton et al., 2001), whereas *Populus* trees could be able to tolerate deeper and more fluctuating water tables than *Salix* (Snyder and Williams, 2000). *Nerium oleander* was located farther from the bank than willows and poplars. *Tamarix* spp. was very similar to the oleander but the data range was wider.

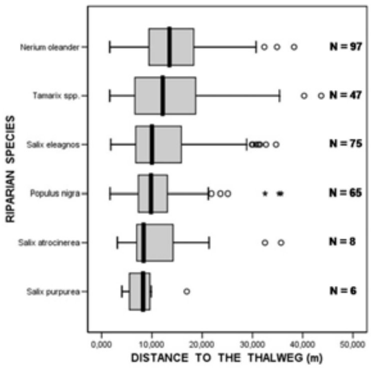

Figure 4 – Box-plots of the distance from the channel thalweg of each species (N=sampling size of each species).

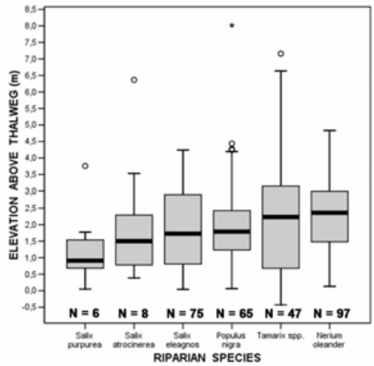

Figure 5 – Box-plots of the elevation above the channel thalweg of each species.

Figure4 and figure 5 show similar results for each species respect to the distance and elevation above the thalweg. The three willows species showed similar location, usually closer to the thalweg (average elevation between 0.5 a 1 m) and to the water, so that the roots are most of the time in the saturated zone (Busch et al., 1992; Horton et al., 2001). *Salix purpurea* was the willow which appeared at lower elevations and *Salix eleagnos* had a wider range of elevations (up to 4 m above the thalweg). This fact makes us think that *Salix eleagnos* can live in a wide range of soil moisture in the floodplain. *Nerium oleander* and *Tamarix* spp. were usually at higher elevations with respect to the thalweg (2 m average), being the tamarisk the species with larger range of variability, reaching a distance of 7 m in some cases.

Salix purpurea and *Salix atrocinerea* did not give confident results due to the low sample size, but we have shown their results as a reference of the position of the main species respect to the river channel. These species seemed to localize in the first line exposed to flow.

These differences between species can be applied to design plantation modules when it is necessary to combine species with similar characteristics in rehabilitation projects taking place in the studied area.

Considering the outlayers, we have verified that the vast majority of them appear in a band defined between 30 and 40 m of distance from the thalweg. Probably their presence at that distance is associated to a side channel present in two of the three sites, where water is flowing only during short periods.

4.4 Considerations about regulated flow regime and recruitment

It is important to remark that the maximum viability period of the seeds occurs only in the first month after they are dispersed, so if the soil and the flow are not suitable in May, when the flow decreases (usually September-October) most of the seeds have lost their viability.

The stable flow regime below the Arenós dam, due to flow reduction in magnitude and timing (for irrigation and hydropower use) and the constant contribution of some springs, has reduced the available area for seedlings establishment (because no banks erosion occurs) and does not favour the creation of new areas for the forest regeneration.

The comparison of aerial photographs taken before dam construction (1976) and today indicated a great reduction in the river dynamism and the proportion of gravel bars, but detailed measurements are still needed.

During the field work, we observed only a very small proportion of bared bars and banks available for seedlings establishment. As a consequence and in coherence with our observation, the release of higher flows in specific periods was recommended to maintain the riparian morphology and improve its condition, as there is no periodical transport and sedimentation of seeds on the river banks.

Moreover, based on other studies of poplars, recruitment is naturally episodic, occurring only about 1 year of every 3 to 10, with medium or high spring flows (Scott et al., 1996; Cordes et al., 1997; Mahoney and Rood, 1998). In some Mediterranean rivers, the appropriate bankfull discharge was identified within a range of return intervals of 4 to 9 years. Therefore, such flood frequency could be considered as the minimum in the design of environmental flow regimes in Spain, in order to inundate part of the floodplain and make possible the seeds dispersal in the riparian area.

These recommendations do not necessarily mean compromising the water resources, as regeneration is associated with the management of high flows during wet periods, while in dry years other criteria can be applied to focus on the maintenance of minimum wet conditions for the plants and the habitats of other biological communities.

At the moment we are getting more data to improve some aspects of this study, regarding the spatial distribution of the target species, their growth curves and also the simulation of the regulated flow regime (integrating springs and temporary streams).

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NOSE VELOCITY CALCULATION FOR SPATIAL ANALYSIS OF HABITAT AND ENVIRONMENTAL FLOW ASSESSMENTS

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ABSTRACT

Between 2005 and 2006, field sampling and physical habitat simulation (2D) were carried out in two Catalonian rivers, Ter and Llobregat. The hydrometry included depth and velocity measurements at different heights in the water column. Based on these data, 3 equations were adjusted to the data and tested to estimate velocities at different heights as a function of the mean water column velocity. The accuracy of these equations was compared in the 2 sites separately.

For the environmental flow assessments, physical habitat simulation was applied with the 2-dimentional software River 2D. Habitat suitability criteria for depth, mean velocity, nose height and nose velocity (i.e., at the vertical position where the fish were observed) were considered for the native brown trout. Functions of weighted usable area *vs.* flow were calculated for two alternatives: based on depth and mean velocity or on depth and nose velocity at a fixed height above the river bed. The analyses allowed us to evaluate the feasibility of focal velocity assessments for habitat studies, based on simple and economic methods. The results also showed the influence of considering the fish position in the water column in habitat-based environmental flow studies.

Key words: nose velocities, 2-dim habitat simulation, environmental flow, Spain.

1. INTRODUCTION

In the first decade of the XXIth Century, the European Union is striving hard to implement the Water Framework Directive (WFD), with a relevant change in the way we manage the water resources. In this context, environmental flow assessments are very important to achieve the good ecological status of water bodies. In Spain, the environmental administration has carried out some studies on environmental flow assessment, especially in

Catalonian Basins and the Júcar River Basin (one of the pilot basins for the implementation of the WFD).

Among the available techniques, the physical habitat simulation developed in the framework of the IFIM methodology (Bovee, 1982) is the most frequently used (Tharme, 2003). Nowadays, many studies of habitat simulation are based on 1-dim or 2-dim hydraulic models, which use mean water column velocity; 3-dim models, which simulate velocity profiles, still require a relatively great effort in terms of computation and thus in budget. In spite of the general use of mean velocity, it is well known that not only mean velocity but also nose velocity (point velocity at the location of fish or other aquatic animals) can be critical for the activity of many aquatic species, like benthic fish and invertebrates (Freeman et al., 1990; Grossman and De Sostoa, 1994), or any fish species that occupy different focal-point velocities to optimize energy intake (Hill and Grossman 1993, Hughes 1998).

Only a few studies have estimated water velocity in different positions of the water column, so that fish behaviour can be better integrated into habitat simulation (Milhous, 1999; Martínez-Capel et al., 2004). These studies demonstrated that nose velocities make a clear difference in the estimation of weighted usable area (WUA) and in environmental flow assessments. In this new study, a 2-dim habitat simulation was conducted in two Catalonian rivers, where a detailed work of hydrometry and field survey allowed to address these objectives: I) To observe trends in the errors when estimating nose velocities by 3 hydraulic methods, II) To incorporate nose velocities in 2-dim habitat simulation with current software, River 2D (Steffler and Blackburn, 2002) and PC worksheets, and III) To estimate the importance of using nose velocities instead of mean velocities, in terms of environmental flows.

2. GENERAL SETTING

This study took place in two study sites of the main rivers in Catalonia (NE Spain), the rivers Llobregat and Ter; both rivers flow from the Pyrenees Mountains to the Mediterranean Sea. The environmental flow study was funded by the Catalonian water administration, in order to obtain more information for implementing the regional plan of environmental flows, approved in 2004 (Agència Catalana de l'Aigua, 2005). These rivers are very important for the water supply of Barcelona, and also for irrigation and hydroelectric production. The study sites are shown in Fig.1.

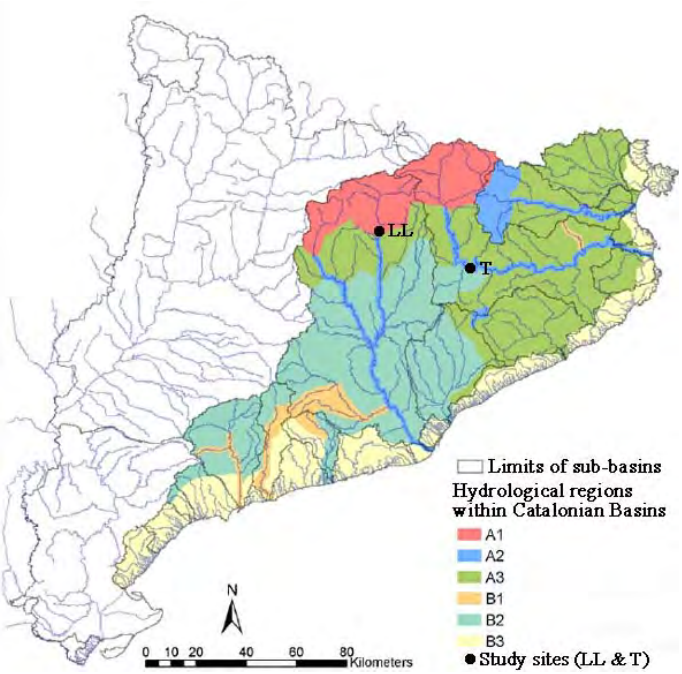

Figure 1 - Map of the Catalonian Basins, for the location of the study sites (LL:Llobregat, T:Ter), hydrological regions are indicated with different colours.

The first site, river Ter, is located below the 3 consecutive large dams of Sau, Susqueda and Pasteral, at 135 m a.s.l., and it was classified as hydrological type A2. With a larger watershed area than the other site, the flow regime is affected by snowmelt but also by a large runoff in the watershed. Maximum flows occur in May but the difference between spring and winter flows are not great. The length of the simulated segment was 173 m, including only a pool and two short riffles. Most representative substrate types were boulders (>1024 mm), cobbles (64-256 mm), gravel (8-64 mm) and bedrock, with an estimated presence of 36, 24, 10 and 10%, respectively. In the first survey (with discharge 1.346 m^3/s) maximum depth was 1.48 m, average width 17.6 m and average gradient 1.6 m/km. In total, 19 transects were analysed for hydrometry, and 5184 points were measured in the survey of the river bed and banks.

The second site, river Llobregat, is located some kilometres below Baells Dam, at 423 m.a.s.l., and it was classified as hydrological type A1 (Agència Catalana de l'Aigua, 2005), with a strong influence of snowmelt, minimum flow in winter and maximum in spring (May). The length of the simulated segment was 256 m, including riffles, glides and pools. Most representative substrate types were cobbles (64-256 mm), boulders (>1024 mm) and bedrock, with an estimated presence of 41, 20 and 9% of the site area, respectively. In the first survey (with discharge 2.066 m^3/s) maximum depth was 2.1 m, average width 19.4 m and average gradient 1.9 m/km. In total 21 transects were analysed for hydrometry, and 7262 points were measured in the survey of the river bed and banks.

3. METHODS

3.1 Field work

In each site, hydraulic and habitat characteristics were measured along 11 transects perpendicular to flow; water depths were recorded with a graduated rod (nearest cm) and water velocity with a Valeport® electromagnetic current meter (nearest mm). Velocity was measured at several heights in the water column; where depth was ≤ 0.45 m, one measurement at the height of 0.4×depth (height from the bottom); where depth was between 0.45 - 1.20 m, two measurements at 0.2 and 0.8×depth; in deeper areas three measurements at 0.2, 0.6 and 0.8×depth (three points method). The average velocity was calculated at each point from the corresponding measurements.

Substrate categories considered were: bedrock, large boulders (>1024 mm), boulders (256-1024 mm), cobble (64-256 mm), gravel (8-64 mm), fine gravel (2-8 mm), sand (62µm-2 mm), and silt (<62µm). In order to obtain a digital elevation model of the river bed and the banks for the 2-dimentional habitat simulation, a total station was used in the survey. In both sites the riverbed survey had a mean density over 1.2 nodes/m^2.

3.2 Data analysis

Before any calculation with the velocity measurements, these data were filtered, in order to discard negative and null values in the database, as well as data from transect points where velocity near the bottom was higher than near the surface (considered as anomalous velocity profiles). The filtered database was used to calculate relationships between mean water column velocity and other velocities at different heights in the water column, hereafter named as nose velocities (velocity measurement at the height in the water column where a fish was located). In all the points of each transect where there were 2 or 3 measurements in the water column, these data were matched to their corresponding height (distance from the river bottom); the average velocity was calculated and matched to a height of 0.4×depth.

We tried three different methods to compute nose velocity from the average at the same point. The first method (A) was the empirical solution based on the power law of velocity distribution:

$$Fvel = Avel \cdot a\,(Fh/D)^{b}$$

Where the symbols correspond to:
Fvel: Nose velocity (m/s) at a certain height (at the fish position),
Avel: Average velocity (m/s) in the water column at the same exact location,
Fh: Nose height (m), i.e., vertical distance from stream bed to fish position,
D: depth (m),
a, b: coefficients obtained by regression analysis.

Coefficients a and b were calculated by iteration, in order to minimize the median error of all the measurements of nose velocities.

The second method (B) was based on the power law equation in the following form (Schlichting, 1968):

$$Fvel = Avel \times \{(m+1)\,(Fh/D)^{m}\}$$

Where the symbols are the same as previously mentioned; *m* is a constant and it was calculated in order to minimize the median error of all the measurements.

The third method (C) for the test was proposed by Milhous (1999):

$$Fvel = Avel \times \{Log\,(a\,Fh/D65)/Log\,(b\,D/D65)\}$$

Where the symbols are the same as previously mentioned. D65 is the 65th percentile of the diameter distribution of the riverbed sediment; in this equation, it is taken as the characteristic roughness height in the reach. In the original form, a and b were fixed, in this case they were calculated in order to minimize the median error of all the measurements.

For each method, the percentage of error was calculated for each measurement (in points where 2 or more velocity measurements were done). These results were summarized in a histogram of the errors in each river for each of the 3 models (in classes, <15%, 16-25%, 26-50%, 51-100%, 101-150%, >150%), and the median error was also calculated. The discussion of the results was based in the errors and the characteristics of each study site.

In the two study sites, physical habitat simulation was applied with the 2-dimentional software River 2D, that allowed us to export the hydraulic results (depth and average velocity) at each node of the river mesh. Then, nose velocities were calculated at each node with the most accurate method of each study site (i.e., with lower median error in percentage).

Given the hydraulic results, the combined habitat suitability at each node was calculated in two ways: based on depth and mean water column velocity ($SI_d \times SI_{mv}$), and based on depth and nose velocity ($SI_d \times SI_{fv}$) at the most suitable nose height for the target species. Habitat suitability criteria for depth, mean water column velocity and nose velocity for native brown trout (*Salmo trutta fario*), with fish length of 10-20 mm, were obtained from other study (Martínez-Capel et al., 2007), which also took place in Mediterranean rivers. Those microhabitat surveys (from September 2005 to August 2007) had a total sample size of 144 independent measurements (235 fish observed). Despite the variability in the maximum total depth and mean velocity across the 5 sites (from 0.83 to 1.55 m maximum depth, from 1.28 to 2.48 m/s maximum mean velocity) the nose height of the fish was in a narrow range, because 85% of the data were within the interval 0 - 20 cm above the river bed (confidence interval 95% was 0.09±0.02 m). For this study 0.09 m was the nose height selected to calculate the nose velocity in both study sites.

With the combined habitat suitability and the areas derived from Thiessen polygons exported from River2D, the weighted usable area curves (WUA *vs.* flow) were calculated in the two ways, based on mean velocity and on nose velocity assessment. For curves comparison, two data were extracted: the optimal discharge (for maximum WUA) and the discharge corresponding to 80% of the maximum WUA; the latter was used in environmental flow studies of Catalonian Rivers (Martínez-Capel et al., 2006).

4. RESULTS

The evaluation of the 3 methods for nose velocity estimation is summarized in Tabale 1. In the River Ter, the methods gave little differences in the median results, and also the errors were considerably lower than in the other site. In the River Llobregat, the errors had a high variability depending on the method, and B was the only method with a median error similar to the ones obtained in the river Ter. According to the results in both sites, method B seems to show the best performance in general, thus it would be recommended to be implemented in other habitat simulation studies.

Table 1 - Frequency histogram data (in terms of percentage) and median error estimated in the calculation of nose velocity, in each study site, for the three methods, A, B and C.

	Error Distribution (intervals)						
R. Ter	0-15%	16-25%	26-50%	51-100%	101-150%	> 150%	Median error
A	50,0%	24,4%	21,1%	2,0%	0,2%	2,3%	15,1%
B	60,9%	19,7%	10,4%	4,7%	1,8%	2,5%	11,1%
C	53,9%	25,4%	15,2%	2,7%	0,4%	2,3%	13,4%
R. Llobregat							
A	21,0%	14,5%	13,8%	50,0%	0,0%	0,4%	58,0%
B	43,1%	19,9%	16,7%	5,4%	2,2%	12,7%	17,6%
C	5,1%	2,5%	14,9%	69,6%	0,7%	7,2%	62,9%

According to these results, the equations used in the nose velocity assessments in the two sites were the following (both following method B):

- River Ter, $Fvel = Avel \cdot (1+0.330)\,(0.09/D)^{0.330}$
- River Llobregat, $Fvel = Avel \cdot (1+0.367)\,(0.09/D)^{0.367}$

Where the symbols mean Fvel = nose velocity, Avel = average velocity, D = depth.

In Fig. 2, both WUA curves for comparison in the two study sites can be seen. The profiles of the curves, in R. Ter, are very similar. However, in the R. Llobregat, the profiles change because of the trend in the last part of the curves, which is decreasing when based on mean velocity but slowly increasing when calculated with nose velocity. Both rivers show in common that the estimation of nose velocities gives a higher estimation of the WUA, because the velocities at the lowest part of the water column are usually more suitable for brown trout (size 10-20 mm), according to the microhabitat suitability studies developed in Mediterranean rivers.

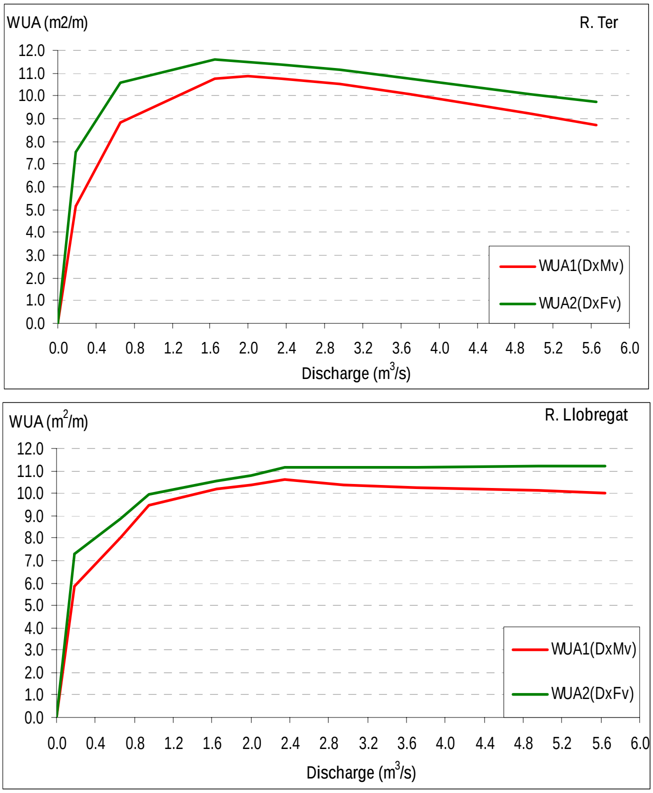

Figure 2 - Comparison of weighted usable area curves (WUA, m2/m) obtained in the river Ter and River Llobregat in two ways, based on depth and mean velocity suitability (WUA1) and based on depth and nose velocity suitability (WUA2) for brown trout (size class 10-20 mm).

From a more practical perspective, the WUA curves are useful to establish objective criteria for minimum flow assessments. The value of two parameters commonly used in other environmental flow studies, as obtained in this study are shown in Table 2. These results showed that there were significant differences when these parameters were used in environmental flow studies; however, there was no clear pattern in the results. While in R. Ter the optimum discharge was larger (21% more) when using mean velocity, in R. Llobregat was the opposite, because discharge doubled when considering nose velocities.

The discharge values needed to obtain 80% of the maximum WUA follow the same trend in the two rivers, that is, discharge was higher when considering nose velocities (38 and 14% more). It is important to note that the calculation of both curves differed in 2 steps, first the use of nose velocities in the nose height where most of the fish (brown trout) were observed, second the use of different habitat suitability criteria, calculated specifically for nose velocities (measured at the height of the fish's nose).

Table 2 - Comparison of critical discharge values (m3/s) obtained from the WUA curves (m2/m) of the river Ter and River Llobregat in two ways, based on depth and mean velocity suitability (WUA1) and based on depth and nose velocity suitability (WUA2) for brown trout (size class 10-20 mm).

	R.Ter		R.Llobregat	
	WUA_1 Curve	WUA_2 Curve	WUA_1 Curve	WUA_2 Curve
Maximum WUA	2.000	1.650	2.350	4.960
80% Maximum WUA	0.635	0.879	0.752	0.855

5. CONCLUSIONS

In our opinion, the large differences in the methods performance, and the high variability in the River Llobregat can be related to some of the factors affecting velocity profile and turbulence in the water column.

One of the main differences between the study sites is habitat diversity, because the River Ter has a high percentage of pool habitat and a very low percentage of riffle; this factor can make the velocity profile very similar throughout the whole reach, therefore the methods for nose velocity predictions can be adjusted more accurately. In this site, gradient is also lower and the water turbulence would be expected to be very little or null in the site. However, in the River Llobregat, the data set is more heterogeneous, because the velocity profile and turbulence can be very different in the pool, with much slower waters and eddies than in riffles and glides, with a relevant area in this site. As a conclusion, method B would be recommended to be implemented in other habitat simulation studies, and similar error ranges could be expected in study sites with homogeneous hydraulic conditions and a dominant habitat type.

The consideration of the fish position in the water column can be of a great relevance in the assessment of environmental flow regimes, from a practical perspective, as was shown in the WUA curves comparison. This result is coherent with other studies (Milhous, 1999; Martínez-Capel, 2004) and the same could happen with other aquatic organisms, like invertebrates. In one of the previous studies, the WUA for rainbow trout was higher when focal velocity was considered instead of mean velocity (Milhous, 1999), but the opposite happened in another study with the Iberian barbel (Martínez-Capel, 2004).

The results indicate that, in general, we could expect higher flow needs when nose velocities are considered; this can be related to the fact that velocity (in this study) was the main variable limiting the microhabitat suitability, and it was necessary to get higher flows to produce high nose velocities unsuitable for the target species, because nose velocity at 0.09 m was usually lower than mean column velocity. When the 80% criterion was used, the trend was clear; however, the optimal flow values gave contradictory results. The differences between sites are due to the different hydraulic conditions, which are related to the proportion of mesohabitat types; in study sites with more habitat diversity we could expect a situation more similar to the River Llobregat.

For further research, nose velocity predictions in uniform habitat types could give more accurate results, thus a stratification of the study sites would be necessary. Nose velocity prediction with simple methods can be a promising tool to improve physical habitat simulation, when 3-dim models cannot be afforded and the behaviour of the target species requires the use of water velocities in different elevations of the water column.

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THERMOPEAKING IN AN HYDROPOWER IMPACTED ALPINE CATCHMENT

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ABSTRACT

The modification of water temperatures caused by hypolimnetic discharges from thermally stratified reservoirs is considered a key threat to the integrity of lotic ecosystems. Within the REPORT project, the impact of turbinated water releases (hydropeaking) on the downstream temperature regime was monitored during 2007 in the Noce River system, a sub-catchment of the Adige River basin in Trentino. Three major reservoirs disrupt the longitudinal continuity of the Noce: two in the upper basin (Careser and Pian Palù) on low-order tributaries, and one in the middle part of the main stem (S. Giustina). The water coming from Pian Palù and Careser returns to the main flow at Cogolo hydropower plant, and the water from S. Giustina at Mezzocorona power plant. Eleven stations were selected in the Noce River basin: one upstream and four downstream of the Cogolo power plant, two on headwater tributaries with natural flow regime (Vermigliana and Rabbies streams), one upstream and two downstream of Mezzocorona power plant, and one on the Adige River, upstream of the confluence with the Noce River. Data-loggers were set to record temperature values every 10 minutes starting from 1st December 2006. Temperature data collected in 2007 were related to flow and air temperature data from three gauging stations adjacent to our sites. "Warm" and "cold" thermopeaking were quantified downstream of the two hydropower plants at different temporal scales (seasonal, monthly, weekly and daily). The reaches impacted by hydropeaking showed minor annual temperature ranges, with lower temperatures recorded during summer and higher temperatures during winter. The effects of thermopeaking are mitigated only at a long distance downstream from the release point. Monitoring will continue in the next years to obtain a long-term description of the Noce basin thermal regime and its alterations.

Key Words: Thermopeaking, sustainable hydropower, stream ecology, Alpine streams.

1. INTRODUCTION

The natural temperature regimes of rivers provide thermal cues that stimulate responses in many aquatic species, e.g. fish spawning, egg hatching, insect development and emergence. The modification of water temperature caused by hypolimnetic discharges from thermally stratified reservoirs is considered a key threat to the integrity of lotic ecosystems and their living communities (Caissie, 2006). Water temperature is probably the most important physical property of rivers (Webb, 1996). Many physical and chemical processes such as oxygen solubility, chemical reaction rates, density and viscosity, are affected by temperature (Webb, 1996). Water temperature has been also widely recognized as a critical environmental variable structuring macroinvertebrate (Cox and Rutherford, 2000; Ward and Stanford, 1982) and fish (Tørgersen et al., 1999) communities. Some authors highlighted the consequence of climate changes on some terrestrial species life cycles, spatial range and migratory behavior (Parmesan and Yohe, 2003; Root et al., 2003; Walther et al., 2002). For instance, an increase in water temperature in the French Rhone River, due to climate warming, caused a gradual increase in relative abundance of warm-water taxa and a decrease in cold-water ones (Daufresne et al., 2004; Daufresne et al. 2007).

Water temperature is influenced by a large set of physical and environmental factors or drivers, which interact to produce differences at local and spatial scales (Poole and Berman, 2001). In natural or semi-natural conditions, the primary factors determining water temperature are those related to climate, such air temperature and solar radiation (Caissie, 2006; Poole and Berman, 2001; Webb et al., 2003; Webb, 2008), stream morphology, groundwater flow influences (Burkholder et al., 2008) and extension of the riparian canopy (Hannah et al., 2008).

Flow alteration is another factor responsible for stream water temperature changes, showing a clear relationship between the flow-rate and river water temperature (Sinokrot and Gulliver, 2000). According to Caissie (2006), reservoirs have a strong impact on river thermal regimes, deeply modifying the natural patterns of the river. Dams heavily reduce downstream discharge, sometimes to the point of river stagnation, affecting the thermal properties of streams and rivers, and can have a direct impact on water temperature in relation with the origin of water release – top or bottom release (Poole and Berman, 2001). Furthermore, Sinokrot and Gulliver (2000) demonstrated that lower flow-rates, downstream of a dam, induced diurnal variations above 10 °C, whereas the range was narrower in the same site at higher flow discharge.

Other studies supported a decrease of mean annual temperature downstream of reservoirs, with significantly warmer water temperatures during winter, preventing winter freezing, and cooler conditions in summer, delaying annual life-cycles (Webb and Wailing, 1993).

Within the REPORT project, the impact of turbinated water releases (hydropeaking) on the downstream temperature regime was monitored during 2007 in the Noce River system, a sub catchment of the Adige River basin in Trentino. In 2007 the Noce, downstream of Mezzocorona power plant, was impacted by 500 hydro- and thermopeaking events that interested the river for 50% of the time. The aim of this study was to quantify the water temperature alteration downstream of two different hydropower plants in an Alpine river at different temporal scales.

2. STUDY AREA

The Noce river basin is located in the North-Western part of the Trento Province (Central-Eastern Italian Alps) and it is one of the main tributaries of the Adige River. The Noce is 105 km long, with a catchment area of 1400 km^2. Starting from the ‘50s, three major reservoirs have disrupted the longitudinal continuity of the Noce: two in the upper basin (Careser, 2600 m a.s.l. and Pian Palù, 1850 m a.s.l.), and one in the middle part on the main stem (S. Giustina, 530 m a.s.l.).

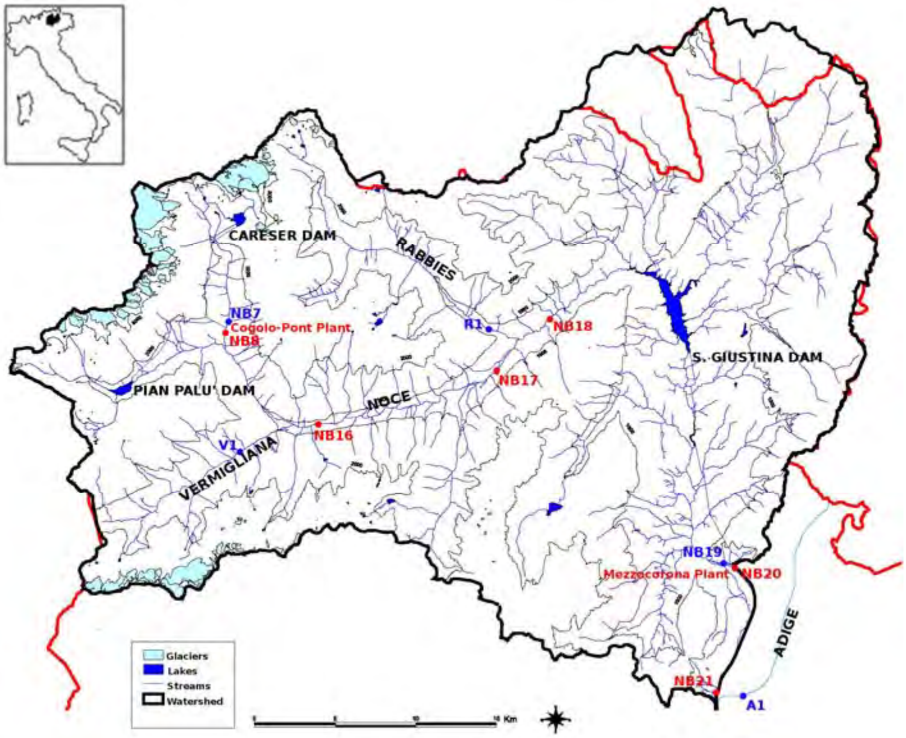

Figure 1 – Study area. In blue the stations not impacted by hydropeaking, in red the impacted ones.

The water coming from Pian Palù and Careser returns to the main flow at the Cogolo hydropower plant (1200 m a.s.l.), and the water from S. Giustina is returned to the channel downstream of the Mezzocorona power plant (200 m a.s.l.).

Eleven stations were selected in the Noce river basin (Fig. 1): one upstream and four downstream of the Cogolo power plant, two on headwater tributaries with natural flow regime, one upstream and two downstream of the Mezzocorona power plant, and one on the Adige River, upstream of the confluence with the Noce River.

3. METHODS

One StowAway® Tidbit™ temperature datalogger was set at each site to record temperatures at 10' intervals. For comparisons with discharge data, 30' intervals were used. Starting from 1st December 2006, we retrieved data every three months, offloading and replacing the loggers. For different reasons, records from NB7, R1, NB18 and NB21 were partially missing, so these sites were excluded from the present analysis. Degree-days, defined as the sum of the mean daily temperatures, were calculated and a Mann-Whitney U test was used to compare the mean between reaches unimpacted and impacted by hydropeaking (V1 vs. NB8 and NB19 vs. NB20).

Water temperature was correlated with flow data and air temperature, recorded at the only three stations with stream gauges (V1, NB17 and NB20), one upstream and two downstream the hydropower plants. Water temperature data were correlated with air temperature, which is an important environmental factor that influences water temperature (Langan et al., 2001). The correlations among water temperature, air temperature and flow regime were investigated using the Spearman's rank correlation. All the analyses were run using the software Statistica 6 (Statsoft Inc, 2004).

4. RESULTS AND DISCUSSION

Degree–days were significantly different between NB8 and V1 (Mann-Whitney test, $p = 0.001$) but not between NB19 and NB20. A significant difference in annual water temperature was observed between NB19 and NB20 (Mann-Whitney test, $p < 0.001$). Fig. 2 shows the differences in water temperature recorded every 30 minutes up- and downstream of Mezzocorona plant (NB19 and NB20). During plant operation, temperature increased during autumn and winter (maximum increase 4.5 °C on November 16th), whereas it decreased during spring and summer (maximum decrease 5.9 °C on May 12th).

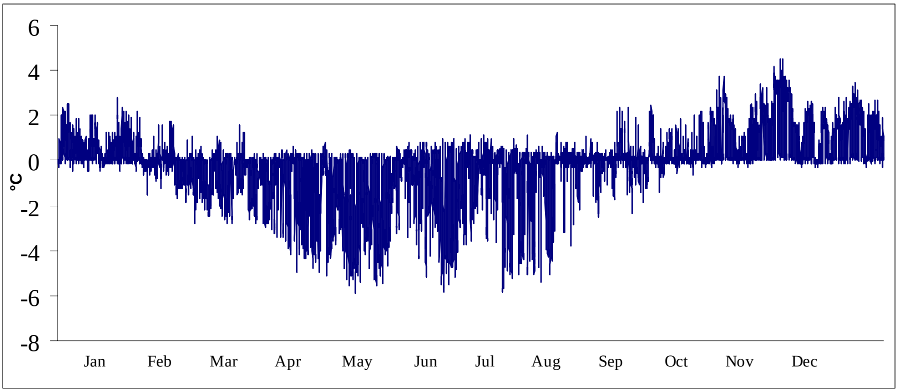

Figure 2 – Water temperature differences between upstream and downstream Mezzocorona power plant.

Figs. 3 and 4 display temperature gradients in 30’(difference between consecutive measures) in the impacted (blue lines) and a non-impacted reaches (red lines) up- and downstream of the two considered power plants. Downstream temperature increased up to 4.7 °C at NB20 and NB8 in a 30’ interval, whereas in natural conditions temperature changes never exceeded 1.4 °C in the same time interval. Differences were significant in both cases (Mann-Whitney U test, $p = 0.01$ and $p < 0.001$ between NB8 vs. V1 and NB19 vs. NB20, respectively).

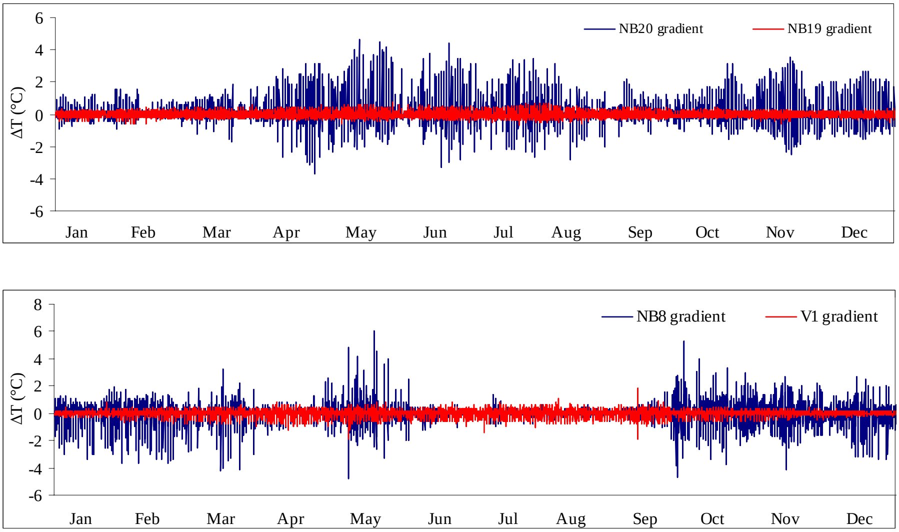

Figure 3 and 4 – Different gradients between impacted and non-impacted reaches. In red upstream and in blue downstream of the power plants.

Fig. 5 illustrates the relationship between temperature and discharge patterns for one week representative of each season, upstream and downstream of Mezzocorona power plant. Downstream increases or decreases in water temperature corresponded to increases in discharge during plant operation. During representative weeks in October (22-28) and January (15-21) temperature increased up to 2.0 and 3.7 °C, respectively. During April (23-29) and July (16-22) the opposite situation was recorded (decrease of 5.1 and 5.9 °C, respectively). The Mann-Whitney U test calculated between upstream and downstream water temperature showed significant differences with $p < 0.001$ for all the investigated weeks.

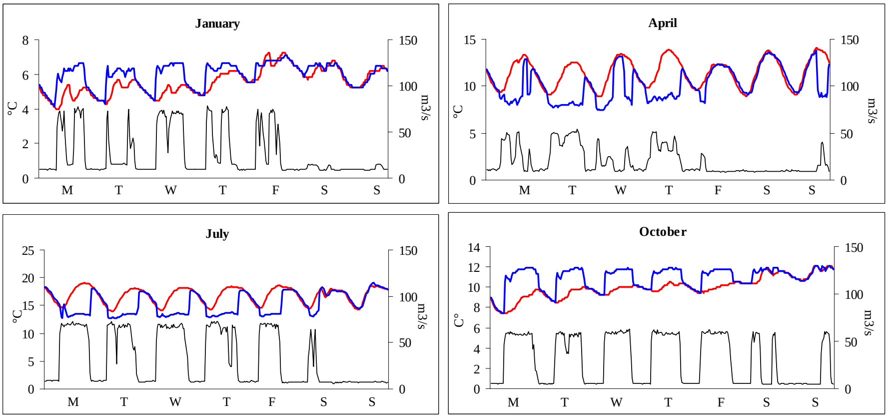

Figure 5 – Temperature distribution upstream and downstream Mezzocorona power plant during for one week representative of each season, compared with discharge. In red upstream, and in blue downstream of Mezzocorona power plant. In black, downstream discharge.

The correlation between water temperature, air temperature and discharge were investigated at yearly and monthly temporal scales. As expected (Langan et al., 2001; Webb, 1996), the yearly analysis showed a significant correlation of water temperature with air temperature and discharge in all the sampling points. The correlation with discharge in the impacted NB20 was negative (rs=-0.19), opposed to the two non- or slightly impacted stations, which had high positive coefficients (V1 rs=0.80 and NB17 rs=0.75).

At the monthly temporal scale, the correlation between water and air temperatures was positive and significant at V1 and NB17 for each months, whereas it was non- or weakly correlated at NB20, especially during spring and summer months. A stronger correlation between water temperature and discharge was found in this reach during spring and summer.

5. CONCLUSIONS

We define as “thermopeaking” the frequent and sudden changes in water temperature, associated to hydropeaking, that exceed the natural variations of the stream reach under study.

Water temperature is known to be a primary driving force in stream ecology (Webb et al., 2008), but little is known about the effects of repeated temperature changes due to intermittent hydropower generation.

Power plants fed by hypolimnetic water from higher elevation reservoirs significantly impact the natural temperature regime, imposing sudden warm and cold temperature variations to the biological community and to the biochemical processes.

The range of temperature alteration downstream of hydropower plants is determined by factors such as timing of power generation, difference in elevation between the reservoir and the power plant, season, structure of the reservoir (with or without stratification). Thus, long-term recording of water temperature is needed to quantify the extent of thermopeaking impact on a river. Moreover, because mean temperature and degree-days do not significantly differ between thermopeaking-impacted rivers and non-impacted ones on long time-scales (monthly, seasonal, yearly), it is necessary to record temperature at short time intervals (30 minutes or less) to detect the impacts in detail.

Further research is needed to understand the possible effects of thermopeaking on freshwater communities and ecosystem processes and de-couple them from those of hydropeaking. River restoration measures should consider the associated effects of hydro- and thermopeaking, which can impose severe restrictions to the expected ecological benefits.

Where feasible, amelioration of hydro- and thermopeaking should be a primary goal while planning operational and structural changes in hydropower plants.

ACKNOWLEDGEMENTS

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CHAPTER 11

Session 8c

Ecohydrology: linking hydrology, geomorphology and ecology

Chairpersons

A. GURNELL, W. BERTOLDI

Introduction
ECOHYDROLOGY: LINKING HYDROLOGY, GEOMORPHOLOGY AND ECOLOGY

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Linkages and feedbacks between hydrology, geomorphology and ecology along river corridors are an increasing focus for research that is generating important insights for river managers. The papers and posters delivered in this session addressed a wide range of perspectives, confirming the diversity, complexity and vigour of current research in this area. Nevertheless, a common theme linked the papers - the importance of interactions between flow, sediment and vegetation in driving form and habitat turnover within river channels.

The first paper, delivered jointly by Walter Bertoldi and Nicola Surian, used the braided, gravel-bed, Tagliamento River, Italy to explore the significance of time and space scales of flow, sediment transfer and plant growth processes and human interventions in driving river dynamics and morphological change. Based on the analysis of a diverse range of historical and contemporary data sources, initiation of bed sediment movement, bar surface inundation, bank full flow and island turnover were found to relate, respectively, to return periods exceeding 3 months, 1 year, 3-4 years and 20 years. Gravel extraction in the lower reaches had led to channel incision and narrowing with consequential impacts on the level of connectivity established for less-impacted upstream reaches.

Alessandra Crosato extended the theme of interactions between plant growth and river dynamics by presenting the results of incorporating varying vegetation colonisation and flow resistance within a 2D morphodynamic model. A ten year simulation with and without a vegetation cover resulted in the initiation of meandering and braiding planforms. Varying climate and hydrological regime have major implications for plant growth, river evolution and the potential outcomes of different river restoration approaches.

Bartlomiej Wyzga illustrated the importance of channel form, vegetation and management for the abundance and diversity of fish fauna. Focusing on the Czarny Dunajec River, Poland, which possesses a spectrum of reach types from heavily engineered to dynamic island-braided, he developed an index of hydromorphological quality and demonstrated its strong association with abundance and diversity of fish.

Jacky Girel investigated sediment-flow-vegetation interactions within the dyked River Isere, France. Over the last few decades, a trajectory of adjustment has been observed between the dykes. The first stage was bar development and coarsening. This was followed by colonisation and establishment of riparian plants on the bar surfaces, accompanied by accumulation of fines and the establishment of non-riparian species. Finally a ten year flood led to massive bar surface aggradation with the instigation of mass failures on the steepening bar edges. As a result, the bars became increasingly unsuitable for riparian species but more suitable for invasion by various exotic plant species. These observations demonstrate that the processes which maintain riparian communities and habitat turnover are no longer present. A series of management options, including bar vegetation shredding, clear cutting and levelling, are being investigated as means of resetting vegetation succession and maintaining a functioning riparian system.

Michele Tremollieres continued the theme of maintaining a functioning riparian system in parallel with flood management measures. She presented observations on the response of an area of alluvial forest, previously part of an anastomosing system, to reconnection with the River Rhine in 2003. Observations of hydrological, chemical, floral and faunal species changes have been conducted with the aim of assessing the degree of recovery of this system and its dynamics, and also the groundwater quality implications of the reinstated inundations.

In the final oral paper, Karl Panek revealed far-reaching ecological responses within a 5.5km reach of an urban river, the Leisingbach, Vienna, to water quality improvements, the removal of bank and bed reinforcement and some riparian replanting. Three years of post-project monitoring have revealed morphological recovery and a massive increase in macroinvertebrate and fish species, with the latter represented by all age classes.

Interactions between flow and vegetation were also highlighted in the poster session.

Donatella Termini explored the impact of flexible vegetation on hydrodynamic conditions through a series of flume experiments. Flow velocity measures within and above the vegetation were used to test the hyperbolic tangent profile of a pure mixing layer and to evaluate the mixing-layer parameters, whilst the formation of turbulence structures inside the vegetated layer was verified using spectral analysis.

Riparian forests are important components of the river corridor and their impact on flow resistance requires attention from perspectives of hydraulic resistance, sediment and organic matter retention, landform building and the creation of refugia during flood events. In their poster, Giovanni Forzieri and colleagues evaluated methods for extracting information on forest characteristics from LiDAR data. They evaluated the accuracy of estimates of characteristics such as height to crown base, total height, crown diameter, stem diameter and total biomass from test sites through multi-regression analysis and wavelet decomposition.

Two further posters focused on defining reference conditions to inform river management.

Andrew Simon and colleagues presented the results of an evaluation and analysis of data from hundreds of monitoring stations in the United States. Geomorphologically stable sites were identified, from which they characterised ‘reference’ magnitude-frequency-duration sediment transport conditions relevant to different ecoregions. A regionalised assessment is crucial to inform river managers of where sediment transport is a genuine problem, since some ecoregions tend to maintain high suspended-sediment concentrations for extended periods whereas other are characterized by much lower values.

Valentina Dallafior and colleagues were concerned with the overall fluvial functioning of Alpine rivers. Because Alpine rivers have a relatively selective environment for biological communities, they have developed specific tools to assess the natural value and the impacts of human activities on such systems. They presented tools to evaluate and compare the absolute functioning of a river stretch with its potential functioning if it were in an unimpacted state and thus functioning completely naturally. Such tools can be used to estimate the natural value of a site and the need to carry out river restoration or conservation projects.

4th ECRR Conference on River Restoration
Italy, Venice S. Servolo Island
16-21 June 2008

LINKING HYDROLOGY, GEOMORPHOLOGY AND ECOLOGY OF A MULTI-THREAD RIVER: TIME SCALES OF VARIABILITY AND CHANGE ON THE TAGLIAMENTO RIVER AS A REFERENCE FOR RIVER RESTORATION

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Note: *The contributions of the authors to this work can be considered equal.*

EXTENDED ABSTRACT

Although no entirely natural river systems exist within mainland Europe, some systems retain sufficient physical, chemical and biological process dynamics and morphological integrity to act as reference systems. One such system is the Tagliamento River, northeast Italy, which retains the most extensive and connected length of dynamic braided river within the Alps. Whilst the River Tagliamento is subject to many human influences, these remain less severe than in most other Alpine river systems, allowing much of its river corridor to remain morphologically intact and highly dynamic.

We assembled and analysed data from contemporary and historical sources (including river stage records, photographs and topographic surveys), from which we identify river stages at which thresholds in surface hydrological connectivity and biogeomorphological adjustment appeared to occur (Figure 1), contributing to a shifting habitat mosaic.

Our analysis has shown that river stage is highly variable on the Tagliamento. Rapid, flashy changes in river level of widely varying magnitude occur extremely irregularly through time and are superimposed on a subdued annual baseflow regime. Such irregular flow regimes are disappearing as many rivers are regulated for human use, with peak flows

being stored for flood control and water supply and, in many cases, being replaced flow peaks of very regular magnitude and frequency associated with hydropower generation.

Since river channel size and form predominantly reflect the river’s flow and sediment regime, it is scarcely surprising that we have identified associations between river stage and the inundation of particular landscape elements within and adjacent to the active tract. However, the relatively unmanaged channel form exhibited by the Tagliamento provides a range of landscape elements that play a crucial role in maintaining a diversity of aquatic and terrestrial habitats across all flow stages. In particular, we have demonstrated that as river stage increases, inundation of the active tract is accompanied by shifts from (i) a single to multiple flowing channels; (ii) surface disconnected ponds and partly connected backwaters to a fully surface connected aquatic system; (iii) the gradual connection of vegetated patches of increasing size to flowing surface water; and finally (iv) progressive island and floodplain inundation. Overall these shifts represent two fundamentally important gradients (Figure 1). First, there is a change from relatively isolated water bodies (ponds, backwaters, side channels) within a connected terrestrial landscape at low flow stages to a fully connected surface aquatic system surrounding disconnected elements of the terrestrial landscape at stages in excess of 200 cm. Second, above a flow stage of approximately 200 cm, there is a change from vegetated patches predominantly surrounded by bare gravel surfaces to vegetated patches predominantly surrounded or inundated by water.

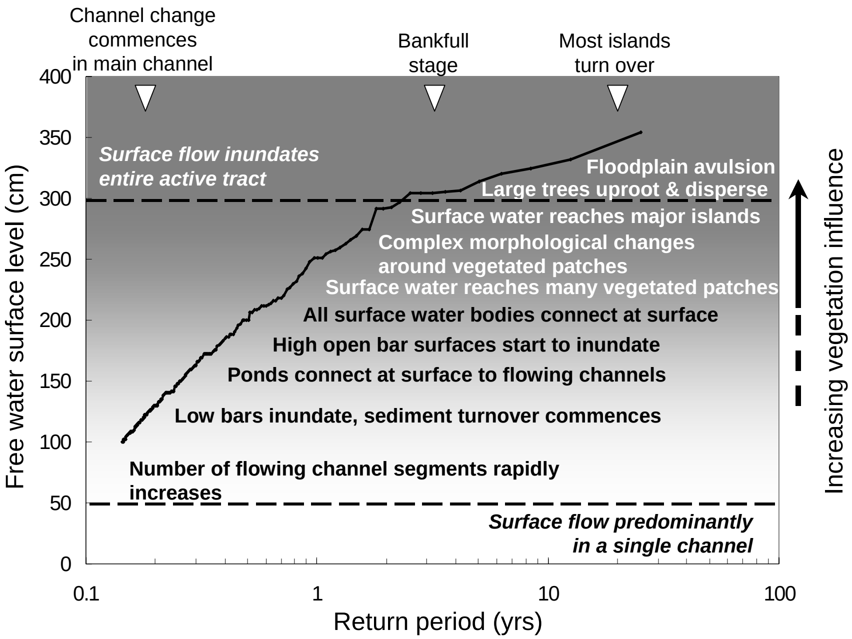

Figure 1 - Summary of relationships between river stage frequency at the Villuzza gauge and inundation and morphological features within the active tract immediately upstream of Villuzza (in the 17 km long Pinzano to Trasaghis reach). The grey shading represents the increasing influence of vegetation on habitats, their hydrological connectivity and turnover, with increasing river stage.

The critical flow stages summarised in Figure 1 are not simply passive phases of inundation and surface hydrological connection. Important biogeomorphological feedbacks exist between river flows, inundation, vegetation and river landscape change. Above 150 cm stage, vegetated patches start to interact with flowing water. The number and size of vegetated patches affected and the strength of these interactions increase dramatically above 200 cm stage. Flow-vegetation interactions may lead to erosion of the vegetated patch or, alternatively, to aggradation and coalescence to form pioneer and larger established islands. Because of their flow resistance, pioneer and larger islands tend to develop scoured areas around their upstream-facing margins that frequently contain ponds. The connection between islands and ponds is indicated by the rapid increase in connected surface water bodies and shoreline length and the disappearance of disconnected ponds between 130 cm and 200 cm stages. Since the largest uprooted, deposited trees are the most likely to sprout successfully, a supply of large uprooted trees is crucial to seeding the next generation of pioneer and larger islands within the active tract. Established islands, which support the largest trees are usually aggraded to floodplain level and so bank full river stages (300 cm) are required to undermine large riparian trees at the margins of islands and floodplain and to disperse them into the active tract. Finally, once islands are established and aggraded to floodplain level, their susceptibility to inundation and erosion is greatly reduced. Bankfull or higher flow stages (> 300 cm) are required to significantly erode floodplain and island margins or to cut avulsion channels that dissect new islands from the floodplain. From our analyses, significant turnover of established islands leading to widespread resetting of bar surfaces, reorganisation of the active tract and widespread deposition of uprooted trees, is associated with high magnitude, low frequency (ca. 10-20 years) flood events.

Since inundation and biogeomorphic change on the Tagliamento reflect interactions between flow, sediment and vegetation, any human intervention in these three components may have far-reaching effects on river corridor characteristics and dynamics. For example, sediment removal from the river bed as a result of gravel mining combined with some bank stabilization using groynes has resulted in up to 2 m bed incision on the lower reaches of the Tagliamento. Such incision reflects a reduced sediment supply combined with a relatively unimpacted flow regime and it appears to be associated with a decline in the extent of vegetated patch cover within the active tract. In effect, incision has drastically changed the relationship between discharge and river stage relative to floodplain level, disconnecting the river from its floodplain, leaving the riparian forest elevated well above local water table levels and restricting the input of mature floodplain trees for island-building. As a result, the potential range of types and sizes of habitat are restricted, and the river-associated mosaic is confined to a narrow strip the width of the pre-mining active tract.

In a broader management context, any human modifications that interrupt the dynamics of the three main controlling components of the river – flow, sediment, riparian trees – will have far-reaching effects on the river ecosystem. Our research continues to address how and when critical threshold conditions might be reached to the detriment of surface and subsurface hydrological connectivity, habitat turnover and biodiversity of the Tagliamento reference river system.

Key words: braided river, geomorphology, surface hydrological connectivity, habitat turnover, time scales, Tagliamento

4th ECRR Conference on River Restoration
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EFFECTS OF RIPARIAN AND FLOODPLAIN VEGETATION ON RIVER PATTERNS AND FLOW DYNAMICS

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ABSTRACT

Flume experiments and field observations demonstrating the effects of vegetation on river planforms are reported in literature, but numerical studies of these effects at the river scale are lacking. We investigated the effects of vegetation in a 2D morphodynamic model using submodels for flow resistance and colonisation of newly formed deposits. In the vegetated areas, the flow resistance was divided into a resistance exerted by the bed and a resistance exerted by the plants, adopting Baptist's formulation. In this way the model was able to reproduce the decrease in bed shear stress thereby reducing sediment transport capacity, and the increase in hydraulic resistance thereby reducing flow velocities. Colonisation was reproduced by assigning vegetation to the areas that became dry at low water stages. Bank accretion and erosion were reproduced as drying and wetting of the computational cells at the channel margins. The rate of bank erosion was related to the rate of bed degradation at the adjacent wet cells. The model was applied to a hypothetical case with the same characteristics as the Allier River near Moulins, France. The river was allowed to develop its own geometry starting from a straight and uniform channel. Different vegetation densities were found to produce different river planforms. At the highest density the flow concentrated in a single channel and the river formed incipient meanders. Without floodplain vegetation the river showed a clear braided pattern, with the formation of several bars. At low vegetation density the river showed a transition pattern, i.e. a low braiding degree with distinguishable meanders. The braiding degree was also influenced by overbank flows. Since both the river hydraulic regime and floodplain vegetation depend on changes such as climate, river damming and restoration, it is recommended that the impacts on river morphology and vegetation are assessed jointly in an integrated manner.

Key words: River morphology, meandering, braiding, flow through vegetation, colonisation by plants, bank erosion.

1. INTRODUCTION

Riparian vegetation increases the bank resistance against erosion directly by root binding, and indirectly by enhancing local deposition of organic material and fine sediment, which increases the soil cohesion (Tal et al., 2004). Besides, the flow resistance due to vegetation reduces the velocities between and above the plants and concentrates the flow in non-vegetated areas. The lower flow velocities between the plants result in a decrease in bed shear stress, soil erosion and sediment transport (Thorne, 1990; Carollo et al., 2002). The effects of vegetation on river banks and floodplains can be seen at all spatial scales. At the cross-sectional scale, vegetation causes deflection of the main flow towards the centre of the river channel (Tsujimoto, 1999), reduces bank erosion and enhances bank accretion, which results in smaller width-to-depth ratios. At the reach scale, riparian vegetation reduces the braiding degree of the river (e.g. Tal et al., 2004 and Kurabayashi and Shimizu, 2003).

Previous numerical studies on the effects of vegetation on the river pattern reproduce changes at the flume scale. Tsujimoto (1999) showed that floodplain vegetation reduces the channel width-to-depth ratio using a 2D model reproducing a laboratory experiment without bank erosion. Jang and Shimizu (2007) reproduced the morphological behaviour of an experimental channel with and without floodplain vegetation with a 2D model including bank erosion. Without floodplain vegetation the channel developed a braided pattern; with vegetation a meandering planform with a smaller width-to-depth ratio. Channel mobility decreased with increasing vegetation density.

This work aims at reproducing the effects of vegetation at a real river scale by means of a 2D model with a simplified bank erosion formulation, taking into account colonisation by plants of newly formed sediment deposits. The model includes the effects of vegetation on the hydraulic roughness, distinguishing between the flow between the plants and the flow above the plants, as suggested by Baptist (2005). The model does not take into account the effects of vegetation in decreasing the local soil erodibility.

The river chosen as example for the investigation is the Allier River just upstream of Moulins (France), which is at the transition between meandering and braiding. The characteristics of this river were used to construct a hypothetical river, which was allowed to develop its own geometry starting from a straight and uniform channel. Different floodplain vegetation densities were considered.

2. GENERAL SETTING

The Allier River is located in Auvergne (France) and is a main tributary of the Loire. In the study area (last 6 km upstream of the city of Moulins), the river forms three meanders and presents one or more channels (Figure 1).

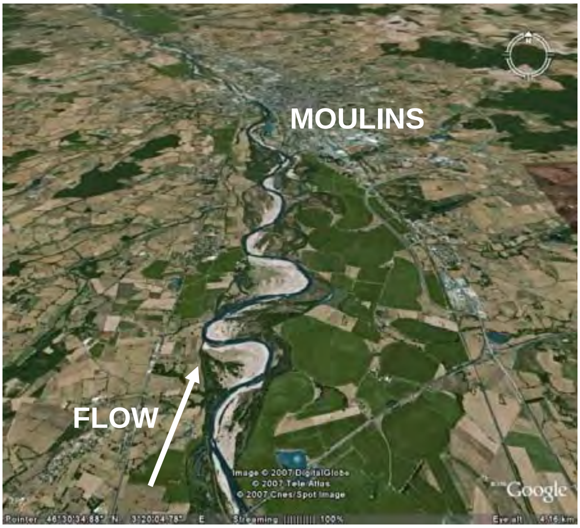

Figure 1 – The Allier River upstream of Moulins (image © Digital Globe Google Earth).

The sediment forming the riverbed is gravel characterised by strong horizontal and vertical variations (sorting and armouring). Discharges vary between 10 and 1400 m^3/s. Bankfull and mean yearly discharges are 300 and 140 m^3/s, respectively; the minimum discharge that is able to move the armour bed layer and produce morphological changes is 200 m^3/s.

In the study area, the river banks are unprotected. Between August 2003 and August 2004 the river bank retreat rates ranged between 10 and 65 m/year, whereas at the other side of the channel the point bars advanced by 30 to 40 m (De Jong, 2005). Moving away from the river, floodplain vegetation varies from pioneer vegetation, herbs and weeds to softwood forest. Table 1 summarises the main river characteristics (Blom, 1997).

Table 1 –Characteristics of the Allier River near Moulins at bankfull conditions.

Main channel width	River corridor width	Valley slope	Mean water depth	Chézy coeff. main channel	D_{50}
65 m	1000 m	0.000833	2 m	50 $m^{1/2}/s$	5 mm

3. METHODOLOGY

The 2D morphological model used for the investigation (Lesser et al., 2004) is based on the continuity and momentum equations for water, coupled to the balance and transport equations for sediment, designed for curved channels. In the equations, the sediment transport direction is corrected to take into account the transverse bed slope and the spiral flow in river bends (Struiksma et al., 1985), whereas the spiral flow itself is reproduced in a parameterised way (Blanckaert et al., 2002). Bank erosion is treated in a simplified way: the model assigns a part of the erosion occurring inside the wet cells that are located at the margin of the water flow to their adjacent dry cells, which then become wet. This "erosion distribution" is weighted by a coefficient having the same value in the entire model domain.

The model simulated the morphological development of a river having the characteristics of the Allier, starting from a straight channel. The sediment was assumed uniform with a diameter equal to the D_{50} (Table 1) and the same sediment characteristics were imposed to the entire model domain. Due to the long-term character of the investigation, the discharge hydrograph was simplified to reproduce a characteristic year, which was repeated for the number of years defining the duration of the investigation period. Two discharge regimes were considered: a varying discharge, derived from the duration curve 1968-1995 (Blom, 1997), ranging between 200 and 800 m^3/s (overbank flow for about one month per year) and a constant discharge of 200 m^3/s (no overbank flow). The modelled area was 1 km wide, including main channel and floodplains, and 6.5 km long. The rectangular grid consisted of 71 cells in cross-sectional direction and 186 cells in longitudinal direction. The size of the grid cells was smaller (10 m) in the central part of the river corridor (Figure 2).

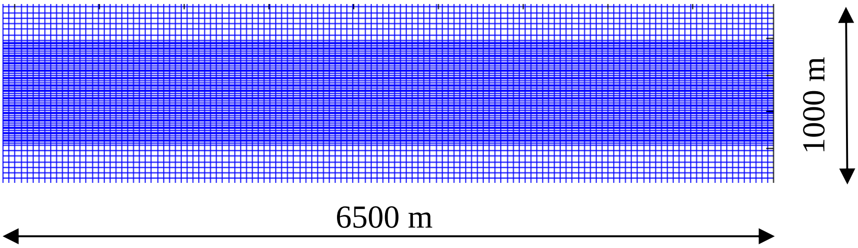

Figure 2 – Computational grid.

The effects of vegetation on the hydraulic roughness were obtained by applying *Baptist*'s method (*Baptist*, 2005; *Baptist et al*., 2005). This method separates the bed shear stress (soil) from the shear stress of vegetation and distinguishes between fully submerged and partly submerged vegetation. Plants are schematised as thin, vertical cylinders with given density. The method assumes that the flow velocity through vegetation is uniform over the vertical, which is valid only for high vegetation density. With this formulation, the model was able to reproduce the decrease in bed shear stress that reduces sediment transport and the increase in hydraulic resistance that reduces flow velocities in the vegetated areas.

In the investigation, the floodplain was assumed to be uniformly covered by 0.2 m high grass, in the form of cylinders (stems) having a diameter of 0.015 m. Two densities were considered: 100 and 4.5 stems/m^2. The highest density value is typical for grassland, whereas the low density value takes into account the situation of the Allier River, in which the point bars are mostly covered by low-density pioneer vegetation. A value of 1 was adopted for the drag coefficient.

The model also included the colonisation of new deposits by plants during low flows, which was done by assigning vegetation having the same density as on the floodplains to the areas that became dry at a discharge of 200 m^3/s.

4. RESULTS

Due to the limitations caused by long computational times the simulation period had to be restricted to approximately 10 years. Since the morphological time scale of the River Allier in the study area was estimated using the formula indicated by de Vries (1975) at 150 years, the simulations could reproduce only incipient large-scale river morphological changes. Nevertheless, clear morphological differences appeared between the cases with and without vegetation and between the two vegetation densities. Figure 3 shows the river morphology obtained with variable discharge after 10 years in the three cases: without floodplain vegetation, with high-density vegetation and with low-density vegetation. Figure 4 shows the development of cross-section 176 (location indicated in Fig. 3) without floodplain vegetation. Figure 5 shows the bed shear stress in the two cases with high-density vegetation and without vegetation.

After 10 years, without floodplain vegetation the river configuration was clearly braided with the formation of several bars in the cross-section (Fig. 3B). The braiding degree drastically reduced with low-density floodplain vegetation (pioneer vegetation), yielding a channel at the transition between meandering and braiding. In this case, clear meanders are detectable but at certain locations the flow splits forming more than one channel (Fig. 3C). Finally, the presence of grass on the floodplains was sufficient to impose an incipient meandering character to the river (Fig. 3D).

It should be noticed that only the effects of vegetation on floodplain roughness and sediment transport rates were accounted for in the model. The coefficient weighing the bank erosion rate was the same in all cases and the effects of vegetation on the soil erodibility were not taken into account. The higher roughness caused by the presence of plants increased the flow concentration and the bed shear stresses in the main channel (Fig. 5), which resulted in lower width-to-depth ratios and reduced number of bars. This result agrees with previous investigations (e.g. Tsujimoto, 1999; Tal et al., 2004; Kurabayashi and Shimizu, 2003; Jang and Shimizu, 2007). On the floodplains, vegetation reduced the bed shear stresses (Fig. 5) and the sediment transport capacity.

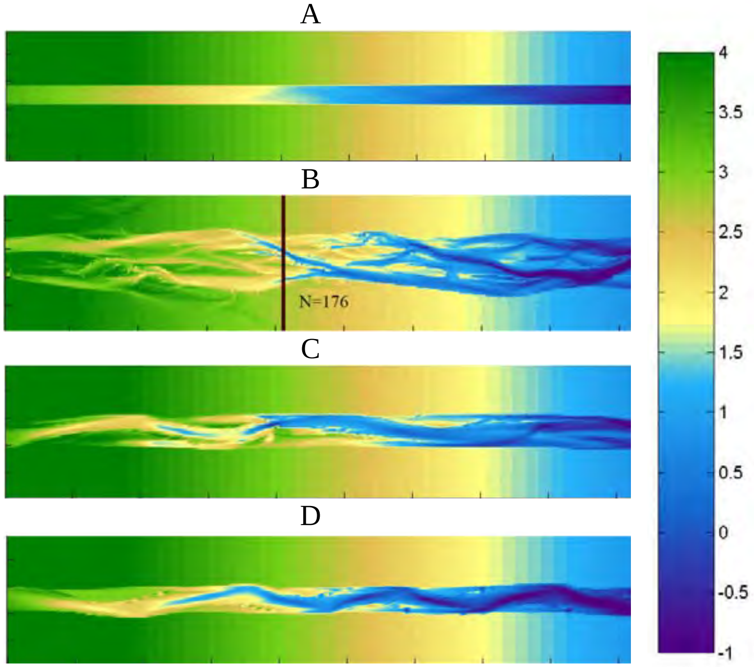

Figure 3 – Initial channel configuration (A) and river morphology after 10 years without floodplain vegetation (B), with low density floodplain vegetation (C) and with high density floodplain vegetation (D). Variable discharge, including overbank flows. Colour bar: bed level in m above reference level.

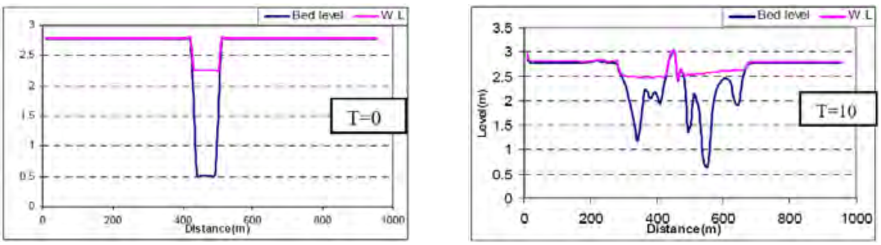

Figure 4 – Initial and final configuration of cross-section N = 176 without vegetation. Purple line: bed level. Pink line: water level (at dry places the model assumes that the water level coincides with the bed level).

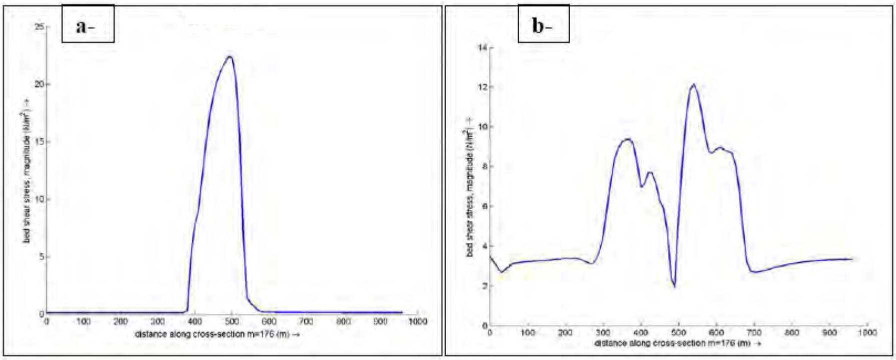

Figure 5 – Bed shear stress at peak discharge (800 m^3/s) at cross-section N = 176 after 10 years, with vegetation (a) and without vegetation (b).

A braided river configuration was obtained also with a constant discharge of 200 m^3/s (lower than bankfull, but sufficient to produce morphological changes), as shown in Figure 6, but in this case the braiding degree was lower than when overbank flows occurred (Fig. 3B).

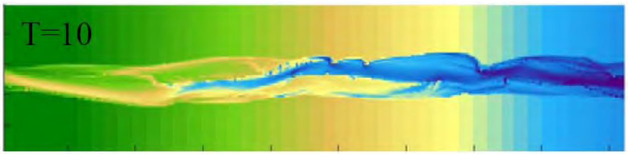

Figure 6 – River morphology after 10 years: no floodplain vegetation, constant discharge (colours as in Figure 3).

5. CONCLUSIONS

We numerically investigated the effects of floodplain vegetation on river planform characteristics at the scale of real rivers, using submodels for bank erosion and colonisation by plants of newly formed sediment deposits. The study shows that floodplain vegetation (grass) is able to transform a braided channel into a meandering one also at the scale of real rivers. The presence of pioneer vegetation (low density grass) is sufficient to lower the braiding degree, producing a channel at the transition between meandering and braiding, as the real River Allier. The investigation included only the effects of vegetation on the hydraulic roughness. Including also the effects of vegetation in reducing the soil erodibility would further increase the detected trend. A braided pattern can result from discharges lower than bankfull, whereas overbank flows were found to enhance the braiding degree.

As a conclusion, floodplain vegetation should be taken into account to assess the long-term morphological changes of river systems. River damming and restoration works, as well as climate changes, by altering hydrology and floodplain vegetation, on the long term alter the river pattern.

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REFLECTION OF HYDROMORPHOLOGICAL CONDITIONS IN A MOUNTAIN RIVER SUBJECTED TO VARIABLE HUMAN IMPACT IN THE ABUNDANCE AND DIVERSITY OF FISH FAUNA

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ABSTRACT

The Czarny Dunajec River, Polish Carpathians, has been considerably modified by channelization or channel incision and varies in morphology from single-thread, incised or regulated channel to unmanaged, multi-thread channel. Hydromorphological river quality was assessed for 12 cross-sections with 1-4 flow threads and compared with the abundance and diversity of fish fauna determined by electrofishing. The variation in depth, velocity and bed material size in each cross-section was also determined. Values of hydromorphological quality for the surveyed cross-sections ranged between 1.08 and 3.96, with the cross-sections with heavily island-braided morphology representing high status conditions and those located in channelized river sections falling into Class 4. The increasing number of low-flow channels in a cross-section was associated with increasing variation in depth, velocity and bed material size. Single-thread cross-sections hosted only 2 fish species and 13 specimens on average, whereas 3-4 species and 82 specimens on average were stated in the cross-sections with four low-flow channels. The reduced abundance and diversity of fish fauna typified single-thread river sections located both upstream and downstream of the multi-thread channel reach. The number of both fish species and specimens increased linearly with increasing variation in depth within a cross-section and exponentially with improving hydromorphological quality. This study shows that the simplification of flow pattern and the resultant aggravation of hydromorphological river quality, caused by human disturbances, is reflected in remarkable impoverishment of fish communities. This indicates a need for increasing morphological complexity and improving hydromorphological quality of the river to recover the abundance and diversity of its fish fauna.

Key words: mountain river, hydromorphological quality, human impact, fish fauna

1. INTRODUCTION

In the 20th century many mountain rivers in Europe were largely modified due to human activity, with the resultant loss of vertical stability of their channels and a dramatic decrease in the biodiversity of riverine and riparian ecosystems (Habersack & Piégay, 2008). Similar detrimental changes occurred also along most rivers in the Polish Carpathians (Bojarski et al., 2005). Channelization works resulted in considerable shortening of the rivers and transformation of their former multi-thread channels into straight, artificial channels with highly increased transport capacities (Wyżga, 2008). Moreover, some Carpathian rivers underwent intense gravel mining from their channels (Rinaldi et al., 2005). The increase in transport capacity of Carpathian rivers together with bed material deficit resulting from gravel mining have led to rapid incision of their channels, which amounted to 0.5-3.8 m over the 20th century (Wyżga, 2008). To prevent bed degradation of the rivers, concrete weirs were constructed in their channels; however, this has disrupted continuity of the rivers for fish (Bojarski et al., 2005).

With the increasing understanding of adverse effects of human intervention in river channels, restoration measures are increasingly being undertaken in mountain rivers in Europe (Habersack & Piégay, 2008), aiming to improve their geomorphological and ecological conditions. In the attempts to restore good ecological status of watercourses, it is essential to determine the relations which exist between the structure of river biocoenoses and the quality of hydromorphological characteristics of the habitats. This will allow to establish whether the good quality of river ecosystems can be re-attained through the improvement of physical characteristics as well as the flow and sediment regime of the watercourse (i.e. of its hydromorphological quality), or the ecosystem degradation has been caused by a decrease in water quality which would then focus restoration measures on improvement of the latter. Determining the biodiversity gradients of riverine communities and the scale of habitat modification in relation to reference (natural) conditions will indicate the range of necessary restoration measures to be undertaken.

This study presents the results of a study on the relations between the abundance and diversity of fish fauna and hydromorphological river quality in a number of cross-sections of the Czarny Dunajec in the Polish Carpathians.

2. FIELD SETTING

The Czarny Dunajec is an example of a mountain river, which has been subjected to considerable though spatially varied modification by human activity. The study area encompasses a 17 km long reach along which the catchment area increases relatively little and the river receives no major tributaries. In the upper part of the reach, up to 3.5 m of channel incision has occurred to date in response to the sediment deficit caused by in-stream gravel mining conducted during a few past decades. In the second half of the 20th century, a 7 km long, middle part of the reach was channelized with the use of concrete weirs. This has resulted in replacement of the former multi-thread channel by a single, nearly straight one, whereas the weirs have disrupted the river continuity for fish. In the lower part of the reach, the river has remained unmanaged, showing island-braided to heavily island-braided channel pattern. At the downstream end of the study reach there again occurs a narrow, regulated channel; however, its slope has not been reduced by drop structures. It is evident from the above description that the present Czarny Dunajec in its middle course highly varies in terms of river morphology and channel management (Krzemień, 2003; Zawiejska & Krzemień, 2004; Wyżga & Zawiejska 2005). There occur channelized and unmanaged river sections, sections with single- and multi-thread channel morphology as well as those with alluvial and bedrock boundary conditions. This variability of channel types conditions high variability in physical parameters of habitats along the reach which, in turn, is likely to be reflected in the differences between local river biocoenoses.

3. STUDY METHODS

Twelve cross-sections representing a range of hydromorphological conditions present in the study reach of the Czarny Dunajec were examined. For each cross-section, detailed levelling was performed and water depth, mean flow velocity and mean grain size of surface bed material were determined at 1 m intervals within the low-flow channel(s). Mean size of gravelly sediment was established in the field by means of transect sampling, while that of sandy and silty sediment in a laboratory. For each cross-section, means and coefficients of variation of the three parameters were next calculated.

Hydromorphological quality of the river in the investigated cross-sections was assessed through scoring of channel, river banks, riparian zone and floodplain features according to their specification in the European Standard EN 14614 (CEN, 2003). The assessment was performed by four specialists in fluvial geomorphology, river engineering and hydrobiology following field site inspection as well as the analysis of river channel changes over the past decades and the presentation of channel cross-sections and river appearance at particular sites on orthophotos and ground photos. Each assessed category was scored on the scale from 1 (near-natural conditions) to 5 (extremely modified conditions). The aggregated score, averaged for the four specialists, allowed to associate each of the cross-sections with a particular class of hydromorphological quality.

Species composition of fish communities was estimated on the basis of results of single electrofishings carried out on 4 September 2006 in 10-m wide stripes along the twelve channel cross-sections. Number and approximate total lengths of the individuals caught in particular low-flow channels were recorded. Juveniles (YOY) and subadult and adult fishes (1+ and older) were recorded separately. These age categories were distinguished taking the total length of 10 cm (brown trout) or 5 cm (other species) as the size limit.

4. RESULTS

The analysis of hydromorphological conditions in river cross-sections with different number of low-flow channels showed that complexity of flow network affects the formation of fish habitats. Multi-thread cross-sections were typified by significantly greater aggregated width of low-flow channels than single-thread cross-sections (Fig. 1). However, the most striking difference between these types of cross-sections was their distinct variation of abiotic characteristics of fish habitats (Fig. 1). Single-thread cross-sections showed significantly lower variation in flow depth (Mann-Whitney test, $p=0.01$), velocity ($p=0.02$) and mean size of bed material ($p=0.02$) than the cross-sections with four low-flow channels. In the former, only gravelly bed occurred whereas in the latter, the dominating gravelly parts of the bed were accompanied by those covered with sand or mud (Fig. 1).

Performed evaluation of hydromorphological quality of the river indicated its considerable variation among the surveyed cross-sections, with the values ranging between 1.08 and 3.96 (Fig. 2). For all cross-sections with four low-flow channels, the river has been classified as representing high status (reference) conditions, with two cross-sections showing heavily island-braided morphology (I and J) considered to be only slightly modified by human activity. In turn, single-thread cross-sections with regulated channel (D–F and L) fell into Class 4. This reflected radical modification of channel geometry in the cross-sections, the lack of erosional and depositional forms, disturbance of fish migrations by weirs, loss of hydraulic connectivity of the river with its floodplain and lateral channel stabilisation. Finally, unmanaged cross-sections A–C (two single-thread ones and one with three low-flow channels) with deeply incised channel were considered to represent good hydromorphological conditions (Class 2).

In total, 1463 fishes (1010 juveniles and 453 older) were recorded in the investigated cross-sections. They belong to four species, i.e. brown trout, *Salmo trutta* L. (16 and 40, respectively), Alpine bullhead, *Cottus poecilopus* Heckel (38 and 92), Eurasian minnow, *Phoxinus phoxinus* (L.) (953 and 316) and stone loach, *Barbatula barbatula* (L.) (3 and 5). Brown trout and Alpine bullhead occurred in all cross-sections, while Eurasian minnow were found in five, and stone loach in only two cross-sections (Fig. 2). The number of both species and older individuals was greater in multi-thread channels (Fig. 2). Single-thread cross-sections hosted 2 species and 4-22

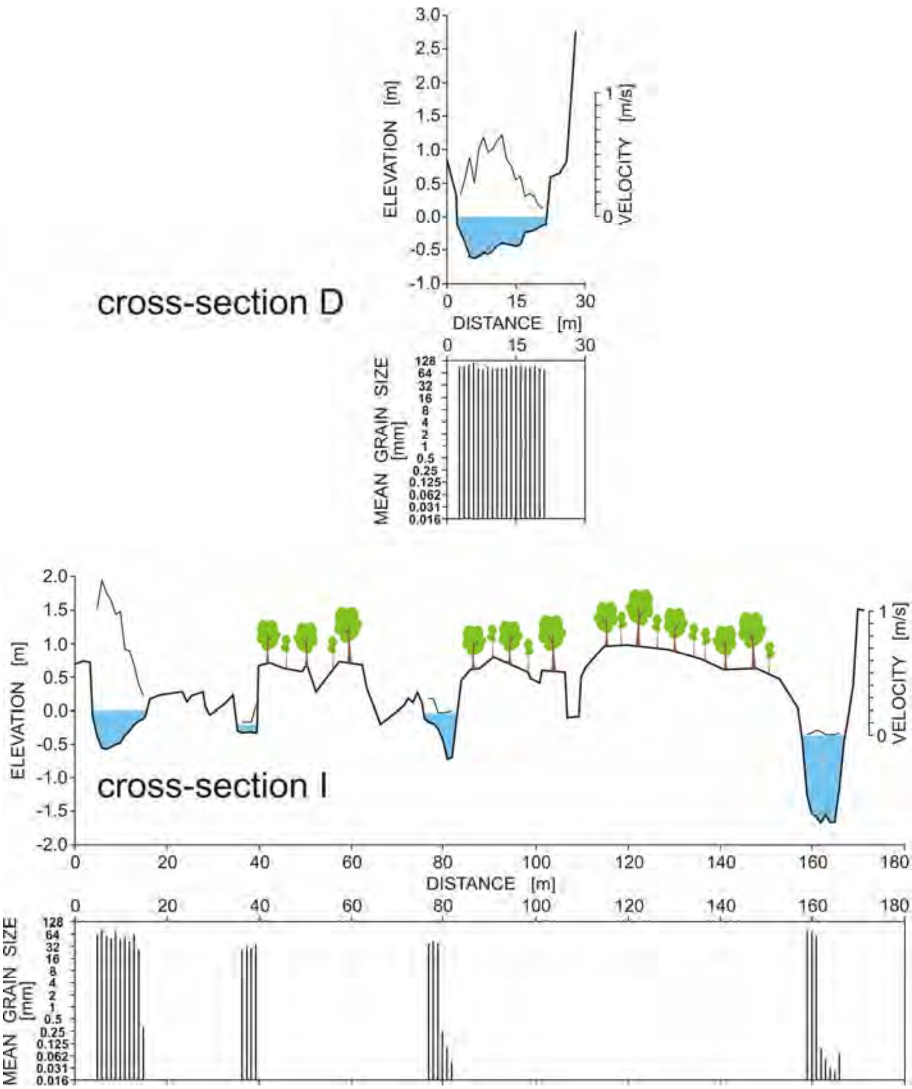

Figure 1 – Examples of cross-sectional morphology of the Czarny Dunajec River in channelized reach (upper) and unmanaged reach (lower). For low-flow channels, mean size of the sediment on bed surface and mean flow velocity are indicated at 1m intervals. A scale for the velocity is movable, with its beginning located on the water surface at each low-flow channel.

specimens (13 on average), whereas 3–4 species and 36–119 specimens (mean: 82) were recorded in the cross-sections with four low-flow channels, and these differences were statistically significant (Mann-Whitney test, p=0.01 for both species and specimens). The occurrence of two-species

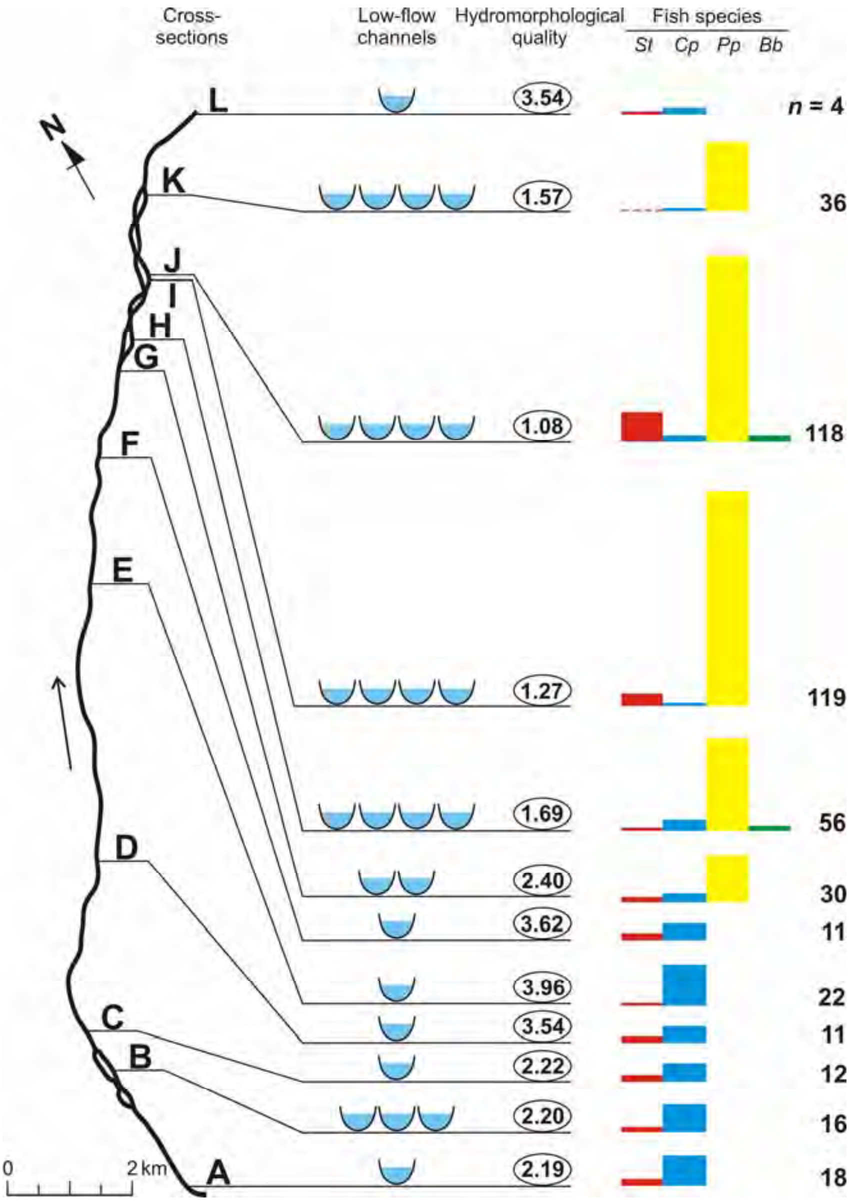

Figure 2 – Comparison of the number of low-flow channels, the assessment of hydromorphological quality and the results of electrofishing carried out in 12 cross-sections of the Czarny Dunajec: *St* – *Salmo trutta* L., *Cp* – *Cottus poecilopus* Heckel, *Pp* – *Phoxinus phoxinus* (L.), *Bb* – *Barbatula barbatula* (L.), n – total number of subadult and adult (≥ 1 year old) individuals caught; dashed line indicates the occurrence of juveniles (YOY) only.

fish assemblages with low numbers of individuals was characteristic of single-thread cross-sections situated both upstream and downstream of the unmanaged, multi-thread river reach (Fig. 2).

Regression analysis of the relations between abiotic characteristics of the studied habitats and the diversity and abundance of fish assemblages indicated the number of both species and specimens to increase linearly with increasing variation of water depth in a cross-section (species: R=0.75, p=0.005; specimens: R=0.71, p=0.009) and exponentially with improving hydromorphological river quality (species: R=–0.76, p=0.000001; specimens: R=–0.94, p=0.000001) (Fig. 3). Especially large increase in the number of specimens occurred with relatively small improvement in the hydromorphological quality of the river that was associated with the change from its island-braided to heavily island-braided morphology. The number of fish specimens increased also with increasing variation of the size of bed material in a cross-section (R=0.58, p=0.047).

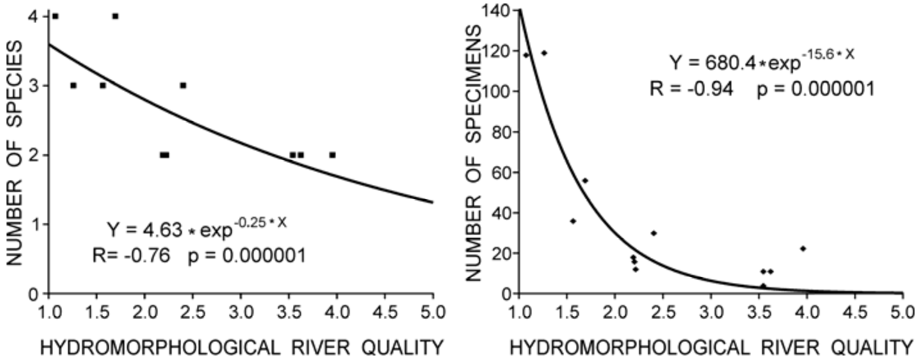

Figure 3 – Scatter plots and estimated regression relationships between the number of fish species (left diagram) and subadult and adult fish specimens (right diagram) caught in the investigated cross-sections of the Czarny Dunajec, and the hydromorphological river quality in the cross-sections.

5. DISCUSSION

With the exception of grayling, *Thymallus thymallus* (L.), which still three decades ago was recorded over most of the length of our study reach (Starmach, 1984), this study documented the occurrence of fish species reported from the Czarny Dunajec in the second half of the 19th century (Nowicki 1883) and confirmed in the years 1975-1980 (Starmach, 1984). However, the extent of stone loach and Eurasian minnow in the study reach has been considerably limited in comparison to the situation from the 1970s. In a few past decades, deep channel incision in the upper part of the study reach (cross-sections A-C) and channel regulation in its middle part (cross-sections D-F) resulted there in an almost complete elimination of multi-thread flow pattern and shallow areas in the channel, that led to the unification of in-stream habitat conditions as well as a considerable increase in flow velocity and mean size of bed material. These changes, together with the disturbance of fish migrations by weirs constructed in the channelized river section, must have contributed to the decline of grayling as well as the reduction of the extent of stone loach (cf. Santoul et al., 2005) and Eurasian minnow in the study reach.

Most of the investigated cross-sections are presently typified by the occurrence of two-species fish assemblage (brown trout and Alpine bullhead) characteristic of mountain streams with fast water flow. In the multi-thread cross-sections, it is completed with Eurasian minnow which represents an additional environmental guild (Welcomme et al., 2006) connected with pools. The abundant occurrence of this species in multi-thread channel enhanced the disparity in fish specimens between the single- and multi-thread cross-sections.

The relations between the abundance and diversity of fish assemblages and physical characteristics of river channel, recognised in the Czarny Dunajec, probably reflect the links that exist between channel form, habitat conditions and riverine communities (Smiley & Dibble, 2005). The research performed in the river highlighted the dependence of the number of species and specimens on the variability in water depth, while their relation with an aggregated width of low-flow channels was not confimed. Therefore, the increase in fish abundance and diversity is not an effect of simple enlargement of habitat area but reflects increasing habitat diversity, especially of those habitats which are crucial for juveniles, mainly as nursery areas and refuges (Langler & Smith, 2001; Dolinsek et al., 2007). Multi-thread channel sections exhibit greater variability in many habitat parameters, such as the co-existence of patches of coarse and fine bed substrate, slow and fast water current, zones of the inflow of hyporheic water and the infiltration of riverine water into the channel bed, or zones of different water shading by tree canopy, which together are reflected in better assessment of hydromorphological river quality. As the relation between channel morphology and habitat conditions in a river is relatively strong (Smiley & Dibble, 2005), it explains the increase in the number of fish species and even more in that of specimens with increasing hydromorphological quality in the Czarny Dunajec.

6. CONCLUSIONS

The study showed that high variability of hydromorphological quality of the Czarny Dunajec, caused by spatially varied human impact, is clearly reflected in the diversity and abundance of fish fauna. More diverse and relatively abundant fish communities were recorded only in a short river reach where natural river dynamics and a multi-thread channel pattern were preserved due to the lack of significant human intervention. This reach is typified by high variability of habitat conditions, reflected in the highly valued hydromorphological river quality in the examined multi-thread channel sections. Preservation of the undisturbed channel dynamics and the high morphological complexity of the river in the reach will be essential to preserve species diversity of fish communities in the Czarny Dunajec and to restore in the future this diversity in the modified river reaches. The dependence of the abundance and diversity of fish communities on hydromorphological river quality and the degree of variability in channel morphology, demonstrated in this study, indicates that future improvement of the ecological status of this and other mountain rivers will require a renewed increase in morphological complexity of their channels (cf. Muhar et al., 2008) and improvement of hydromorphological conditions in the rivers.

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DOES RESTORATION OF FLOODING AND RECONNECTION OF ANASTOMOSING CHANNELS IN THE UPPER RHINE FLOODPLAIN IMPROVE ALLUVIAL ECOSYSTEM FUNCTIONS AND BIODIVERSITY?

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ABSTRACT

Hydraulic works on large rivers have drastically modified the structure and the functioning of alluvial ecosystems. In particular they have led to the disconnection of anastomosing and/or braiding channels, and alluvial forests from the main channel. Nowadays many restoration projects are developed aiming at both flood retention and ecological restoration. One of the objectives is to restore river functional characteristics of the alluvial ecosystems such as surface water/groundwater exchanges, lateral hydrological connectivity, water purification, diversity of habitats and species. Within the Upper Rhine floodplain (Eastern France), the “Erstein polder” is a pilot site which allows monitoring of the impact of re-flooding of alluvial areas. The re-flooding of the polder by flood waters, which are usually highly charged with suspended and soluble matter, may change the physical and chemical composition of different compartments -water, sediment and soil- of the alluvial system. Additionally, the hydrodynamics of the anastomosing channels is enhanced by the re-flooding and reconnection with the main channel. The objectives of the monitoring are : i) to identify the risks of water pollution, related to transfer of floodwaters into the groundwater. This requires the monitoring of pollutants brought by the Rhine; ii) to define the impact of floods on habitats, flora and fauna through relevant biological indicators; iii) to analyze the ability of the alluvial system to recover its specific functions. Since 2003 (reference year) two types of studies were conducted, one focusing on the hydrological, hydraulic, hydrochemical and geomorphological factors, the second addressing the impacts of these factors on biological compartments (terrestrial and aquatic plants, fishes, amphibians and invertebrates). Four short flood events occurred during the investigation period (2004-2007). We present the main results of the observed changes as a consequence of re-flooding and channel reconnection obtained after four years of monitoring.

Key words: Upper Rhine, “Erstein polder”, restoration of flooding, anastomosing channels reconnection, multi-disciplinary monitoring.

1. INTRODUCTION

Hydraulic works on large rivers such as straightening and canalisation impacted drastically the alluvial ecosystems and increased flooding downstream the embedded reaches. Nowadays many restoration projects for previously flooded areas are developed with the joint aims of flood retention and ecological restoration. In the Rhine floodplain (eastern France) a program to prevent flooding has been signed between France and Germany, and flooding areas, called “POLDER”, were newly created for temporarily storing important volumes of water during the peak flows of the Rhine. The *Erstein polder* is a part of this vast French-German program of flood retention. In addition to the flood retention objective, the management of the *Erstein polder* aims also to restore the hydroecological functioning of the hydrosystem as closely as possible to that which existed before the canalisation (1970 in this sector of the upper Rhine) through a combination of “ecological flooding” and “anastomosing channels reconnections”.

In order to assess the benefits of these restoration measures, we used an integrated approach, mainly based on the comprehension of both the physical and biological processes. The main objectives are as follows: (i) analyse the hydrogeomorphic functioning and more particularly the surface-groundwater exchange processes, (ii) identify the risks of contaminant transport related to floodwater transfer from the Rhine into the alluvial aquifer (control and monitoring river water), (iii) define the impacts of floods on the habitats, flora and fauna through relevant indicators and (iv) analyze the system's ability to restore original functions of alluvial ecosystems. In this paper the main results of the flooding restoration and impacts on physical and biological compartments are summarised.

2. GENERAL SETTING

The *Erstein polder* is located 20 km south of the town of Strasbourg (France) and implemented in a 600 ha forested area. There has been no flooding for 40 years in the eastern area, and for 200 years in the western part outside of the dykes built at the 19th century (Fig 1). Three types of management of the polder are applied depending on high flow discharges: “reconnection” of anastomosing channels when the discharge is higher than 1,550 m^3/s, ecological flooding when the discharge is higher than 2,000 m^3/s, but only during the period of June-July, flood retention when the discharge is higher than 3,600 m^3/s (all the polder area is flooded).

Scientific monitoring has been conducted for 5 years in order firstly to observe and measure the impacts of these different modes of flooding on hydrogeomorphological and ecological functioning, and secondly to propose management rules for the polder based on lessons learned from the monitoring results. The scientific monitoring is divided into two parts: (i) an initial phase to update and collect data before the first reflooding and (ii) for a second phase over a period of 5 years the first flooding (January 14, 2004). Monitoring comprises: (i) hydro-geomorphological analyses of suspended deposits, variations of discharge and groundwater levels, and surface/groundwater exchange processes, and (ii) ecological studies, including water quality, an analysis of floristic composition and health state of forests, macro-invertebrates, aquatic macrophytes, fish and amphibian fauna in aquatic ecosystems (ponds, lateral arms), large mammals.

In the context of restoration, a key question is which state is interesting or necessary to obtain? Is it the state of the free braiding and anastomosing Rhine before the first engineering works (1841-1871) (Trémolières et al. 2002)? This ideal reference, however, has not existed for a very long time (Piégay et al. 2006). It emerged from preliminary work and ecological knowledge of *Erstein polder* that a reasonable, attainable objective state was the state of Rhine between 1872 and 1967 (before canalisation). Although the Rhine thalweg was definitively established in 1872, a large floodplain still existed until 1967. The floods were mainly caused by summer high water levels and occurred on average 14 days per year. However they exhibited low morphodynamics. The pioneer forest has, therefore, evolved to a post-pioneer stage and softwood forest has been maintained without renewal until today. The forest was inundated when the Rhine discharge at Strasbourg ranged from 1,800 to 2,000 m^3/s, and the groundwater level varies from about 3 to 5m. At that time, lateral arms of the Rhine in the polder area were fed by the Rhine, at a discharge of about 1,000 m^3/s. The arms flowed at 10 to 30 m^3/s for 180 days per year on average and drained 4 to 5 m^3/s of groundwater during low flow (CSA 1998).

3. RESULTS OF THE MONITORING

3.1 Results of the initial state (2003) and expected benefits by restoration

3.1.1 Geomorphic structure

After 40 years without flooding, most of the anastomosing channels showed significant silting in the downstream part of the polder (silting rate of about 4 cm/year). With the restoration of floods and channel reconnections, fine sediments brought by flood water and by re-suspension of endogenous silt could potentially increase the rate of silting in the downstream part of the polder. On the other hand, scouring process in channels is expected to increase in the upstream part of the polder. This could modify the conditions of surface/groundwater exchanges, with regards to the situation described in 2003.

The alluvial soils differ in their depth and their degree of hydromorphy. The more superficial soils are stony and are located mainly in the upstream-Western part. Deep soils are located in the intermediate zone, with clayey hydromorphic soil in the East and downstream along some anastomosing channels. This soil distribution shows a sectorisation of the polder in 4 zones conditioned by the hydrological functioning of polder (Fig. 1).

3.1.2 Ecological analysis

Different compartments (water, sediment and aquatic plants), show in general, good chemical quality for aquatic life except in anastomosing channels during low water periods, which then shows a tendency to anoxia due to accumulation of organic matter. Micropollutants are present at low levels in the different compartments, having their origin, when detected, in the historic pollution of the Rhine. Restoration of polder, given the water quality of the Rhine, is likely to boost the alluvial system and improve the physical-chemical quality. The results of studies of *Altenheim polders* (Germany , 1993-1996) confirm this assertion. In areas outside the polder (downstream), the risks of pollution in the context of ecological floods are very low.

The aquatic flora, with nearly 35 species of macrophytes identified so far, is rich, and varied locally depending on the origin of water (Rhine or groundwater fed). Macrophytes indicate that the majority of streams are meso-eutrophic (community with *Callitriche* and *Berula)*, with locally eutrophic sectors (community with *Potamogeton pectinatus, Ceratophyllum* and *Elodea nuttallii*). The sectors with running water are dominant, except in some reaches of channels.

The fish yields per hectare are low (140kg/ha), which is common in lowly eutrophicated groundwater streams (Trémolières et al. 1993, Bornette et al. 1998). We observed an exclusive dominance of the eel, unlike the national trend of decline of the species. The fish community is specific to this type of lowland stream, with the presence of trout supported by groundwater seepage and gravel beds, mixed with varying proportions of running or standing water Cyprinids. Flooding should promote the arrival of species from the Rhine and an increasing density related to inputs of eutrophic waters.

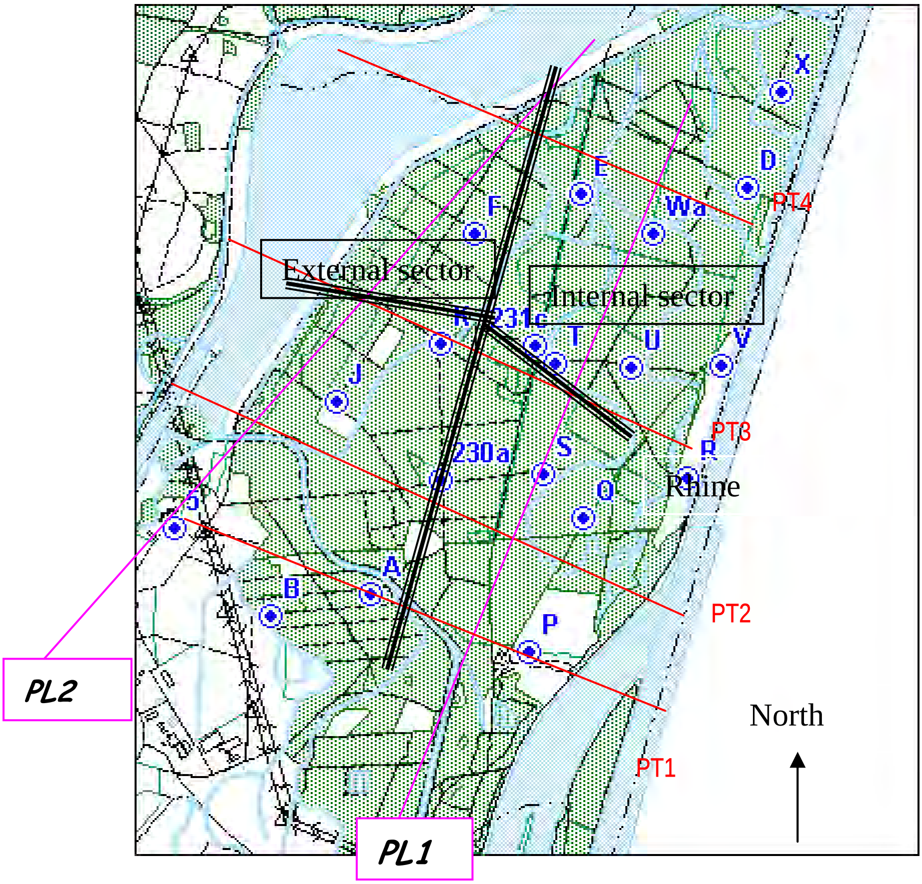

Figure 1 - Sectorisation of the Erstein polder in four zones and location of the piezometers. (PT transversal piezometric profile, PL longitudinal profile)

The amphibian community of the Rhine Valley in Alsace is composed of 16 species. Four of them are typical of this habitat (*Lissotriton vulgaris*, *Triturus cristatus*, *Rana dalmatina* and *Pelophylax* kl. *esculenta*). At least 9 species occur in the amphibian assemblage found in the Erstein polder. The great crested newt *Triturus cristatus*, a species with an European conservation status, is quite common. The flooding of the polder could in a way enhance this assemblage by creating suitable habitats that would enable the settlement of the yellow-bellied toad (*Bombina variegata)*. On the other hand, the great crested newt, which is linked to specific types of ponds, could suffer a decline in its numbers.

Large mammals are strongly influenced by the former practice of hunting, which was oriented towards intensive supplementary feeding (external sector) to maintain populations of wild boar and roe deer inside the forest. This resulted in high densities and a significant negative impact on vegetation. While some species will suffer damage related to floods (small mammals, deers), others typical of alluvial zones, such as the beaver, could expand (observations in 2001 in Kehl). However, colonisation by the beaver, a good indicator of improvement of the functionality of alluvial environment, will be enhanced by the development of the *Salix* community.

The dominance of the hardwood community is related to the absence of river morphodynamics which limits the occurrence of pioneer or post-pioneer forest. The pioneer *Salix* community tends to disappear after suppression of floods. The effect of flooding on the forest will be especially noticeable in the long term. As an immediate effect, the decline or even disappearance of the most drought-tolerant woody species introduced over 40 years, a change in the regeneration of wood in general, and a rapid reorganization of the distribution of herbaceous plants are expected. More drought-tolerant species or those susceptible to flooding could disappear and species tolerant of summer floods could be promoted. The quality of these habitats of European interest within the meaning of the Habitats Directive (1992), could be improved, benefitting zoocenoses associated with the forest, such as birds and beetles, which are sensitive to improving structure (increase the diversity of ecological niches).

3.2 Impact of flooding. What main changes are recorded?

The hydrology of the Rhine for the four study years led to the following duration of channel reconnection (CR) and numbers of ecological flooding (EF), each year. 2004: 6 days of CR and 1 EF; 2005: 12 days of CR and 1 EF; 2006: 87 days of CR and 1 EF; 2007: 45 days of CR. One complete flood retention occurred in August 2007.

Four years after the first flooding and channel reconnection, the piezometric regime seems to have improved through an increase of groundwater amplitude, especially in 2007 (Tab. 1) during which there was a strong increase in the maximum groundwater level associated with the summer reconnection.

Table 1 - Variations of groundwater levels and amplitude for four years of the monitoring2003

Year	2003	2004	2005	2006	2007
Mean groundwater level (m)	146,89	146,85	147,02	146,80	146,86
Variation Coefficient	0,1 %	0,1 %	0,1 %	0,1%	0,2%
maxi level (m NGF)	147,27	147,48	148,07	147,71	148,91
mini level (m NGF)	146,50	146,66	146,74	146,53	146,35
Groundwater amplitude (m)	0,77	0,82	1,33	1,18	2,56

An increase of groundwater drainage has been observed through an increase of exchange between river and groundwater (Tab. 2), which may be associated with increased exfiltration of the previous exchange areas by groundwater raising and /or activation of new exfiltration areas by channel scouring of areas that were silted up before restoration. However all channels are not affected by drainage, the groundwater drainage having increased only in the channels closer to the Rhine.

Table 2 - Drainage in the polder during the four years of the monitoring. Channel discharge was measured monthly : *without April ** without July (reconnection period) and June and December (no measurement)

	2004	2005	2006	2007
Mean annual discharge inputs	3,53 m^3/s	4,31 m^3/s	3,69 m^3/s	3,82 m^3/s
Mean annual discharge outputs	4,84 m^3/s	6,27 m^3/s	6,89 m^3/s	5,61 m^3/s
Drainage discharge	1,21 m^3/s	1,96 m^3/s	1,76 m^3/s*	1,77 m^3/s**
% of drainage	**27,1%**	**31,3%**	**32,1 %***	**31,5 %****
Mean Rhine discharge in Strasbourg	887 m^3/s	857 m^3/s	1037 m^3/s	1055 m^3/s

The Rhine feeds the groundwater during flooding and high water periods (Eglin et al. 1997; Trémolières et al. 1993) and so groundwater amplitude is a function of distance of any particular location from the Rhine (assuming that the degree of silting up of the banks is the same, Fig.2).

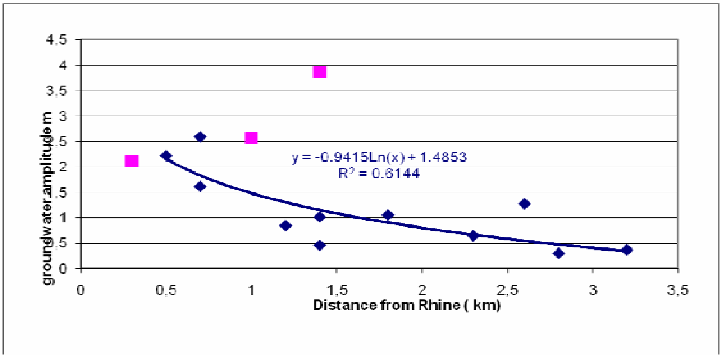

Figure 2 - Relationship between distance from the Rhine and groundwater level amplitude in 2007.

(■ : piezometers submersed during the complete overflow in august 2007, not included in the relationship ◆ : representative piezometers)

The annual temperature variations and chloride used as hydrological tracers confirm the exchange areas we observed by hydrological measurements: all the channels fed by groundwater present low temperature variations and relatively high chloride content (around 30mg/l, due to an historical pollution of groundwater) as compared to the Rhine. The chloride concentration has decreased in the Rhine water since 2003 (from around 40 in 2003 to 20 mg/l in 2007).

In surface and groundwater, the risk of pollutant contamination is negligible. Nitrate concentration in groundwater could be an indicator of ecological functioning. In fact in alluvial ecosystems the nitrate concentration in groundwater is always low, due to denitrification in temporarily saturated soils. In the polder, nitrate concentrations remain very low in the internal sector (unflooded for 30 years) and rather high (> 30 mg/l NO_3^-) in the external zone (not flooded for 200years) (Fig 3). A small change in water chemistry has been observed since 2003 in spite of the short duration of flooding and the rarity of flooding in the western sector (only one complete overflow of the polder during the study period). Variations of nitrate concentrations are lower after polder reflooding in both sectors.

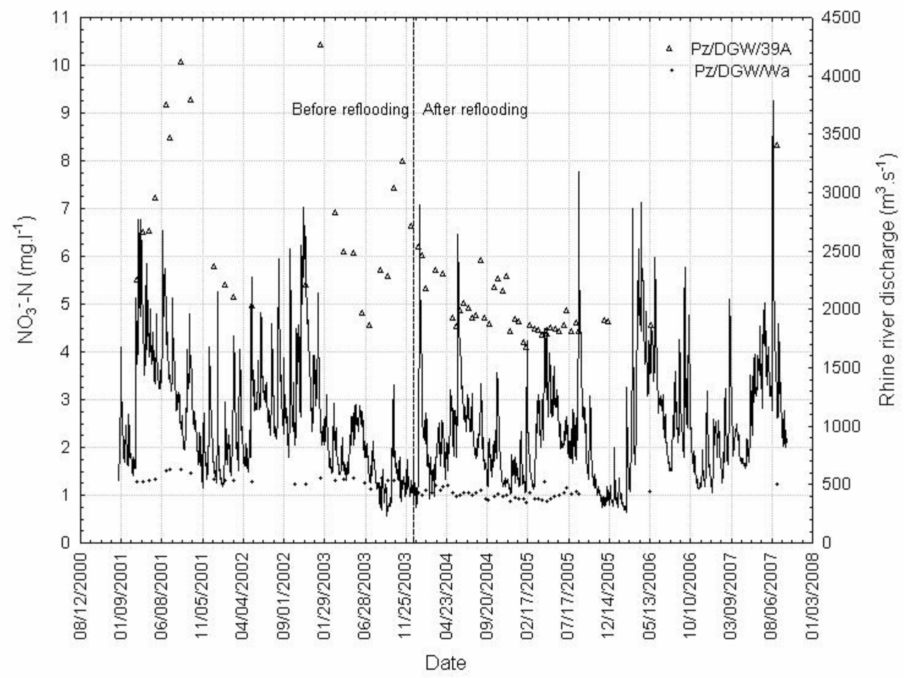

Figure 3 - Variations of nitrate concentrations in the groundwater and river discharge at Strasbourg PzDGW/39A, in external sector , PzDGW/WA in internal sector.

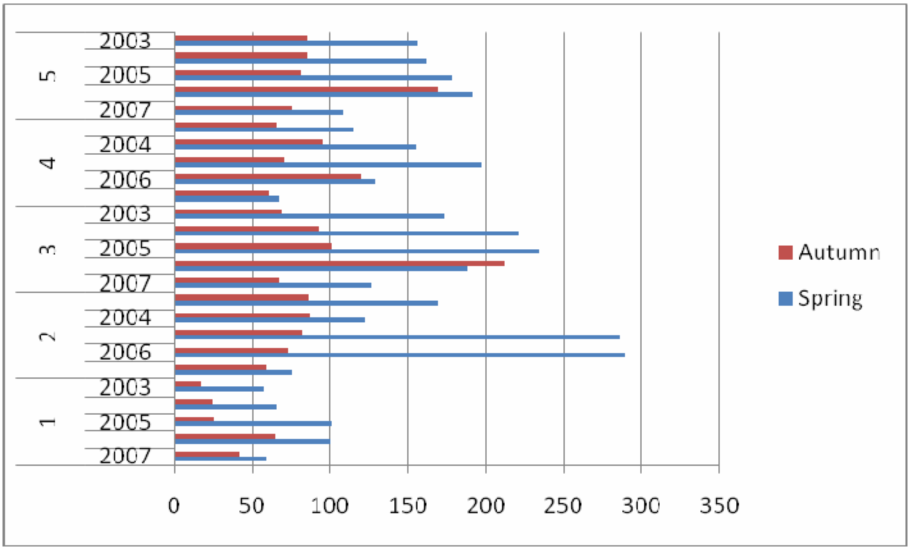

Figure 4 - Nitrogen storage kg/ha in five soils (1,2, 3 internal sector), (4,5 external sector) in spring and autumn of the five years (initial state and monitoring after re-flooding).

In the soils, total nitrogen was always lower in the lower part of the polder (downstream, soil 1, Fig. 4) probably due to the denitrification process which was maintained even after suppression of floods. There is no change in nitrogen storage or a small increase between 2003 and 2006, but a marked decrease in 2007 in all soils studied (Fig.3) which can be explained by climatic conditions (we suggest a decrease of nitrification and/or leaching of nitrate by precipitation). There is only a small increase in phosphorus storage since 2003.

Concerning biological compartments:

The only change in the amphibian community detected until now is the finding in 2008 of one new species, the marsh frog *Pelophylax ridibundus*, in a pond. Its reproductive status and its population size remain to be studied. Since 2003 macrophyte and fish community composition has not changed. The macrophyte communities revealed mesotrophic to eutrophic levels and mesotrophic communities were identified in the exchange areas where groundwater-drainage is most important. In the fish community, the eel density decreased and the trout population disappeared (but it was low in 2003).

No results on terrestrial vegetation are yet available. However some preliminary investigations in 2008 show an improvement in forest health, which may be due to favourable climatic conditions in 2007 and spring 2008.

4. CONCLUSION

Based on an integrated characterisation and analysis of the physical and biological aspects, we have observed small changes in the structure and functioning of the polder after four years of flooding, i.e. increase of surface/groundwater exchanges, storage of nitrogen and phosphorus in soil. Impacts of flooding on biological compartments are still to be analysed. A series of strategies and measures for future river management and restoration need to be identified, including for example conditions of flooding and reconnection of anastomosing channels (depending on Rhine discharge) and the period of ecological flooding (all the year rather than only June and July).

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MONITORING RESULTS OF REVITALISATION MEASURES ON AN URBAN LOWLAND RIVER (LIESINGBACH, VIENNA, AUSTRIA)

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ABSTRACT

The Liesingbach, flowing through the south of Vienna, Austria, is an urban stream that has been designated as a heavily modified water body mainly because the river was channelised, its bed was hard and the water quality poor due to considerable wastewater discharge. A study in 1999 before the restoration confirmed the poor ecological status in terms of hydromorphology, aquatic biocoenosis, riparian vegetation and water related terrestrial fauna. Until 2005, a 5,5 km long reach close to the south-eastern city limit was revitalised with the intention to induce an ecological development by improving the hydromorphological conditions. However, the creation of a typical lowland river morphology was limited due to the difficulties in acquiring adjoining premises.

The ecological monitoring commenced at the end of the year 2004 and ended in 2007. Investigated parameters were river morphology, sediment composition, vegetation ecology, dragonflies, carabids, ciliates, macrozoobenthos and fish. This showed that the morphological setting has dramatically improved resulting in an increased variability in water depth, channel width and bank design. Wet and damp sites with typical plant species developed. Riparian wood was planted in sections but it still needs time to provide a considerable river shadowing. The species richness of carabids increased distinctly reflecting an improvement in habitat heterogeneity. In particular, ripicol carabids, which were rarely found before the revitalisation, appear in considerable numbers now. Dragonflies were also nearly missing before, but 15 spp., including endangered and protected taxa, occur frequently now. At least 5 spp. of these are considered autochthonous. While only some young specimens of four fish species were found prior to the restoration, 16 species were detected afterwards and the dominant taxa occurred with all age classes. Even some of the less frequent species are now obviously spawning within the reconstructed river stretch.

Key words: River restoration, Liesingbach, monitoring, aquatic coenoses

1. INTRODUCTION

The Liesingbach rises in the eastern foothills of the Austrian Alps, in the Vienna woods, at an altitude of 520 m a.s.l., flowing east for almost 30 km before discharging into the river Schwechat. The two major tributaries, Reiche Liesing and Dürre Liesing, have geologically different catchments and are therefore showing different flow characteristics. The Reiche Liesing flows through flysch-sandstone with an impermeable underground causing rapid and high flood peaks after intense rain. In contrast, the Dürre Liesing has its source in the limestone alps, showing considerable infiltration to the point of drying-up in low water periods (Fig. 1). Annual precipitation varies between 800 mm in the headwaters and 550 mm in the downstream area. After the confluence of both tributaries the Liesingbach enters the Vienna basin, flowing through the south of the capital city. Within the city limits the running length is 22,7 km. Of the total catchment area (112,4 km²), 45% are situated in densely populated urban surroundings.

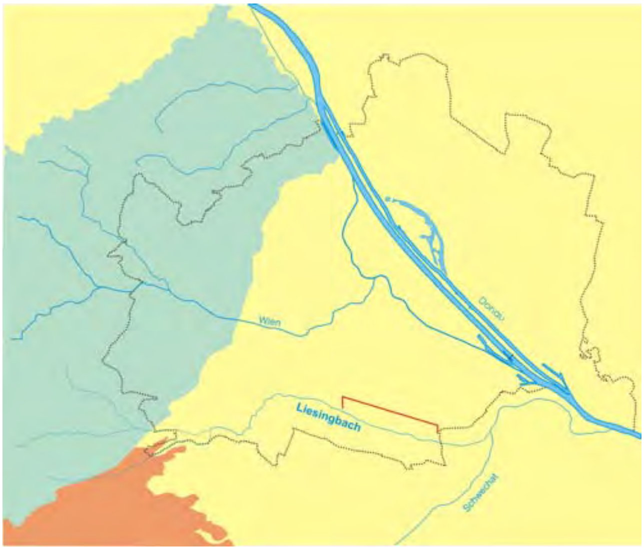

Figure 1 – The Liesingbach flowing through the south of Vienna (dotted line) in the Vienna basin (yellow). Tributaries arise in the flysch-sandstone (blue) and limestone alps (orange). The red bracket indicates the revitalised river stretch.

River management of the Liesingbach commenced many centuries ago. First hydromorphological alterations took place in the early 13th century, when several mills and sawmills were built. Due to a series of devastating flood events at the beginning of the 20th century, when urban development reached the plain tract, the idea for extensive river training came up. These plans were finally carried out between 1947 and 1969. The predominantly meandering river course with amplitudes up to 200 m was dramatically straightened, the resulting increase of the bed slope was counterbalanced by many ground sills with drops up to 3 m. The uniform cross section was carried out in a double trapezoid form completely covered with cobblestones in a concrete bed. Furthermore, sediment control dams severely limited the natural sediment transport.

In addition, the immission load grew significantly over the years. Main sources were about 380 surface water discharges and untreated effluents of hot springs. Furthermore, the inflow of a sewage plant in relation to the low flow of the Liesingbach was rather high. Not surprisingly, routine examinations in the last decades of the past millennium confirmed a poor ecological status and a nearly non-existing functional integrity of the aquatic system within the hard constructed urban reach.

The implementation of the European Water Framework Directive into national legislation gave rise to an interdisciplinary assessment of realistic development objectives for an urban river like the Liesingbach. Consequently, the Liesingbach was classified as a heavily modified water body. To improve the ecological status of the Liesingbach, it was decided to reduce the immissions significantly. The discharge of sulphureous hot spring wastewater was stopped and also a small municipal sewage plant was shut down while its wastewater was redirected to Viennas main clarification plant. For this, a new main sewer had to be built following the river course. These necessary construction works were used for the physical habitat rehabilitation of 25% or 5,5 km of the channelised Liesingbach-stretch up to the south-eastern city limit of Vienna. Main aims were the removal of the hard bed and banks, demolision of ground sills and to enable a certain lateral dynamic.

Comparative investigations before and after the implementation of the revitalisation measures were carried out to prove the development of instream and riparian habitats. The reference study was performed in 1999 while the subsequent monitoring ran from autumn 2004 to the end of 2007.

2. HYDROMORPHOLOGY

According to the evaluation scheme proposed by Werth (1987) and Spiegler et al. (1989), the hydromorphological status in 1999 showed adverse and unnatural conditions (structural status class IV). Beside interrupted passability for sediment and fish, the hard construction caused several deficits such as a straightened river course without bed sediments, lacking variability in width and depth as well as missing riparian vegetation. Surface water velocity was monotonous and rather high despite the reduced bed slope due to ground sills.

In the course of the revitalisation measures, the hard construction was removed from both the river bottom and banks. The river bed was stabilised by inserting coarse cobbles, which were covered with natural, site-specific fine gravel. In some sections, an extension of the river course was made. A meander-like bend and several expansions of the river bottom were built. Unfortunately, a continuous widening of the river bed was not possible due to a conflict of interests: The required space for roads, bicycle lanes, promenades, bridges and new settlements often accounted for the maintenance of the straight-line character. The river banks were enhanced by planting groups of autochthonous trees and shrubs. These actions resulted in a significantly improved hydromorphological setting with variable flow velocities, heterogenous bed sediments, developing small islands and gravel banks.

A preliminary assessment of the hydromorphological status indicated that the habitat characteristics were at least one status class better than in 1999. It is assumed that further improvements will take place, since the development of river banks and slopes as well as the growth of the riparian vegetation is still continuing. For reasons of flood control, however, the sediment is still retained in the upper catchment. Nevertheless, gravel discharge is observed in places because sediment dynamics within the revitalised river stretch were initialised. This indicates, that the re-establishment of the natural passage of sediment is quite essential to achieve a sustained revitalisation success.

3. VEGETATION ECOLOGY

As the succession in dynamic habitats along running waters proceeds rapidly, vegetation surveys were taken twice a year. The monitoring program was based on a system of long-term vegetation plots of 2 x 2 m, which are subdivided into four smaller plots to estimate the proportional coverage of plant species. The monitoring started in autumn 2004 on sandy, muddy and gravel sediments of the riverbanks and the river bed and covered the entire vegetation periods of 2005-2007.

A clear trend was already visible in 2006 on muddy sediments, where pale smartweed (*Persicaria lapathifolia*), which dominated the riverbanks in 2004, decreased distinctly in favour of Canary grass (*Phalaris arundinacea*), which became then the dominant species. This trend was slightly weakened in 2007, because new sediment deposits occurred. The further development of the muddy riverbanks is heading towards a bush-dominated riparian forest consisting of different willow species (*Salix* spp.) when floodwaters do not clear away the sediments again. The previous dynamics in some parts of the Liesingbach were obviously not sufficient to maintain the habitat conditions for a more species-rich stadium of succession. The development of the vegetation towards an alluvial forest is responsible for the decrease in species number per monitoring plot, e.g. the species number declined from 40 in 2005 to 20 in 2006 in selected plots, however, it increased slightly in 2007. This shows that muddy riverbanks at the Liesingbach are subject to a very rapid natural succession, leading to a dense and species-poor reed vegetation. Similar observations were made in flood detention basins in some rivers in the neighbourhood.

At the gravel banks, the association of the *Rumici crispi - Agrostietum stoloniferae* represented the first step of succession, but was followed already in 2006 by a more dense *Polygono lapathifolii - Bidentetum*. In general, habitats with sandy and muddy sediments have already developed a dense and species poor reed composed of Canary grass (*Phalaris arundinacea*). Only at sites exposed to higher dynamics and with a higher proportion of gravel, a species-rich and loosely covered vegetation is able to withstand the overall succession trend. The vegetation cover of these habitats differs only slightly from that in 2004 and still shows a *Rumici crispi - Agrostietum stoloniferae* or a *Polygono lapathifolii – Bidentetum* association, which are more diverse than the Canary grass reed. A small portion of the gravel deposits of the Liesingbach do not reach above water level (possibly due to an inadequate bed load) and bear no initial vegetation yet.

On one gravel bank, the endangered water cress (*Nasturtium officinale*) occurred in 2004. Subsequently, however, it was apparently washed away and could not establish itself again in 2006 and 2007 due to high water levels. In 2007, two other endangered species, the round-leaved cancer wort (*Kickxia spuria*) and the brown galingale (*Cyperus fuscus*), were detected in another plot on an approximately 40 m long gravel bank.

4. DRAGONFLIES

Dragonflies are particularly suitable for long-time studies of new inshore waters because of their high mobility, size, noticeable color and colonisation potential. These insects also play an essential role in the assessment of the ecological integrity of aquatic systems and are reliable indicators of habitat heterogeneity, connectivity aspects and ecological quality of the land-water-interface. Only long-time studies will give information about succession processes and other ecological issues (Chovanec & Waringer, 2005). Between 2005 and 2007, the colonisation of the revitalised river stretch was investigated. Four sites, each 100 m long, were periodically examined. Adults, juvenils, exuviae and larvae of dragonflies and the reproduction behavior were recorded.

In 1999 prior to the revitalisation, only one species, *Calopteryx splendens*, was found at one sampling site at the Liesingbach. Colonisation started shortly after completion of the construction works and total number of species as well as number of endangered species were continously increasing. In total, 20 species were identified including eight species classified “vulnerable” or “endangered” according to the Red List of Austria (Raab et al. 2006). Total number of breeding, i.e. autochthonous, Odonata was highest at the meander-like site, which was already completed in 2004.

Not surprisingly, species arrived first in areas with completed revitalisation measures while the Odonata appearance was delayed in river sections with a later completion date. Consequently, the similarity of the fauna shows a gradient from the lowermost sampling site, where the rehabilitation started, towards the uppermost sampling site. The shorter the distance between the sampling areas the higher the similarity between their species spectra. Furthermore, the steadiness, defined as an expression of appearances, increased over the years at all sites. In 2007, 16 of 18 observed species are classified as widespread because they occurred in at least three of the four sites.

Within the few years, a typical "*Gomphus* - *Calopteryx splendens*-coenosis" (Jacobs, 1969) developed with the rheophilic representative species *Gomphus vulgatissimus* and *Onychogomphus forcipatus*, *Platycnemis pennipes* and *Calopteryx splendens* as well as the concomitant species *Ischnura elegans*.

Odonata colonised the reconstructed part of the Liesingbach rather quickly because of numerous potential sources in the neighbourhood and the aquatic vegetation developed rapidly. Thus, a fairly stable community occurred within the few years.

5. CARABIDS

Ground beetles (Coleoptera, Carabidae) are a very sensitive indicator group (Günther & Assmann, 2005; Gerisch et al., 2006). They were surveyed at various types of riverbanks (different slope angle, exposition, shading, vegetation) along the revitalised Liesingbach in the years 2005-2007 using pitfall traps and compared to the carabid community prior to the revitalisation (1999).

Activity abundance is 2.5-4.0 times higher than in 1999 and highest in habitats with exposed river sediments and no mowing on banks near the south-eastern city limit. In total, 107 carabid species were recorded after the reconstruction. Annual species richness varied from 54 spp. in 2006 to 82 spp. in 2007 and is distinctly higher than before revitalisation measures (36 spp.). Also, the Shannon-Wiener diversity index increased slightly from 2.77 (1999) to 3.07 (2007). The species composition in recent findings differs significantly from that in 1999 (Shannon Diversity t-test; PAST; at most $p=0.0109$). A high proportion of sporadic abundant species (42-56%), a low proportion of constant abundant species in each monitoring season (27%) and a high proportion of macropterous individuals (currently ca. 85% vs. 35% in 1999) indicate dynamic recolonisation processes.

The species composition of the ripicole carabid group as well as of all carabids changed immediately after revitalisation. Most ripicole species were found in 2007. Only *Harpalus luteicornis* (sporadic abundant) and the less ripicole species *Bembidion subcostatum* (subdominant and dominant, respectively) are found in every monitoring season. In general, the development of the carabid community showed a decreasing abundance of xerophilous open habitat species (*Amara* sp., *Harpalus* sp. and *Anchomenus dorsalis*) and an increase of hygrophilic forest and/or ripicole species (e.g. tribes Bembidiini, Trechini, Pterostichini, *Agonom* sp.).

These results indicate a dynamic and less constant carabid community three years after reconstruction of the river and the riverbanks due to changing habitat structures and their continuing epigaeic recolonisation.

6. CILIATES

The ciliate coenosis is a well-suited bioindicator for the water quality in running waters. Thus, the ciliate fauna in the Liesingbach reflects the organic pollution rather than structural improvements due to the revitalisation.

In 1999 prior to the rehabilitation, the saprobity index according to Blatterer (1995) indicated β- to α-mesosaprobic (water quality class II-III) and α-mesosaprobic (water quality class III) conditions, locally even a tendency to polysaprobic conditions (e.g. sapropel was widespread). After completion of the reconstruction works and the redirection of wastewater discharges, water quality improved slightly, i.e. by about 0.2 units of the saprobity index, indicating that a considerable organic load still remains.

The species richness increased slightly after the rehabilitation (119 spp. in 1999 vs. 150 spp. in 2005). However, the lower species number before the reconstruction may be influenced by the rather high flow velocities then (up to about 2 m/s) and the hard river bed, which often lacked any sediments. A slight change occurred also in the species composition. For example, *Trochilioides recta*, which feeds mainly on sulphur bacteria, was abundant in 1999 but disappeared after the redirection of the sulphureous wastewater. Some other species, e.g. *Stylonychia mytilus* and *Vorticella campanula*, appeared and occurred in high densities after 2004.

7. MACROZOOBENTHOS

Before revitalisation measures, habitats for benthic invertebrates were rare. Only small areas of very unstable, accumulated sediments on the cobbled riverbed and bunches of green algae (mainly *Cladophora* sp.) inserting in cracks were inhabited. The coenosis showed a highly fluctuating species composition. Oligochaets were distinctly dominant and represented up to 90% of the total invertebrate fauna. *Nais elinguis* (Naididae), *Tubifex tubifex* (Tubificidae) and *Lumbricillus rivalis* (Enchytraeidae) appeared with highest numbers indicating that organic pollution was high (water quality class III, α-mesosaprobic).

The insertion of natural bed sediments was the main prerequisite for the development of a stable macroinvertebrate fauna. In fact, shortly after revitalisation measures the species number increased by 20-40%. Also, species diversity (Shannon-Wiener-Index) considerably increased from around 2,0 to 2,5-3,2. The latter findings result in part from increasing proportions of Ephemeroptera, Plecoptera and Trichoptera species, which reach up to 34% of the total species number in 2007, while the larger part results from an abrupt rise in larvae of *Hydropsyche* sp. (*H. angustipennis*, *H. bulbifera*, *H. modesta*). Prior to the revitalisation, these groups appeared only sporadically with proportions well below 1%. On the other hand, the percentage of Oligochaeta species decreased well below 50% in 2007.

Concomitant with a reduced wastewater discharge, the organic pollution declined significantly resulting in water quality class II-III (β- to α-mesosaprobic), which is now observed throughout the entire revitalised river stretch.

Three years after recolonisation, some species typical for small lowland rivers are still absent. The main reason for this is the spatial isolation of the revitalised river course. The natural catchment area can hardly act as source, since it is situated in higher faunal regions, and is separated by several kilometres of city from the revitalised stretch. Other running waters with a suitable stock of species are at least about 5 km distant, which is too far for most of the volant adults.

8. FISH

Fish inhabit nearly all aquatic environments. Many species require certain habitats and are bound to certain structures in a river, particularly for spawning. This, their comparatively long life expectancy and the high mobility qualify the ichthyocoenosis as a suitable indicator for the ecological status of running waters.

Before the revitalisation in 1999, only a few individuals of four euryoecous species (chub, *Squalius cephalus*; minnow, *Phoxinus phoxinus*; stone loach, *Barbatula barbatula*; pumpkinseed sunfish, *Lepomis gibbosus*) were found in the Liesingbach. After completion of the rehabilitation, on average eight species occurred per sampling site. This increase in diversity is also corroborated by the fact, that 16 different species were detected between 2005 and 2007. Now the dominant species are chub, gudgeon (*Gobio gobio*) and stone loach. Their age structure shows stable populations with juvenile age classes dominating. The barbel (*Barbus barbus*), the minnow, the Prussian carp (*Carassius gibelio*) and *Pseudorasbora parva* (introduced species) occurred regularly in the revitalised stretches. Some of these species are obviously even spawning here. Less frequent or rare were, e.g., brown trout (*Salmo trutta fario*), common dace (*Leuciscus leuciscus*), Crucian carp (*Carassius carassius*), roach (*Rutilus rutilus*), rudd (*Scardinius erythrophthalmus*) and spirlin (*Alburnoides bipunctatus*). Some typical lowland-river species are still absent. A main reason for this is a migration barrier between the Liesingbach and the downstream systems of Schwechat and Danube, so that a recolonisation from downstream is at least severely limited.

Individual numbers and biomass varied considerably between sites and years, but compared to the results before the revitalisation a distinct increase occurred. Even though the recolonisation of the revitalised stretch started immediately after the reconstruction works and was rather successful, it will take some more time until a species-rich and stable fish community will establish.

9. CONCLUSIONS

In the course of the reconstruction of a 5,5 km long stretch of a lowland river, a comparative study of important abiotic and biotic parameters was carried out. The removal of the monotonous, plain structures of the hard river bed led to the enhancement of the land-water transition zone and enabled certain lateral and longitudinal dynamics. Thus, the development of habitats was initiated for the benefits of a rapid and extensive recolonisation of many organisms. As accompanying measure, the immission load was markedly reduced, which improved the water quality.

The newly built and developed structures were quickly colonised. Beside ubiquitous organisms, faunal elements typical for lowland rivers and some endangered species appeared in important numbers. The immigration of additional species depended strongly on adequate sources and the capability of species to cover longer distances.

The results indicate that even in an urban sourrounding with significant spatial restrictions a revitalisation can be successful. Three years after completion of the reconstruction works, the biocoenotic development is still in progress.

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FLOW CHARACTERISTICS IN A VEGETATED FLUME

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ABSTRACT

Vegetation altering hydrodynamic conditions of an open channel flow controls the exchanges of sediment, nutrients and contaminants. Thus, the knowledge of the hydraulic characteristics of flow over vegetation is very important to support the management of fluvial processes. In this paper the flow over real flexible vegetation is experimentally studied. A 2D-ADV (Acoustic Doppler Velocimeter) is used to measure the local flow velocities for different vegetation concentrations and varying the discharge and the flume slope. The flow velocity measures are used to test the hyperbolic tangent profile of a pure mixing layer and to evaluate the mixing-layer parameters. The formation of turbulence structures inside the vegetated layer is verified through spectral analysis.

Key words: Vegetation, flow characteristics, experimental investigation

1. INTRODUCTION

Investigations concerning river ecology are ever more oriented toward quantitative information based on the study of the linkages between physical processes and ecological response in rivers. Suitable habitat of aquatic life may be dependent on discharge and on different scenarios of watercourse development. Particularly in industrialised countries, river restoration or rehabilitation is also widely practised in order to ‘revitalize’ degraded aquatic ecosystems.

In reality, many interrelated factors, such as non-uniform cross-sectional profiles, bed deformation (riffles and pools), non-uniform plan shape (meanders) and natural vegetation, increase the heterogeneity of water depths and flow velocities, creating variable habitats and affecting the conditions of the aquatic ecosystem. Thus the estimation of local velocities and water depths is essential in protection or restoration of suitable habitat for flora and fauna.

In such context, the definition of predictive methodologies of the kinematic characteristics of flow and of the morphological evolution of the river is of great interest for ecological and economic optimisation of hydraulic engineering projects.

Of particular interest are rivers with vegetation, where the analysis of the flow velocity field is rather complex and the accurate estimation of flow velocity profiles is essential to establish the conveyance of flows and the retention capacity of the channel.

The main difficulty to analyze the effects of the flexible vegetation is that it oscillates in the flow changing position and assuming different inflection degrees. Essentially, vegetation can assume either the erect position (rigid behaviour) or it can be flattened towards the bed (waving position) or it could be in prone position (Palmer 1945).

Many theoretical and experimental studies (Kouwen et al. 1969, Gourlay 1970) have been carried out in order to define the vertical velocity profiles in vegetated channel and to test the applicability of logarithmic law. From a theoretical point of view, the logarithmic velocity profile is applicable above a reference distance from the bed which would be the level where the bottom layer of constant velocity matches with the shear layer above it. On the other hand, the experimental studies conducted in this field (Ikeda & Kanazawa, 1996, Tsujimoto & Kitamura 1990, Carollo et al. 2002) have highlighted that the temporally averaged velocity profile has an inflection point near the top of the vegetation layer.

Taking into account such behavior and the analogy of submerged vegetation in aquatic flows with terrestrial canopies, Ghisalberti & Nepf (2002) demonstrated that flows with submerged vegetation are best represented by a mixing layer than a rough boundary layer. Furthermore, the presence of the inflection point in the velocity profiles of mixing layer renders it subjected to Kelvin-Helmotz (KH) vortex instability (Ikeda & Nakagawa, 1996). Thus, Ghisalberti & Nepf (2002) showed how the large-amplitude waving of the flexible submerged aquatic vegetation, termed as "monami" by Ackerman & Okubo (1993), is a response to the streamwise velocity associated with the passage of vortex.

In this paper the flow velocity profiles measured, for different vegetation concentrations, over flexible submerged vegetation are used to validate the mixing layer analogy. The formation of turbulence structures, affecting the vegetation waving, is verified through the spectral analysis.

2. EXPERIMENTAL APPARATUS AND MEASUREMENT TECHNIQUE

The experimental runs were carried out in a rectangular straight flume constructed at the Dipartimento di Ingegneria Idraulica ed Applicazioni Ambientali of University of Palermo (Italy). The flume, 0.60 m wide and

14,4 m long, has a sloping bed. The water discharge was measured by an orifice plate installed in the feeding pipe. The water depth was measured by a point gauge. The measurement reach, located at 7.9 m from the entrance channel section, was 3 m long. The channel banks were rigid, while the channel bed was of grass, produced by a mixture of stable Loietto (50%), Festuca rubra (40%) and Poa pratensis (10%). The resulting turf was composed by ribbon-like stems large about 4-5 mm. The experimental runs were carried out for three vegetation concentrations, (=280, 310, 440 stems/dm^2), determined as the mean of stems per unit area, evaluated by 15 samples along the measurement reach. The first measurement cross-section was at 90 cm downstream from the beginning of turf reach and the following three cross-sections had a relative distance of 40 cm.

The bent vegetation height observed in presence of flow through the transparent walls, k_V, and the non-submerged vegetation height, H_V, were estimated as the mean of three measurements by three decimal rules fixed to flume wall.

The experimental runs were carried out varying, for each stem concentration, the flow rate and the flume bed slope. The water depth measurements ranged from 6.1 to 27.2 cm, which corresponded to depth-vegetation height ratio values ranging from 1.02 to 6.04 and Froude numbers varying from 0.22 to 0.73 (see in Carollo et al. 2002). During experimental runs the vegetation was always inflected, both prone and waving, and characterized by an inflection degree, k_V/H_V, ranging from 0.25 to 0.73. A 2D side-looking Acoustic Doppler Velocimeter (ADV) was used for the measurements of longitudinal and transverse flow velocity components. For each measurement point the maximum sampling rate of 25 Hz was used. The local flow velocities were measured in five verticals of a cross-section located in the middle of the measuring reach. The measurements verticals were located at a distance of the wall equal to 4 cm (V1), 7 cm (V2), 14 cm (V3), 22 cm (V4) and 30 cm (axial vertical - Va). The details of the measurement techniques can be found in Carollo et al. (2002).

The influence of the depth/vegetation height ratio, h/k_V, and of the stem concentration on velocity has been analyzed for sixteen of the all experimental runs. For such runs, Table 1 lists water depth h, flume slope s, discharge Q, non-submerged vegetation height H_V, stem concentration, , and bent vegetation height, k_V. During all runs, the vegetation was submerged. Runs 1-14 were carried out with a vegetation which was always prone; while for runs 15 and 16 the vegetation was cut obtaining more rigid stems having a quasi-erect configuration.

3. MIXING LAYER CHARACTERISTICS

The mixing layer variables can be analyzed through the schematic representation of the vertical profile of the mean stream-wise flow velocity, $U(z)$, reported in Figure 1.

In this figure, U_1 and U_2 indicate the lowest and highest value of flow velocity, respectively, where the velocity gradient is approximately zero; $U = U_2 - U_1$ and t_{ml} indicates the mixing layer thickness. The water depths z_1 and z_2 are respectively the lower and the upper limits of the mixing layer.

Previous research carried out in order to analyze the structure of turbulent mixing layers (Ho & Huerre, 1984) have highlighted that flows with an inflectional velocity profile are unstable such that the mixing layers are subjected to Kelvin-Helmholtz instability.

Table 1 – Experimental data.

Run	*h* [cm]	*s* [%]	*Q* [l/s]	H_v [cm]	δ [stems/dm^2]	k_v [cm]
1	11.9	1.0	37.6	11.0	310	4.8
2	13.5	1.0	30.1	20.0	440	8.0
3	14.6	0.2	30.1	20.0	440	8.0
4	14.0	0.2	26.9	20.0	440	8.2
5	12.5	1.0	26.9	20.0	440	7.7
6	17.8	0.2	77.6	20.0	440	7.0
7	16.8	1.0	77.6	20.0	440	6.6
8	19.9	0.2	105.9	20.0	440	6.3
9	18.3	1.0	105.9	20.0	440	5.9
10	12.8	0.2	26.9	11.5	280	7.0
11	19.0	0.2	77.6	11.5	280	5.4
12	21.7	0.2	105.9	11.5	280	4.9
13	24.5	0.2	135.0	11.5	280	4.7
14	27.2	0.2	170.8	11.5	280	4.5
15	27.7	0.2	188.7	5.9	337	3.8
16	27.2	0.2	189.2	3.5	337	3.1

The linear stability analysis for such layers suggests that the frequency of maximum instability should be estimated as follows:

$$f_{KH} = 0.032\left(\frac{\overline{U}}{\theta}\right) \quad (1)$$

where $\overline{U} = \left(U_1 + U_2\right)/2$, θ is the momentum thickness of the primary flow, estimated as (Ghisalberti & Nepf, 2002):

$$\theta = \int_{-\infty}^{+\infty} \left[\frac{1}{4} - \left(\frac{U - \overline{U}}{\Delta U} \right)^2 \right] dz \qquad (2)$$

Such instability grows until to produce a roller-type vortex dominating the mass and momentum transfer through the mixing layer.

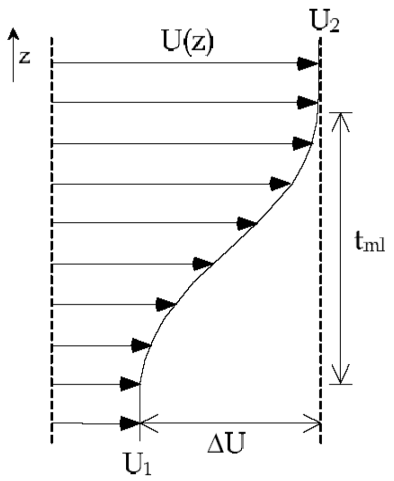

Figure 1 – Schematic representation of mixing layer variables.

Thus, the inflection point of the velocity profile of submerged vegetated flows renders them subjected to the Kelvin-Helmhotz instability. As it was previously observed by Ghisalberti & Nepf (2002) and by Ikeda & Nakagawa (1996), organized vortices form and grow migrating downstream over the vegetation layer, so to generate a wavy movement of the flexible vegetation.

4. EXPERIMENTAL FLOW VELOCITY PROFILES AND MIXING LAYER APPROACH VALIDATION

$$U = \overline{U} + \frac{\Delta U}{2} \tanh\left(\frac{z - \overline{z}}{2\theta} \right) \qquad (3)$$

where $\overline{z}$ is the distance from the bed where $U = \overline{U}$.

The variables of the mixing layer (U_1, U_2, $\overline{z}$, θ) have been estimated using the experimental profiles and by fitting eq. (3) to the experimental data through the minimization of the mean of the errors squared (Carollo et al., 2008). In Figure 3 all the experimental velocity profiles are plotted on the plane ($\left(U-\overline{U}\right)/\Delta U$, $\left(z-\overline{z}\right)/\theta$). The same figure reports the velocity profiles measured by Ghisalberti & Nepf (2002) and the curves of equation (3), with parameters estimated as aforementioned.

As Figure 3 shows, especially in the mixing region, all profiles collapse in a single curve, confirming that the mixing layer approach is valid (see also in Carollo et al., 2008).

5. VELOCITY SPECTRA ANALYSIS

Ghisalberti and Nepf (2002) highlighted the significant coupling of the plant motion and the hydrodynamics. The Authors observed the formation of an ordered sequence of long-term large-scale vortices moving downstream with the same velocity as the mean flow and producing a motion of fluid, toward both the bed (sweep) and the free surface (ejections), involving the whole flow depth.

In the case of flexible vegetation, the vortex-driven oscillation of velocity drives coherent vegetation waving, producing a spatially and temporally variable drag force. The large-amplitude waving ("monami") on one side depends on vegetation concentration and, in fact, with decreasing concentration, the vegetation becomes sufficiently sparse and no pronounced inflection point at its top is observed; on the other side, it depends on the vegetation inflection degree. In fact, in the case of rigid vegetation, the fixed drag interface generates a more coherent vortex than that of a waving vegetation.

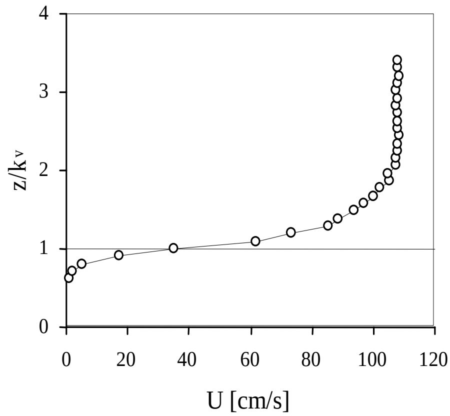

Figure 2 – Experimental velocity profile.

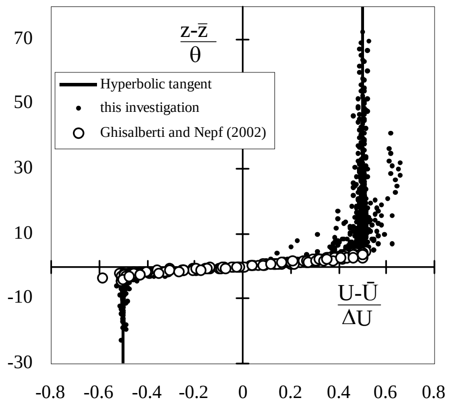

Figure 3 – Comparison between all velocity profiles and eq. 3.

Furthermore, it has been observed that monami occurs when the flow velocity increases above a threshold value (Ghisalberti & Nepf, 2002).

Thus, according with Ghisalberti & Nepf (2002), spectra of the measured stream-wise velocities can be used to examine oscillations in stream-wise velocity within the mixing layer and to compare them with the predicted frequencies, f_{KH}, given by (1).

For each measurement vertical, the stream-wise velocity spectra have been estimated through the Fourier transform (sampling frequency of 1/25 Hz =0.04 sec). The peak frequency, f_C , of such spectra (observed frequency) has been compared with the frequency, f_{KH}, determined as function of the mixing layer thickness, i.e. through equation (1). Five points inside the mixing layer have been considered for the analysis, as indicated in Figure 4. As an example, in Figure 5 the power spectra estimated for the considered points, in vertical V2 of run 10, are reported. In Figure 6, for each stem concentration, the observed frequencies are compared with the predicted ones. It can be observed that for concentrations of 280 and of 337 stems/dm^2 a good agreement between the observed and the predicted frequencies is observed, especially inside of the mixing layer (points pt2, pt3, pt4). In the case of 440 stems/dm^2 the aforementioned agreement is not verified. This is probably due to the fact that the increase of stem concentration limits the momentum exchange.

In Table 2, for each measurement vertical (V1, V2, V3, V4, Va) and for each considered point, the mean values of the observed and predicted frequencies are also compared in the cases of 280 and 337 stems/dm^2. The agreement between such frequencies confirms that the peaks in stream-wise velocity spectra are associated with the Kelvin-Helmholtz instability.

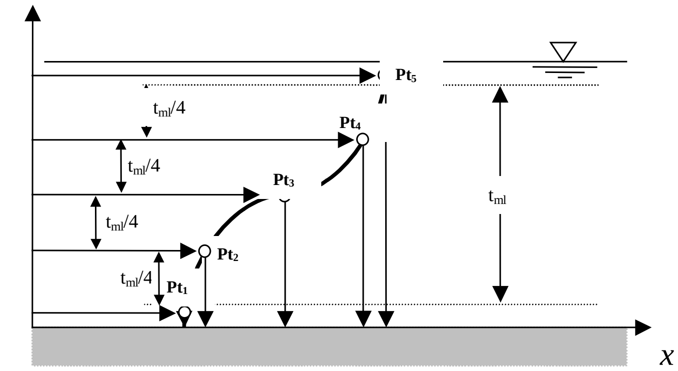

Figure 4 – Controlling points inside the mixing layer.

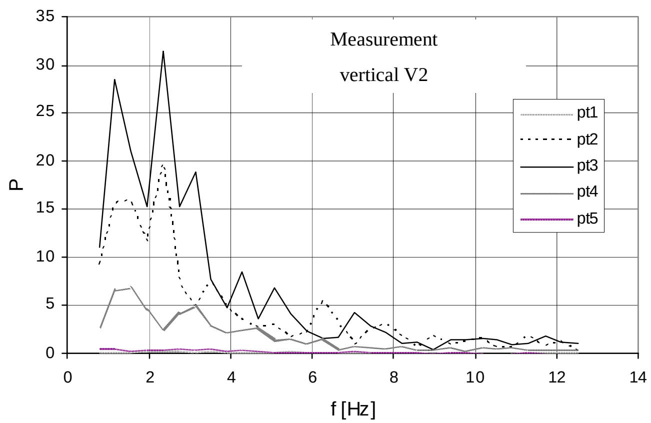

Figure 5 – Velocity spectra.

6. CONCLUSIONS

The application of the mixing layer approach to interpret the vertical profile of stream-wise velocity component in a vegetated channel has been verified using data collected in a straight laboratory channel with flexible vegetation on the bed. According with Ghisalberti & Nepf (2002), the velocity profile is approximated by a hyperbolic tangent law.

In order to verify the existence of Kelvin-Helmholtz instability, the spectra of the stream-wise velocity have been also analyzed. The comparison between the observed frequencies and the predicted frequencies, that are determined as function of the mixing layer thickness, has confirmed that in the case of concentrations of 280 and 337 stems/dm^2 the peaks in stream-wise velocity spectra are associated with the Kelvin-Helmholtz instability. The increase in stem concentration (440 stems/dm^2) probably limits the momentum exchange inside the mixing layer and the aforementioned agreement is not verified.

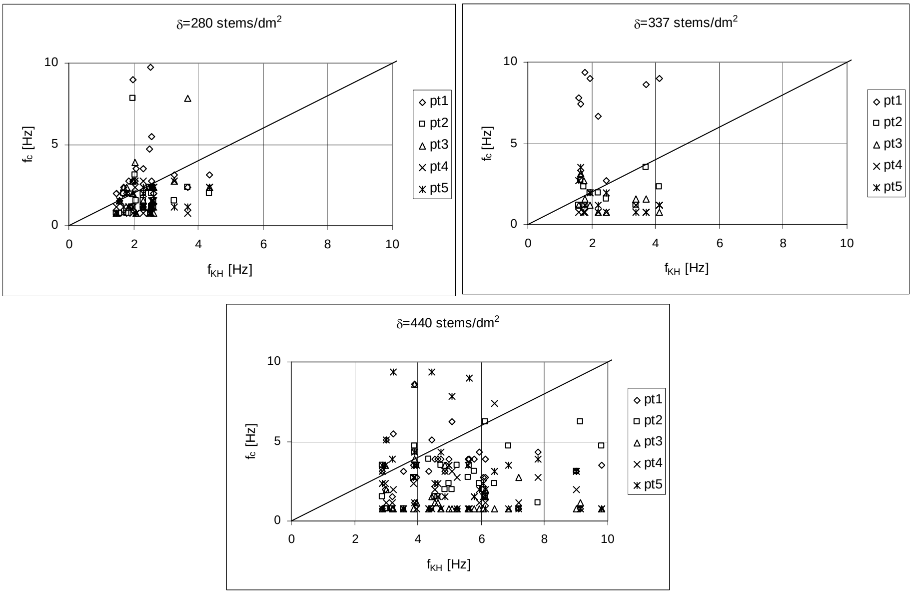

Figure 6 – Comparison between predicted and observed frequencies.

Table 2 – Observed and predicted mean frequencies.

δ [stems/dm^2]	Measurement Vertical	f_{KH} [Hz]	f_c [Hz]
280	V1	1,65	1,43
	V2	2,07	2,05
	V3	3,18	2,73
	V4	2,78	2,34
	Va	2,29	1,95

δ [stems/dm^2]	Measurement Vertical	f_{KH} [Hz]	f_c [Hz]
337	V1	2,83	2,74
	V2	2,46	1,56
	V3	2,80	1,95
	V4	1,77	1,76
	Va	1,62	1,17

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REMOTE SENSING DERIVED WOODY STRUCTURAL PARAMETERS IN RIPARIAN CORRIDORS

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ABSTRACT

In floodplains emergent vegetation frequently provides most of the resistance to surface water flow, changes backwater profiles and modifies sediment transport and deposition causing difficulties in hydraulic design and making necessary significant operational maintenance burdens, especially at flood sensitive sites. For this reason a considerable amount of research has been carried out in developing resistance laws for channels with stiff vegetation. However, the conventional ground-techniques are time and cost expensive and they are difficult to apply over long reaches.

In this study a remote sensing data fusion procedure was proposed in order to estimate some functional woody-vegetation structural parameters (stem diameter, plant density, crown diameter, crown base height, tree height) for flow resistance modelling.

Keywords: Flow resistance, Manning's coefficient, Hydraulic modelling, Stiff vegetation, Quickbird, LiDAR.

1. INTRODUCTION

In recent years, the use of airborne LiDAR technology to detect individual tree crowns and to measure forest biophysical characteristics has been rapidly increasing. In addition to providing a characterization of ground topography, LiDAR data give new information about the vegetation vertical structure and biophysical characteristics such as stem diameter, spacing or density, crown base height, crown diameter, that are not directly recovered from optical sensor (Andersen et al. 2005, Persson et al. 2002, Hyyppä et al., 2001; Brandtberg et al., 2003; Leckie et al., 2003; Popescu et al., 2003; Popescu and Wynne, 2004, Næsset and Bjerknes 2001, Næsset and Økland 2002; Popescu et al., 2002).

More accurate information on roughness of riparian stiff vegetation for use in resistance equations and eventually in flood modeling over large study areas can be obtained thought time-efficient automated procedures and remote sensing data analysis.

The dataset of this study included a Quickbird image and LiDAR data respectively acquired in 07/2004 and 09/2006 along a 14 km stretch of the Sieve River (Tuscany, Italy) characterized by high woody-vegetation density, and field measurements used for calibrating the procedure. A five-step approach was used (more details in methodology flow diagram Fig. 1).

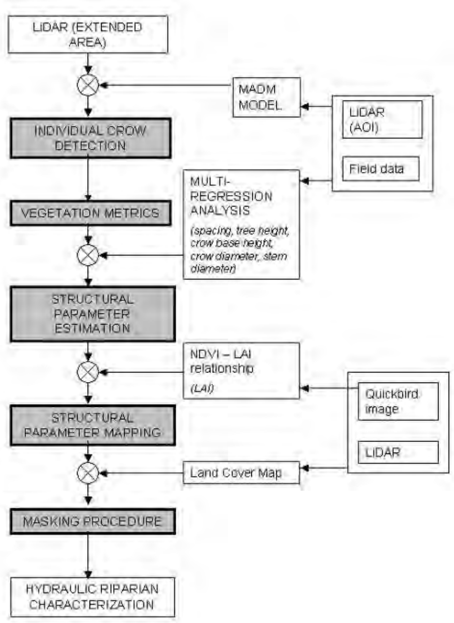

Figure 1 – Methodology flow diagram.

2. STUDY AREA and CALIBRATION TEST SITE

The model is calibrated on a test site (Fig. 2C) (Gauss Boaga, Rome M.Mario: x 1700731m, y 4856231m, dimension 0.001km^2, elevation 114m) that contains the principal vegetal association classified as “Riparian forest of high stem” (De Philippis, 1937).

The mixed forest is characterized by a dominant floor of Cottonwood (*Populus nigra L.*). Close to cultivation activities it is easy to find Black Locust (*Robinia pseudoacacia L.*). The shrub floor consists of Field Maple (*Acer campestre L.*), Elder (*Sambucus nigra L.*), European Cornel (*Cornus mas L.*) and blackberry (*Rubus ulmifolius S.*).

The field surveys included: absolute stem position, stem diameter at chest height, crown diameter, tree height, crown base height. The estimated calibration parameters were extended over all the study area (Fig. 2A).

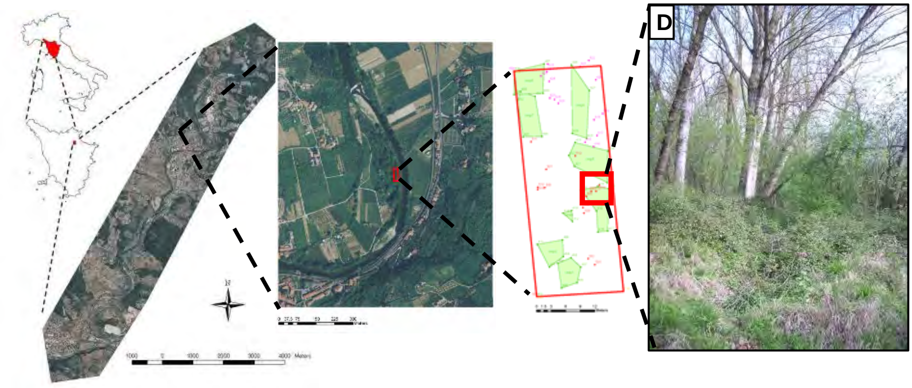

Figure 2 – Study area (A); zoomed shot study area (B), calibration test site (C) and cottonwoods and willows in the explored riparian corridor (D).

3. METHODOLOGY

3.1. Individual tree crown detection

The individual crown detection was performed using a Multi-Attribute Decision Making Simple Additive Weighting approach using airborne LiDAR data (Forzieri et al., in progress a). The Crown Height Model was assimilated to a gray level image (Andersen et al. 2001) and it was analyzed through watershed algorithms (fig. 3 - 4).

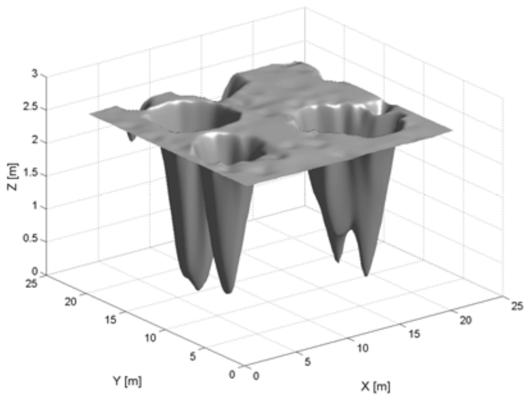

Figure 3 – Inverted Crown Height Model over a sampled area.

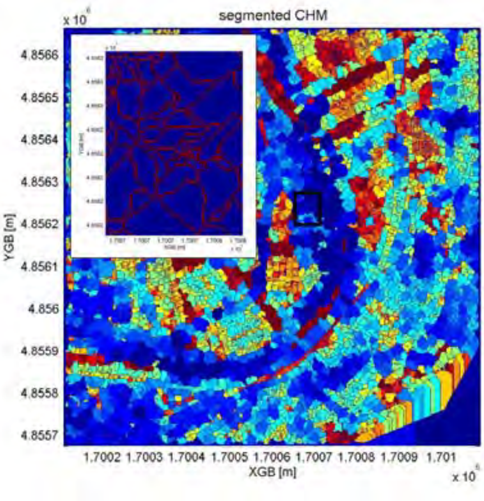

Figure 4 – Example of segmented Inverted Crown Height Model generated by watershed algorithm.

3.2. Vegetation metrics

Over each crown's identification a detailed description of forest structure was produced by extracting the vertical distribution of LIDAR raw data through a limited number of LIDAR-based predictor variables (Naesset and Bjerknes 2001).

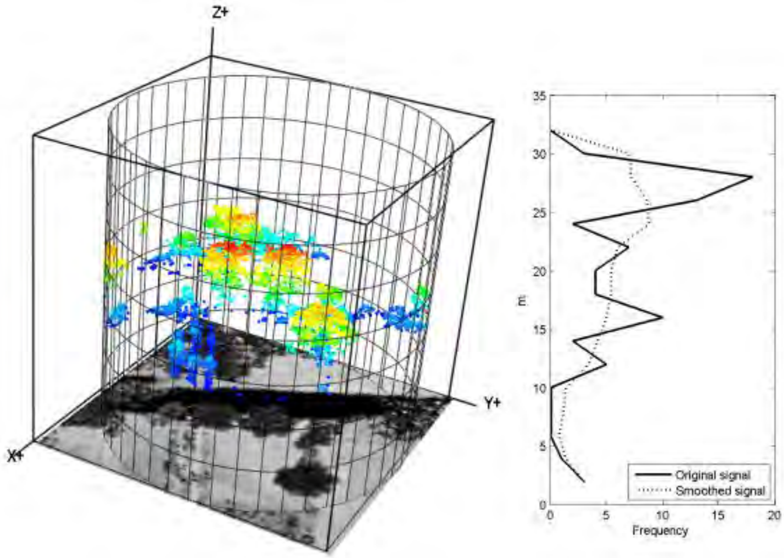

Figure 5 – Example of LiDAR-derived vegetation metrics over a sample circular window: stereoscopic prospective of LiDAR raw data, orthophoto as background (4A); vegetation vertical structure using original and smoothed signal (4B).

3.3. Structural parameter estimation

The estimation of the vegetation structural parameter for each detected crown is performed using different procedures: for tree height, crown base height, crown diameter and stem diameter. Multiple regression techniques linking the vegetation structure variables to vegetation metrics were used; the density was estimated by counting for each simulated stem position the number of plants which fell inside a circular neighbourhood with predefined radius (semivariogram analysis); the leaf area index was obtained by multi-spectral image-derived vegetation indices (Nagler et al., 2004).

3.4 Structural parameter maps

The local parameters for each modelled tree position (centroid of detected crown) were estimated using a cubic 2-D interpolation to elaborate structural parameter maps (Fig. 6).

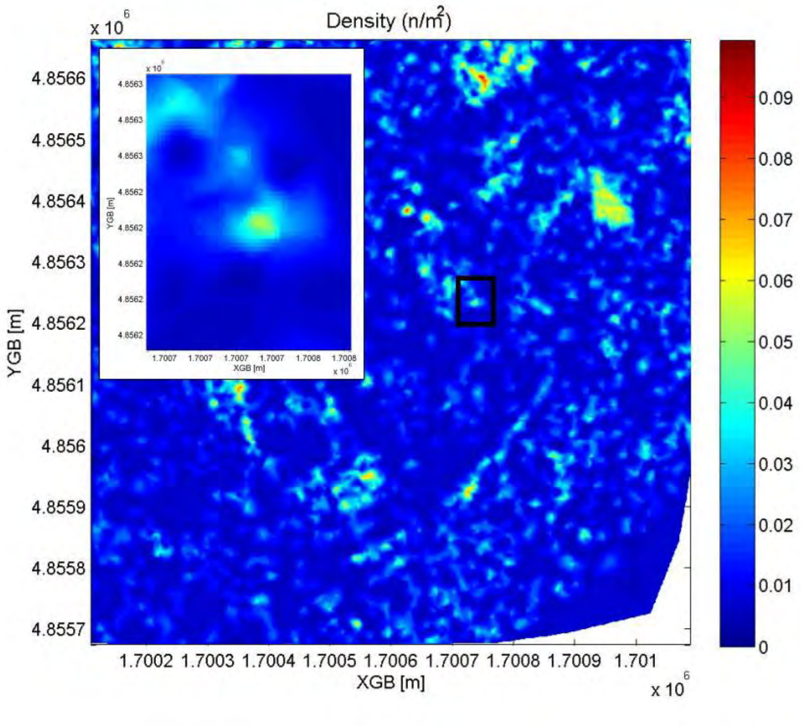

Figure 6 - Vegetation structural parameter maps.

3.5. Masking procedure

In order to extract the structural parameters only over stiff vegetation we applied a masking procedure using a riparian vegetation mapping previously obtained from remote sensing data analysis (Forzieri et al., in progress b).

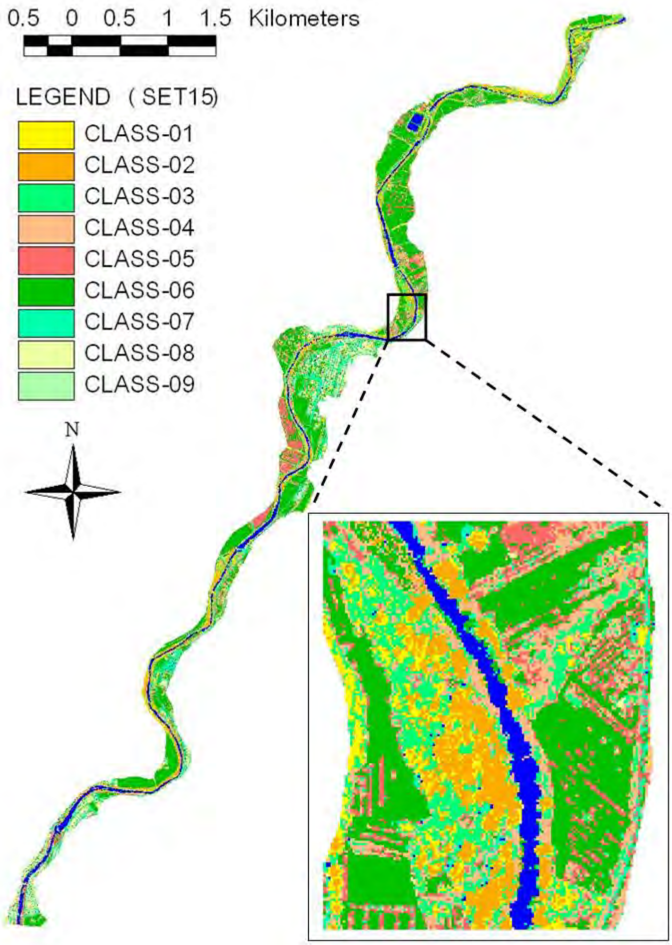

Figure 7 - Classification map: class 1) cleared land with tree stumps, with and without sprouts; class 2) heavy stand of timber, few down trees, little undergrowth, flow below branches; class 3) same as above, but with flow into branches/ willows; class 4) scattered brush, heavy weeds, light brush and trees, in winter and summer light brush and trees, in winter and summer medium to dense brush; class 5) mature row crop and mature field crop, pasture no brush (short and high grass); class 6) earth, rock, gravel, cultivated areas (no crop); class 7) asphalt; class 8) concrete; class 9) water.

4. HYDRAULIC RIPARIAN CHARACTERIZATION

Local and spatial accuracies were evaluated using the coefficient of determination and geostatistical procedure respectively. In order to analyze the spatial distribution of the errors we compared simulated and observed structural vegetation parameters over the test site by simple subtraction of the maps generated by interpolation of modelled and measured parameters. Despite forest scenes with very high vegetation density, the model generates structural vegetation parameters maps able to explain the plant spatial variability that plays a more important role in the riparian vegetation parameterization for hydraulic purposes (Tab. 1).

Table 1 - RMSE calculated on the spatial error maps obtained by simple subtraction between interpolated observed and simulated maps over the test site.

Structural parameter	RMSE
Diff. density (n/m^2)	0.011
Diff. Crown diameter (m)	1.691
Diff. Stem diameter	0.085
Diff Crown base height	1.876

In order to show the improvements obtained with the proposed approach in vegetation modelling for hydraulic applications we compared the flow resistance estimated over the roughness classes 1 and 2 in the calibration test site at each pixel using structural vegetation parameters derived from observed and simulated maps and a constant reference value (Chow 1959) (Fig. 8). The total flow resistance, expressed as Manning's coefficient, is calculated using the general equation (Chow 1959). The vegetation flow resistance is calculated by applying two different models Petryk and Bosmajian (1975) and Thompson and Roberson (1976).

Table 2 - Performances of the flow resistance simulations quantified using the RMSE estimation calculated between reference values and remote sensing approach for both classes 1-2.

	Petryk and Bosmajian 1975		Thompson and Roberson 1976	
RMSE	$n_{obs} - n_{norm}$	$n_{obs} - n_{\mathrm{mod}}$	$n_{obs} - n_{norm}$	$n_{obs} - n_{\mathrm{mod}}$
CLASS -1	0.0159	0.0067	0.0305	0.0002
CLASS -2	0.0245	0.0063	0.0247	0.0009

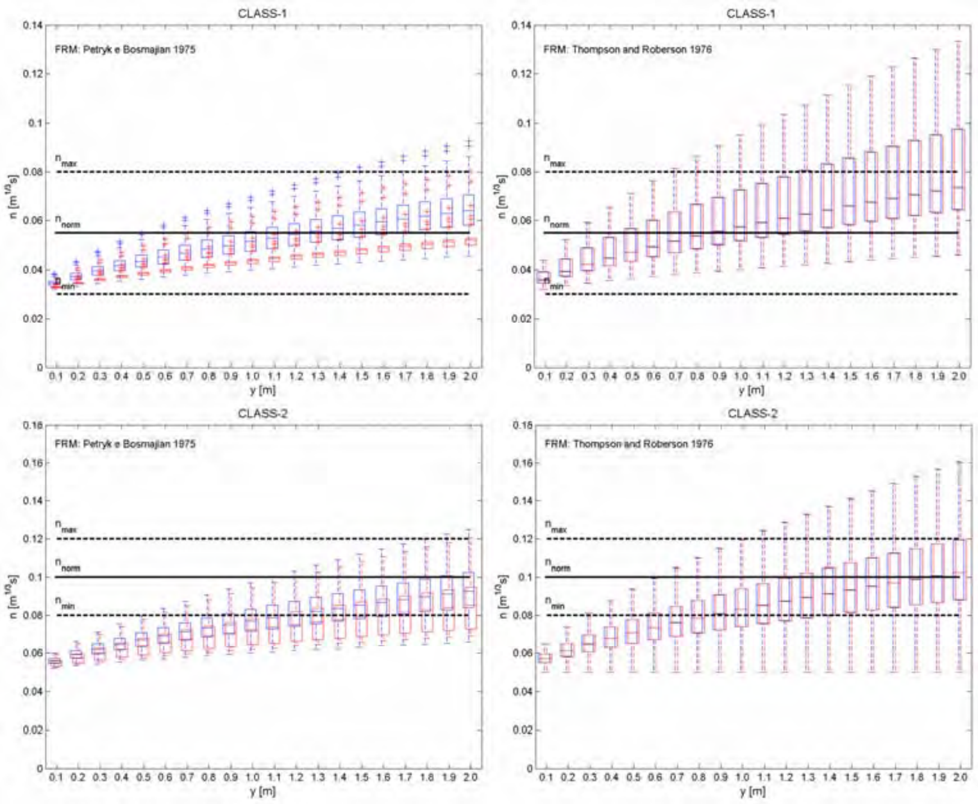

Figure 8 - Flow resistance simulations. On x-axis and y-axis there are respectively the hydraulic stage and the Manning's coefficient. The reference values (Chow 1959) are displayed in black line; the blue and red box plot represent the distributions of flow resistances obtained using structural vegetation parameters correspondingly from observed and simulated maps.

5. CONCLUSIONS

In this study we propose an integrated remote sensing data fusion process to estimate woody structural parameters (tree height, stem diameter, spacing or density, crown base height, crown diameter, leaf area index) in riparian corridors combining LiDAR data and spatial pattern produced by VHR optical image. The biophysical properties tree height, stem diameter, spacing or density, crown base height and crown diameter are estimated using consolidated multi-regression approaches over each tree, previously detected through a segmentation procedure. The leaf area index is estimated using a Quickbird image. All the structural parameters are developed within a spatial maps format and masked over the woody riparian vegetation using a land cover classification map. Despite the monitored complex scenario for overlapped crowns and high density vegetation, the proposed methodology generated structural vegetation parameter maps able to accurately demonstrate the biophysical patterns that play a crucial role in the riparian vegetation parameterization for hydraulic simulations. The generated maps represent spatially explicit data layers that can be used as direct inputs in hydraulic models to support the analysis of flood risk and the implementation of integrated mitigation management.

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MAGNITUDE, FREQUENCY AND DURATION OF SUSPENDED-SEDIMENT TRANSPORT IN STABLE ("REFERENCE") STREAMS OF THE SOUTHEASTERN UNITED STATES: REGIONAL WATER-QUALITY TARGETS

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ABSTRACT

Sediment is listed as one of the leading causes of water-quality impairments in surface waters of the United States. A water body becomes 'listed' by a State, Territory or Tribe if its designated use is being impaired, requiring the development of a Total Maximum Daily Load (TMDL) target to improve water quality. TMDL targets for sediment transport have been developed for many Level III ecoregions over the past several years using suspended-sediment yield (load per unit drainage area) as a metric. Target values were based on data from stable, or "reference" reaches, defined as those exhibiting geomorphic characteristics of equilibrium. Although one can use this methodology to differentiate between sediment-transport yields between stable and unstable streams in a given ecoregion, one cannot conclude that if a stream exceeds the target range, the aquatic ecosystem will be adversely impacted. To address this problem, historical flow and sediment-transport data from hundreds of sites in the Southeastern United States were re-examined to develop metrics such as frequency and duration of sediment concentrations. These relations could then be used to develop functional links between sediment and biologic response. Sites determined as geomorphically stable were sorted by Level III ecoregion. Mean-daily flow data were applied to sediment-transport rating relations to determine distributions of the frequency and duration that a given concentration was equalled or exceeded. "Reference" distributions were created for the stable sites in each ecoregion. As with the "reference" suspended-sediment yields, there is a broad range of frequency and duration distributions that reflect the hydrologic and sediment-transport regimes of the ecoregions. Ecoregions such as the Mississippi Valley Loess Plains maintain high suspended-sediment concentrations for extended periods whereas coastal plain ecoregions show much lower values.

Key words: Suspended sediment, ecoregion, channel stability, reference conditions

1. INTRODUCTION

Sediment is listed as one of the leading causes of water-quality concern in surface waters of the United States. A water body becomes ‘listed’ by a State, Territory or Tribe if its designated use is not being attained, i.e., impaired. In many cases, the prescribed designated use is aquatic life support or habitat, requiring the development of a Total Maximum Daily Loads (TMDL) target to improve water quality. TMDL targets for sediment transport have been developed for many Level III ecoregions over the past several years using suspended-sediment yield (load per unit drainage area) as a metric. Target values were based on data from “reference” reaches, defined as those exhibiting geomorphic characteristics of equilibrium where no temporal trends of net erosion or deposition occurred over a period of years. First developed for a constant recurrence-interval flow representing the effective discharge and subsequently for annual values, the suspended-sediment yield metric has proved useful to some states developing TMDLs for suspended sediment. Although one can use this methodology to differentiate between sediment-transport yields between stable and unstable streams in a given ecoregion, one cannot state that if a stream exceeds the target range, the aquatic ecosystem will be adversely impacted. This is because there is limited data and knowledge on the functional links between suspended-sediment transport rates and ecologic function in streams.

Because an aquatic organism cannot sense a suspended-sediment yield, suspended-sediment data must be parameterized so that they can be linked to life-cycle attributes of aquatic organisms. Newcombe and MacDonald (1991) and others have found that aquatic organisms may be negatively impacted by high-sediment concentrations over un-specified time periods. Sediment metrics that reflect these findings are, therefore, needed. The hypothesis is that unstable sites will show greater frequencies and durations for specified transport rates than stable, reference sites. Given these issues, the purpose of this investigation was to test whether frequency and duration relations for suspended-sediment transport could be differentiated for stable and unstable streams on an ecoregion-wide basis.

2. GEOGRAPHIC SCOPE and METHODOLOGY

The geographic scope of this research was the Southeastern United States. This region covers eight states and 14 ecoregions (Figure 1). Ecoregion boundaries do not follow political borders and several of the ecoregions contain only small sections within the regional boundary. Thus, ecoregions 69, 70 and 72 are excluded from this study.

There were two main phases of research used during the course of this study: (1) field- data collection (Rapid Geomorphic Assessments; RGAs; Simon, 1995) at locations where flow- and sediment-transport data had been historically collected by the U.S. Geological Survey (USGS; Figure 1), and

(2) synthesis and analysis of the available sediment-transport data at these same locations. These sites represent locations with 30 or more suspended-sediment samples and associated flow data.

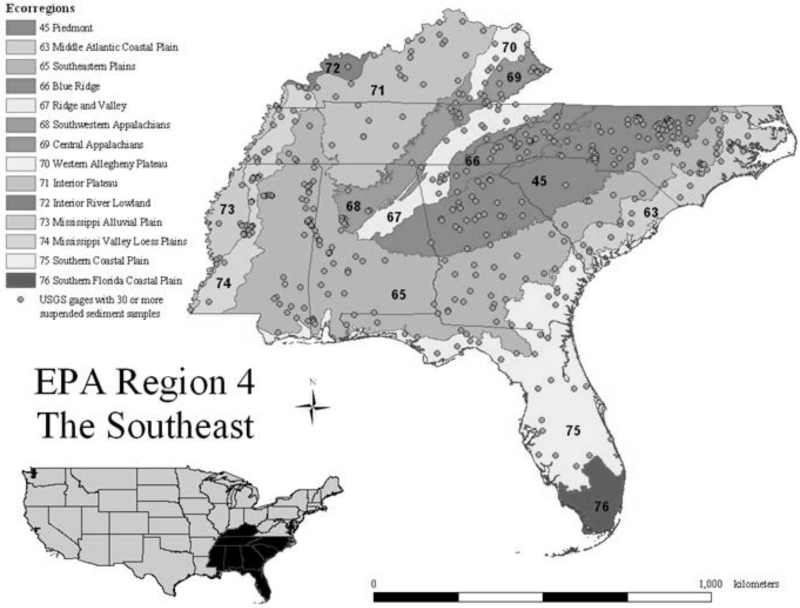


Figure 1- Map of the southeastern United States showing Level III ecoregions and sites with historical flow and sediment-transport data.

To identify those sediment-transport conditions that represent impacted or impaired conditions, it was essential to first define non-disturbed, stable-stream conditions that could be identified as “reference” conditions. For the purposes of this study and report, stability was defined in geomorphic terms; that is, a stream in dynamic equilibrium, capable of transporting all sediment delivered to the system without altering its dimensions over a period of years. This is not to say that the stream is static, but that short-term, local processes of scour and fill, erosion and deposition, are balanced through a reach such that the stream does not widen, narrow, degrade or aggrade over time. RGA data were used to differentiate between stable (“reference”) and unstable sites. This approach has proved successful as channels represent the major conduit of energy and materials transported through a watershed.

2.1 Field-Data Collection: Rapid Geomorphic Assessments (RGAs)

RGAs were conducted at each of the locations shown in Figure 1. This work entailed evaluating the relative stability and dominant channel processes (Simon, 1995) of the stream channel for 6-20 channel widths centered on the site. Diagnostic information such as the degree of incision, percent of reach with failing banks, bank accretion, and woody vegetative cover are evaluated. Stage of channel evolution (Simon and Hupp, 1986; Simon, 1989) is also determined, bed-material samples collected, channel-slope surveyed and photographs are taken. An advantage of a process-based channel-evolution scheme is that Stages I (pre-modified) and VI (re-stabilized) represent true “reference” conditions for use in the development of TMDLs. Channels are unlikely to recover to Stage I, pre-modified conditions where land-clearing activities near the turn of the 20th century caused massive changes in rainfall-runoff relations. Stage VI, a re-stabilized condition, is a much more likely target under present regional land use and altered hydrologic regimes (Simon and Rinaldi, 2000) and can be used as a “reference” condition.

2.2 Synthesis and Analysis of Suspended-Sediment and Flow Data

Analysis of suspended-sediment transport data at each USGS gauging station involved establishing a relation between flow and sediment concentration, or load, termed a sediment-rating relation. It is acknowledged that these power functions tend to mask specifics of governing sediment-transport processes, yet they still provide a useful foundation for calculating the amount of suspended sediment being transported over a broad range of flows. Because the relations between water discharge and suspended-sediment load or concentration are approximate, high coefficients of determination between these variables (for example 0.90) may still have order-of-magnitude 95% prediction limits. However, prediction of mean transport rates over a suitably long period of time (represented by a transport relation) should have a higher degree of reliability if a dataset has been collected over the range of flows. In studies carried out in other ecoregions across the United States, trends of these data (in log-log space) often increase linearly and then flatten at high discharges. Preliminary analysis shows that although sand concentrations continue to increase with discharge, the silt-clay fraction attenuates, causing the transport relation to flatten (Kuhnle and Simon, 2000). To alleviate this problem, a second (or even third) linear segment (in log-log space) was often fit to the upper end of the dataset (Figure 2).

Once a power function(s) was obtained by regression, mean-daily flow data for each gauging station was then applied to the associated sediment rating relation to obtain daily suspended-sediment load for each day of record. Results of this analysis were initially used to calculate annual and mean-annual loadings and yields (load divided by basin area) for each site.

To address the specific objectives of this study, however, daily suspended-sediment load data were also used to establish sediment frequency and duration curves by calculating the percentage of time selected sediment concentrations were either equalled or exceeded. This was accomplished by dividing daily loadings data by discharge to obtain daily concentrations as a means of comparing sites of different drainage areas within an ecoregion. The frequency that a given sediment concentration was equalled or exceeded was then calculated to produce a frequency distribution for each site.

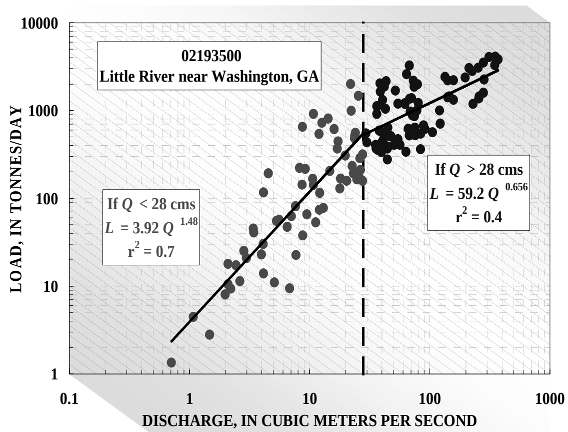


Figure 2 – Example two-segment sediment-rating relation used to describe suspended-sediment transport over the range of flows.

An example of the concentration-frequency distribution is shown for a site on Town Creek, MS (Figure3a). To obtain "reference" frequency and duration values over the range of concentrations within an ecoregion, sites determined to be geomorphically stable from field evaluations and from analysis of gauging- station records were sorted by Level III ecoregion. "Reference" distributions were created for the stable sites in each ecoregion by averaging all of the distributions at specified exceedance intervals (0.01, 0.1, 1, 5, 10, 25, 50, 75, 90, 95, and 99). A similar analysis was also conducted to determine the durations of given concentrations. Figure 3b displays the duration for the same site as above (expressed in the number of consecutive days) where various concentrations persist.

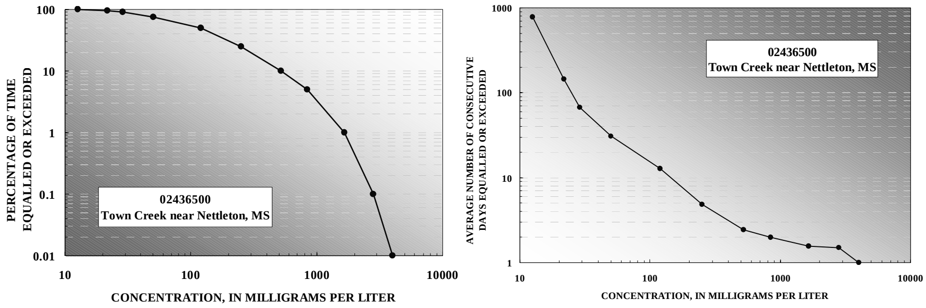


Figure 3 - Median frequency that sediment concentrations were equalled or exceeded (A; left) and average duration (number of consecutive days) a given concentration is equalled or exceeded (B; right) for Town Creek near Nettleton, MS.

3. RESULTS

Channel stability and suspended-sediment transport rates were determined for all sites in the region according to the above procedures. The majorityof channels in mountainous Ecoregions (#66, #67 and #68) and coastal Ecoregion 75 were found to be stable by means of on-site RGAs (Table 2). Channels located in the highly erodible loess region (Ecoregion 74) were found to be the most unstable.

3.1 Mean-Annual "Reference" Suspended-Sediment Yields

Having determined channel stability for all sites within a given Level III Ecoregion, calculated mean-annual suspended-sediment yields were sorted into stable and unstable groups. As the data are not normally distributed, it is appropriate to use median values and other percentile measures, as opposed to means and standard deviations, which in all cases were far greater than the calculated median values provided. Results are provided in Table 1 for all, stable, and unstable sites. As not all gauges had sufficient historical data for calculations of mean-annual yield (ie. mean-daily data or drainage area), the final row of each table shows the number of sites ('COUNT') used. In some cases the COUNT is notably low, such as Ecoregion 74 where the median "reference" value was calculated from just 4 stable sites.

States that have used these types of data to develop TMDLs for sediment generally rely on a measure of the central-tendency of the "reference" distribution to establish targets for a specific ecoregion. To provide more flexibility, however, rather than use a single value such as the median (50th Percentile in Table 1), values represented by the inter-quartile range (25th – 75th percentiles) are sometimes preferred. For comparative purposes, Figure 4 shows each distribution as a box and whisker plot. Ecoregions 73 and 74 clearly stand out in Figure 8 as having the highest "'reference" annual suspended-sediment yields in the southeastern United States (78.9 and 52.4 T/y/km^2 respectively). It is not surprising, given that the loess region is by nature a highly erodible area, with characteristically poorly drained soils and fine, silty, alluvial materials, that the Mississippi Alluvial Plains (#73) and the Mississippi Valley Loess Plains (#74) have the highest mean-annual yields. Much of the area has been disturbed over the past century by land clearing, intensive agriculture, with many channels under-going channelization. Previous researchers have noted that this region produces some of the highest suspended-sediment yields in the continental United States (as much as 400 – 2300 T/y/km^2) (Ruhe and Daniels, 1965; Piest et al., 1976; Little and Murphey, 1981; Simon, 1989b; Simon and Thomas, 2002; Simon *et al*, 2004).

Table 1 - Mean, annual suspended-sediment yields for Level III Ecoregions in the southeastern United States. Stage II (constructed) sites are not included.

ALL SITES Mean annual yield in T/y/km^2

	Ecoregion									
	45	**63**	**65**	**66**	**67**	**68**	**71**	**73**	**74**	**75**
10th Percentile	10.2	1.62	3.26	7.16	6.77	12.3	11.4	29.0	119	1.31
25th Percentile	**17.1**	**2.70**	**5.89**	**13.1**	**15.2**	**22.9**	**21.6**	**43.3**	**213**	**1.78**
50th Percentile	**39.0**	**5.60**	**12.1**	**33.7**	**28.8**	**36.9**	**33.0**	**71.1**	**418**	**3.29**
75th Percentile	**56.6**	**10.4**	**37.3**	**58.5**	**56.1**	**81.2**	**60.0**	**145**	**979**	**6.50**
90th Percentile	108	15.4	88.5	83.6	84.4	132	89.7	387	1805	11.0
COUNT	72	24	94	27	55	9	34	28	30	30

STABLE SITES Mean annual yield in T/y/km^2

	Ecoregion									
	45	**63**	**65**	**66**	**67**	**68**	**71**	**73**	**74**	**75**
10th Percentile	4.73	1.00	3.04	7.47	6.76	11.5	6.09	28.6	31.1	1.297
25th Percentile	**11.8**	**1.70**	**3.84**	**12.7**	**13.2**	**20.6**	**10.2**	**38.8**	**36.2**	**1.58**
50th Percentile	**19.6**	**2.40**	**8.64**	**20.9**	**19.3**	**36.2**	**14.9**	**52.4**	**78.9**	**2.77**
75th Percentile	**33.8**	**3.25**	**16.4**	**34.5**	**31.8**	**60.8**	**28.0**	**82**	**143**	**4.16**
90th Percentile	40.3	4.20	34.5	58.4	50.3	88	42.1	137	187	6.75
COUNT	25	11	44	18	34	8	12	15	4	21

UNSTABLE SITES Mean annual yield in T/y/km^2

	Ecoregion									
	45	**63**	**65**	**66**	**67**	**68**	**71**	**73**	**74**	**75**
10th Percentile	15.1	6.55	4.85	48.7	26.5		25.4	41.8	166	3.25
25th Percentile	**26.8**	**7.23**	**9.20**	**58.1**	**44.9**		**30.4**	**73.3**	**258**	**4.06**
50th Percentile	**50.2**	**11.1**	**24.7**	**64.6**	**64.4**	246	**51.7**	**136**	**498**	**6.50**
75th Percentile	**86.3**	**25.2**	**62.4**	**86.2**	**75.4**		**66.5**	**173**	**1084**	**11.61**
90th Percentile	117	43.4	209	110.9	433		96.4	365	2384	21.9
COUNT	37	6	36	7	11	1	15	8	26	8

The high-relief regions of The Piedmont (#45), Blue Ridge (#66), Ridge and Valley (#67) and Southwestern Appalachians (#68) form the group with the next highest stable, "reference" mean annual suspended-sediment yields, ranging from 19.3 to 36.2 T/y/km^2. This suggests that the majority of the channels in the region are stable (Table 1), transporting sediment from the surrounding upland areas through the channels of these higher-relief ecoregions, ultimately being delivered to the channel system during high magnitude, low frequency events such as intense, summer convective rainstorms and hurricanes. As slope and relief decrease with increasing distance from the mountainous regions eastward, there is a consequent decrease in sediment supply and transport capacity in the channels. As a result, mean annual suspended-sediment yield values decrease with distance from the mountains. Stable, mean-annual yields for The Interior Plains (#71) and The Southeastern Plains (#65) are less than half that of Ecoregion 68. The low elevation, low relief plains lining the coast (Ecoregions #75 and #63) have the lowest stable, mean-annual yields, producing an average of 2.8 and 2.4 T/y/km^2, respectively. That the Middle Atlantic Coast (#63) has a “reference” yield almost 33 times smaller than that of Ecoregion 74, attests to the need to establish “reference” conditions at the very least, at the Level III ecoregion level.

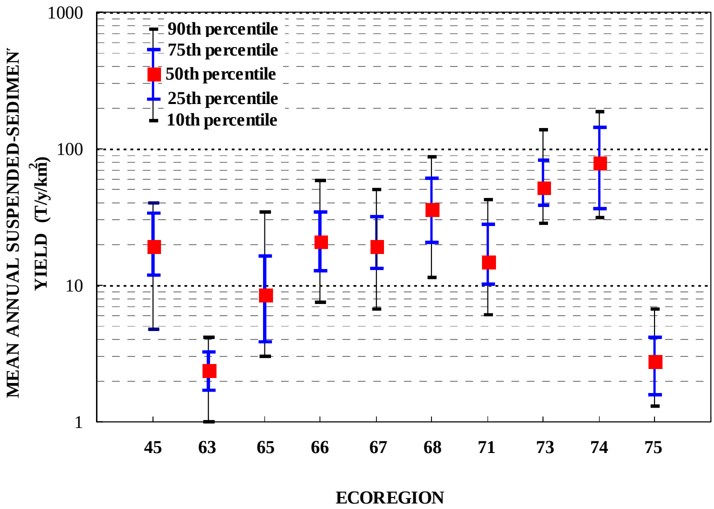


Figure 4 - Distribution of mean, annual suspended-sediment yields for stable, “reference” streams in Level III ecoregions of the southeastern United States.

3.2 Magnitude, Frequency and Duration of “Reference” Concentrations

“Reference” frequency and duration values were derived for stable streams for each of the Level III ecoregions. The “reference” frequency-magnitude data clearly show the groupings of ecoregions as indicated above regarding trends of decreasing mean annual suspended-sediment yield with distance from the higher-relief ecoregions (Figure 5a). During 99th percentile storm events (those exceeded on average 1 % of the time, or 3.65

days a year) "reference" concentrations mirror patterns observed from the annual suspended-sediment yield data (Figure 4). "Reference" reaches in the Middle Atlantic (#63) and Southern Coastal Plains (#75) transport the lowest concentrations of suspended-sediment, 10.5 and 13.5 mg/l, respectively. Moving inland, stable reaches of the Southeastern (#65) and Interior Plains (#71) have the next lowest concentrations; 35.6 and 44.7 mg/l, respectively. Higher concentrations are calculated for the high-relief regions as follows: Blue Ridge (#66, 57.1 mg/l), Southwestern Appalachians (#68, 66.5 mg/l), Ridge and Valley (#67, 88.6 mg/l), and Piedmont (#45, 99.2 mg/l). The Mississippi Alluvial Plain (#73) and the Mississippi Valley Loess Plains (#74) maintain the highest concentrations during a 99th-percentile storm event; 202 and 243 mg/l, respectively. These frequency data are converted from percentage of time to number of days per year and presented graphically in Figure 5b.

4. DISCUSSION AND CONCLUSIONS

Results on magnitude, frequency and duration of suspended-sediment concentrations for stable, "reference" streams may prove useful to TMDL practitioners. However, it is the differences between these parameters for stable and unstable streams in a given ecoregion that may ultimately be the most informative for identifying threshold conditions for aquatic health by comparing aquatic communities from representative streams. An example from the Blue Ridge Mountains (#66) clearly show the greater frequency and duration (1-2 orders of magnitude) of specific concentrations for unstable streams (Figure 6).

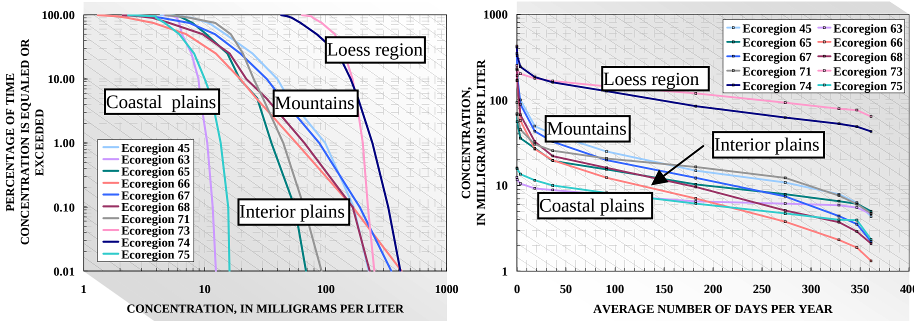
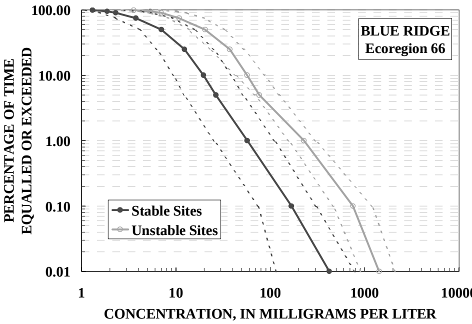


Figure 5 - Percentage of time that sediment concentration (A; Left) and average number of days per year (B; Right) that concentration is equalled or exceeded in stable channels of Level III Ecoregions of the southeastern United States.

Historical flow and suspended-sediment data, obtained from the USGS, in combination with field evaluations of channel stability, were used to determine mean, and annual suspended-sediment yields for stable and unstable streams for each of the Level III ecoregions in the southeastern United States. Median values for stable or "reference" streams range from 2.8 T/y/km^2 for the Southern Coastal Plain (Ecoregion #75) to about 79 T/y/km^2 for the Mississippi Valley Loess Plains (Ecoregion #74). These data were re-analyzed to develop relations for magnitude, frequency and duration of given concentrations for purposes of developing a format that could ultimately be used to evaluate relations between suspended-sediment transport rates and aquatic health, Results are expressed in terms of the (1) percentage of time, or frequency, and (2) duration a given concentration is equalled or exceeded. As with the "reference" suspended-sediment yields, there is a broad range of frequency and duration distributions that reflect the hydrologic and sediment-transport regimes of the ecoregions. Ecoregions Such as the Mississippi Valley Loess Plains (#74) maintain high concentrations for extended periods whereas the coastal plain ecoregions (#63 and 75) show much lower values. Future research aimed at establishing functional links between suspended-sediment and aquatic health may need to rely on differentiating sediment-transport regimes and aquatic community structure for stable and unstable streams. An example of the differences in frequency and duration relations within an ecoregion is provided for the the Blue Ridge Mountains (#66).



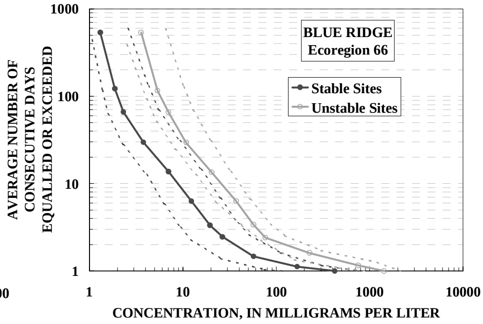


Figure 6 - Comparison between frequency (A; Left) and duration (B; Right) of suspended-sediment concentrations for stable and unstable streams in the Blue Ridge Mountains Ecoregion (#66).

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CONSIDERATIONS ABOUT POTENTIAL AND RELATIVE FLUVIAL FUNCTIONING OF ALPINE RIVERS

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ABSTRACT

Mountain river stretches, whether above or below the tree line, have peculiar physical-chemical characteristics which generate a selective environment for the biological communities and a reduction in the functioning capacity of the ecosystem. Therefore it is necessary to develop specific tools to assess the impacts produced by human activities, and to estimate the natural value of mountain river stretches in order to inform restoration or conservation projects.

In this paper, we consider the degree to which the Fluvial Functioning Index (FFI, Siligardi *et al.*, 2007) is an appropriate tool to assess the environmental value of alpine rivers. Some of the peculiar characteristics of alpine rivers (such as the absence or the limited widths of the riparian vegetation margin and the floodplain) mean that even when these rivers are in a totally natural condition, their FFI index does not reach the maximum value. As a result, rather than considering the absolute value of the FFI in isolation, it is more useful to compare the observed value with the potential value for the reach if it were in a pristine state. In this way it is possible to obtain an estimate of the relative river functioning (absolute functioning value/potential functioning value), that is more informative in a restoration or management context than the absolute value.

Alpine rivers are often deemed to be uncontaminated ecosystems devoid of environmental alterations, probably due to the absence or low density of permanent human settlement. However, the absence of apparent human pressure does not necessarily imply the existence of highly natural conditions. Although of apparently limited impact, many human interventions may disturb the delicate equilibrium of these fragile ecosystems and produce significant alterations. Through the analysis of the typical characteristics of alpine river ecosystems it is possible to gather

appropriate information to assess the potential river functioning of these environments, resulting in the development of a specific tool for the study of mountain river ecosystems.

Key words: relative fluvial functioning, alpine rivers, naturalness

1. INTRODUCTION

This research focuses on mountain stretches of alpine watercourses, which in the study areas in Italy are situated above an elevation of 1000 m and below the altitudinal tree limit. Within this elevation range, mountain rivers are peculiar environments in which the ecosystem is continuously rejuvenated by the action of meteorological events such that animal and plant populations never reach a stable stage of maturity. It is as if stream biocenosis were perennially pioneer (Minelli *et al*., 2002).

Human intervention, even if of limited significance, frequently alters the delicate equilibrium of these mountain watercourses ecosystems, which are characterized by physiological, ecological and functional fragility (Minciardi *et al*., 2003). However, even in the absence of human alterations, mountain river ecosystems usually display limited values of ‘functioning’, that is their capacity to guarantee the fulfilment of river ecological functions such as the provision of a diverse range of habitats, chemical buffering etc., and they display “limited homeostatic capacity and system resilience to possible pressures” (Siligardi *et al*., 2007).

2. STUDY AREA AND METHODS

Mountain stretches of some alpine watercourses in Trentino, Veneto (BL), Piemonte (TO) and Valle d’Aosta were examined, with the aim of developing an effective means of assessing their actual and potential fluvial functioning. The Fluvial Functioning Index (FFI, Siligardi *et al.*, 2007) was evaluated for about fifty river reaches during the 2007 and 2008 growing season. Figure 1 shows a typical survey reach on the Grigno stream, Trentino.

Figure 1 – Grigno stream (TN-Italy)

The FFI method is applied to homogenous river stretches and the survey sheet includes 14 questions which relate to the main river system components (Table 1). For each question there are 4 possible answers. An FFI score is produced separately for each river bank by summing the scores obtained in answer to all 14 questions for each bank. A functioning level and judgment (represented by a specific colour) are then attributed to the reach according to the FFI total score.

The FFI index is the most widely-used tool in Italy for the evaluation of the fluvial ecosystem. Up to now 4000 Km of rivers have been surveyed with this method. Furthermore, many training activities on the application of the FFI method are still being implemented.

Even if in a totally natural condition, the value of the FFI for alpine rivers often does not reach the maximum value. As a result, rather than considering the absolute value of the FFI in isolation, it is more useful to compare the observed value with the potential value for the reach if it were in a pristine state. In this way it is possible to obtain an estimate of the relative river functioning (absolute functioning value/potential functioning value), that is more informative in a restoration or management context than the absolute value.

In the present study, surveyed reaches that displayed negligible human impacts were investigated to identify approaches to establishing a potential values of the FFI with which the observed FFI score for mountain river stretches could be compared.

3. RESULTS

Of the total fifty mountain alpine reaches surveyed, twenty were characterized by high naturalness (absence of human impacts) and evaluated to identify the ecological components that presented limited functioning scores. The components that were notably affected were:

- ✓ typology of perifluvial strips: in most of the situations these tended to be shrubby and relatively underdeveloped; the presence of two or more riparian formations, of which at least one contained mature trees, was very uncommon;
- ✓ overflowing efficiency: frequently in mountain rivers, the floodplain is confined by steep mountain slopes or may be non-existent. As a result, the lateral dynamism of the river channel is significantly reduced;
- ✓ hydromorphology: in mountain stretches the morphology is typically dominated by a “step and pool” typology, although some stretches may display a diverse mosaic of hydromorphological elements.

Table 1 – Potential functioning in mountain alpine river stretches.

FFI QUESTION		CASE 1		CASE 2	
		mountain stretch with a shrubby or arboreous riparian formation and an arboreous autochthonous not riparian formation		mountain stretch with a shrubby riparian formation, an arboreous riparian formation and an arboreous autochthonous not riparian formation	
		MINIMUM POTENTIAL FUNCTIONING	MAXIMUM POTENTIAL FUNTIONING	MINIMUM POTENTIAL FUNCTIONING	MAXIMUM POTENTIAL FUNTIONING
1	Land use pattern of the surrounding area	25	25	25	25
2	Vegetation present in the primary perifluvial zone	25	25	40	40
3	Width of the functional formations of the perifluvial zone	15	15	15	15
4	Continuity of the functional formations of the perifluvial zone	15	15	15	15
5	Water conditions	20	20	20	20
6	Overflowing Efficiency	1	25	1	25
7	Riverbed substrate and retention structure of the trophic matter	15	25	15	25
8	Erosion	1	20	1	20
9	Cross-section	20	20	20	20
10	Ichthyic suitability	5	25	5	25
11	Hydromorphology	15	20	15	20
12	Plant component in wet riverbed	15	15	15	15
13	Detritus	15	15	15	15
14	Macrobenthic community	20	20	20	20
FFI SCORE		**207**	**285**	**222**	**300**
FLUVIAL FUNCTIONING LEVEL		II	I	II	I
FLUVIAL FUNCTIONING JUDGMENT		good	excellent	good	excellent

(green)	questions of group A (indipendent from the watercourse typology)
(orange)	questions of group B (defined on the basis of the watercourse typology)
(yellow)	questions of group C (site-specific)

Based on these considerations and on the expert judgement of the surveyors, potential functioning conditions were defined on the basis of the possible answers that could be attributed to each of the individual FFI questions in a mountain river context.

For every stretch typology it is therefore possible to determine the range of variation of the potential functioning score, considering the maximum and minimum value for the site-specific questions (Table 1, group C), fixing the potential score for the questions relating to water course type (group B. Table 1) and keeping the maximum score obtainable for the site-specific questions (Group A, Table 1).

Table 1 represents the minimum and maximum functioning scores estimated for mountain stretches located between 1000 meters and the altitudinal tree limit. In Table 1 two hypothetical cases, differing according to the characteristics of their perifluvial vegetation strip, are represented. The two cases are visualized in Figure 2 and 3, where for each question (x axis) three scores (y axis) are displayed: the maximum score achievable for each question, the minimum score and maximum one for the potential functioning.

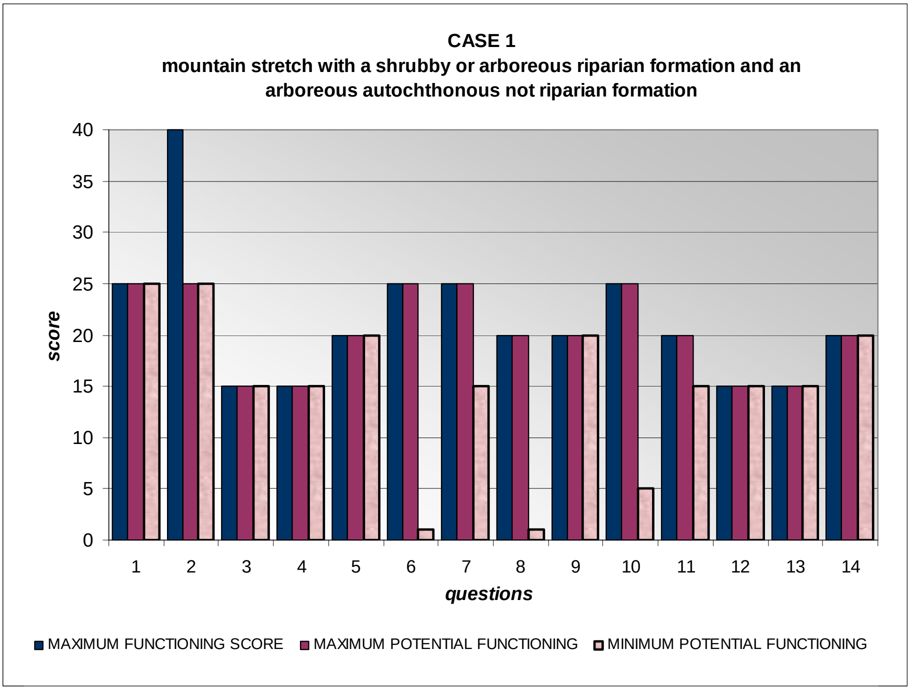

Figure 2 - Comparison between the maximum score and the one of maximum and minimum potentiality for each FFI question in case 1.

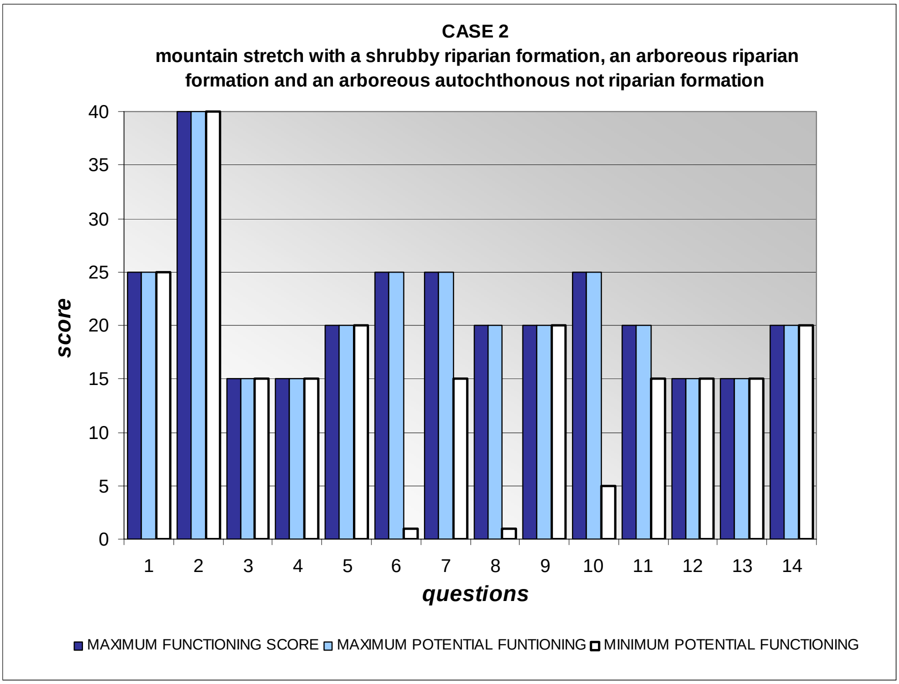

Figure 3 - Comparison between the maximum score and the one of maximum and minimum potentiality for each FFI question in case 2.

4. CONCLUSIONS

The FFI is being applied in Italy to express a judgment based on the theoretical conditions of maximum functioning, characteristic of an ideal watercourse. Whilst the index is very effective in most circumstances, in those circumstances where the conditions of maximum functioning do not correspond to those of maximum ecological integrity evaluations (e.g. mountain river stretches), it is necessary to assess their functioning relative to what is actually achievable. Thus, we have developed a method of assessing the potential value of the FFI for mountain watercourses (i.e. their FFI value if they were unaffected by human impacts) as a datum against which their observed FFI can be evaluated.

The introduction of the concept of potential functioning allows quantitative evaluations of the maximum level of functioning achievable by the watercourse and also its level of deviation from this potential state. Such considerations can support, for example, the evaluation of the efficacy of river restoration projects, particularly the degree to which may be able to obtain improvements in particular situations.

Furthermore, the evaluations about relative functioning place the FFI in an international context, since in this way it is possible to consider ecological integrity as the reference value as requested by the Water Framework Directive (2000/60/CE).

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CHAPTER 12

Session 9

Urban rivers

Chairperson

J. JORMOLA

Introduction
URBAN RIVERS

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In the session Urban rivers, different aspects of urban river restoration like goal setting, constrains and planning methods were discussed. Restoration of urban rivers is challenging because of intensive land use, danger of flooding and impacts of human activities for water quality and for the ecology of rivers. The present state of rivers is much dependent on the history and trends of the society in each country. In many situations water quality is still unsatisfying, but increasing efficiency of sewage treatment gives new opportunities for recreation of inhabitants and enhancement of river morphology and ecology. In urban environments sufficient flood control and the hygienic quality of water must be considered as a basis for normal living with rivers. The importance of urban rivers and streams for green areas and urban ecology and thus, quality of life in cities is an increasing concern worldwide

The session contained nine presentations, of which three were posters. About 30 people attended the session. The session gave a good overview of the situation of rivers and river restoration in different continents. The goal setting for river restoration varies in each restoration project, which was a key subject in an international project URBEM, concerning a wide range of urban river restoration projects. An example from Lisbon, Portugal shows that the goal setting in river restoration schemes may sometimes be based more on social aspects than ecological river restoration.

In heavily urbanized metropolitan areas, like Mexico city, urban development has lead to a total change of the original hydrology. An ancient river and lake system has been diverted through centuries because of flooding problems. Growing population has caused degradation of water quality, leading to a covering of watercourses out of sight. A restoration proposal may contribute to a renewal in attitudes of urban planning for further river restoration activities. In Australia, in the Sydney area, where more nature is preserved in despite of urban development, a multitude of existing stream types have been investigated and priorities for protection and restoration have been set. This forms a basis for future work for a comprehensive targeting of stream conservation and restoration in metropolitan scale, of which examples already can be seen.

Changes in former land use like ceasing of industry, can provide opportunities for river restoration, which is a new sign of interest in a post-industrial urban environment. In the Emscher region in Germany, which was an important industrial centre with coal mining, promising results have been gained by restoring former sewage canals to a system of ecologically viable streams with numerous riverine species. Accordingly, a change of mind in considering the value of urban streams can be seen in cities with municipal small water programs, which are a good basis for future restoration of urban streams in green area maintenance. In the city of Helsinki, Finland two experimental sites of such a program have been accomplished with low planning and construction costs, but nevertheless with promising results. Beginning with the work of volunteers, new spawning and rearing habitats have been created for the vulnerable sea trout population of the Baltic Sea region. Urban stream restoration can have ecological value not only for a city centre or a suburb but also through natural or restored connectivity for larger watercourses.

In urban circumstances, where space is limited and danger for severe erosion or flooding problems exist, planning of river restoration needs consideration of river processes and hydrology in advance. In Illinois, USA modeling was used for evaluating erosion, sedimentation and ecological circumstances. Bed stabilization was needed because of land use near to the stream. After construction, fish were observed in the restoration area. In Hong Kong, modeling has been used to define planning options for future restoration of a small urban stream, at present constructed with concrete. The effects of different restoration methods for stability and flooding have been evaluated, aiming for a self sustainable bed with flood terraces.

The outcome from the session was that the degradation of urban rivers may be extreme, but that river restoration projects in urban circumstances can provide surprisingly good results with real ecological values. Through restoration the change from former bad state can be phenomenal. Because of increasing urbanization worldwide, restoration of urban rivers is a growing interest of inhabitants. Municipal river restoration programs, considering also stormwater management and urban hydrological regimes give a strategic tool for incorporating river restoration into other urban interests. Urban river restoration should be promoted in all levels, from strategies to demanding engineering schemes, normal maintenance practices and volunteer participation of inhabitants. The session gave inspiration and confidence to long term work for the restoration of urban rivers.

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THE RECONSTRUCTION OF THE EMSCHER SYSTEM - AN INTEGRATED PLANNING PROCESS ACCORDING TO THE WFD

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ABSTRACT

Part of an integrated river basin management for the Emscher Region (865 km^2, 2.700 inhabitants/ km^2) is the restoration of the Emscher and its tributaries as an urban river system. Due to industrialisation, the waterbodies were systematically used as open wastewater sewers. The system will be restructured to become an attractive urban river system, integrated in its surroundings, and with its unique character. The planning approaches described here, show the course to be taken. They form the basis for further discussions, which will produce a general concept for the restoration of the Emscher system. With the restoration new chances will be opened for the entire region. Economic, ecological and social progress will follow.

In order to assess the conditions of the waterbodies an extensive monitoring programme was set up, which included water quantity and quality, biological indicators and morphological structures.

Enough time has to be given to waterbodies after they have been restored to allow them to recuperate their typical biodiversity. Brooks which were restored long ago today are already showing the type of biodiversity that can occur in the Emscher system. The sandy bed of the stream forms the habitat for numerous molluscs, insects, crustaceans and oligochaetes. In the water itself, a variety of different fish species have settled. A 2004 study has identified 360 species of invertebrates and fish in the Emscher system, some of which are rare species.

The multidisciplinary planning approach proved to be very successful. The constant sharing of work steps between the various disciplines lead to an efficient planning process.

Because the development of a stable biocoenosis that reflects the reconstructed stream morphology and external pressures needs quite some time, monitoring needs to be continued in order to show whether the restoration was a success or further complementary measures need to be taken.

Key words: urban river, Emscher River, integrated river basin management, WFD

1. INTRODUCTION: THE EMSCHERGENOSSENSCHAFT

The Emschergenossenschaft is the oldest of 11 water boards in Northrhine-Westfalia, founded in 1899 in order to solve the problems caused by increasing industrialization and volumes of sewage, and health problems including epidemics and underground coal mining in the Emscher catchment. With a size of 865 km^2 and 2.3 Mio inhabitants (=2.700 inhabitants/ km^2) the Emscher catchment is one of the most densely populated regions throughout Europe. The Emschergenossenschaft is a self-managed public association and thus a non-profit company which is controlled by its members. Since 1926 the Emschergenossenschaft works together with the Lippeverband. Both water boards are based on special legislation with the following tasks:

- elimination of sewage / treatment of municipal & industrial waste water
- flood protection and stormwater management
- maintenance and ecological development of water bodies
- supply of process/industrial water
- management of drainage and sewage systems
- treatment of sewage sludge

The most important aim is to combine the technical work with landscape and urban development and related projects on art, leisure and waterfront architecture. At this purpose, a close cooperation of the customers and members of the Emschergenossenschaft is needed, not only with the municipalities but also with industrial partners, who often are “global players” and consequently difficult to convince that formal and informal tasks need to be accomplished together.

With the fall of the “old industries”, unemployment became a growing problem in the region and at the same time the increased amount of fallow lands lead to the question of how to develop the region to attract new employers. The aim of all planning partners of the region is to solve these problems not only by offering building areas, but by improving the quality of the region for the future through several measures. One important step to develop an attractive region is the restoration of the Emscher system and the development of the surrounding area.

2. REGIONAL STRUCTURES AND CHALLENGES

The original Emscher and its tributaries have been turned into open wastewater channels since 1906. Sewage treatment was centralised in a river treatment plant next to the Rhine. Economic and technical alternatives such as closed sewer systems could not be implemented due to constant subsidence caused by mining.

The restoration of the Emscher and its tributaries as an urban river system is part of an integrated river basin management for the Emscher Region. Due to industrialisation the Emscher and its tributaries (340 km length in total) were systematically developed as open wastewater sewers. The changed topography as a result of mining subsidence made it necessary to lower the bed of long stretches of the 82 km long Emscher River and to build dykes. The river has cut into the terrain up to a depth of 9 m. The middle and lower reaches for a stretch of more than 75 km were provided with dykes, with heights of up to 10 m. A great part of the catchment became a polder. Most of the tributaries were constructed in the same way. At the same time, the surrounding area has become multi-structured. Urban areas alternate with green areas, woodland, or agricultural landscapes. Over wide stretches, industrial facilities cover areas immediately adjacent to the Emscher.

When at the beginning of the ‘90s this system, which had been accepted for about 80 years, was no longer able to fulfil current wastewater treatment criteria, it was decided to stop the open transportation of untreated, or only mechanically treated, wastewater, to relocate biological wastewater treatment within the Emscher catchment area, and thus to decentralise the system and prevent the introduction of wastewater into surface waters.

Whilst maintaining flood protection and ensuring transportation of the purified wastewater, the Emscher will be developed into a recreational and accessible area in order to fulfil the requirements of the WFD. Studies on the feasibility of restoring the Emscher show that it will not be possible to return the Emscher to its original, meandering state of about 80 years ago. The densely built-up areas and the changed topography due to mining subsidence preclude this solution.

In order to achieve these objectives, an ambitious restoration programme has been developed:

1. Construction and improvement of treatment plants (phase completed).
2. Building 400 km of waste water sewers within 2014 (182 km of which have already been completed) and stormwater treatment measures, flood retention measures.
3. Ecological rehabilitation of 340 km of open water courses within 2020 (45 km of which have already been completed).

⇨ Investment of 4.4 billion Euro in 30 years (up to now 2.1 billion have already been spent).

Generally speaking, the planned measures will lead to a considerable improvement of surface water quality in the Emscher area. In particular, their wastewater character will be eliminated, i.e. odour or optical inconveniences.

3. CREATING SPACE FOR A LIVING RIVER-SYSTEM

Each waterbody has its own special character. The Emschergenossenschaft has a great deal of experience in the ecological improvement of waterways – however, it must first be determined whether typical waterway topologies are compatible with the given constraints and potentialities. This applies all the more to a river-system like the Emscher, which now flows through the region as an alien body without any ecological function. Neither the courses of the river and its tributaries, nor their profiles, nor the design of their river beds correspond any more to the original, natural state. The basis for a nature-orientated transformation must therefore be a model that is able to define the optimal waterway design from an ecological point of view. The closer the tangible restoration of the waterbodies comes to this ideal, the greater the possibilities for new river-system to develop and self-enhance, with minimal human maintenance and maximum sustainability of its natural development. What is important in practice is to set concrete development targets for the profile, topology and vegetation of the waterbodies. These objectives must be anchored somewhere between what is theoretically desirable and what is practically feasible in such a densely-populated region.

The new waterbodies profiles should primarily enable the creation of flood meadows. These are areas along the riverbanks that are frequently flooded, allowing a highly diverse flora and fauna to settle. The flood meadows are particularly important where brooks flow into the Emscher. These form the “joints” of the interlinked system of biotopes, allowing a rapid and stable exchange of organisms.

Figure 1 – Deininghauser Bach - Regulation in the upstream area 1938 and situation after restoration 2002;

In order to assess the condition of the waterbodies an extensive monitoring programme was set up. This included the following aspects: water quantity and quality, biological indicators and morphological structures.

4. NEW LIFE AFTER REDEVELOPMENT - PLANTS AND ANIMALS REPOPULATE THEIR NATURAL HABITATS

Enough time has to be given to waterbodies after they have been restored to allow them to recuperate their typical biodiversity. During the first three years, robust pioneer species will first and foremost settle in newly created natural habitats. For instance, tall forbs grow on the river banks before the characteristic hardwood and softwood flood-plain thickets can develop. It normally takes eight to ten years for a species-rich community to develop, so that numerous specialist varieties can also grow.

Brooks which were restored long ago, today are already showing the type of biodiversity that can occur in the Emscher system. The sandy bed of the stream forms the habitat for numerous species of mollusc, insects, crustaceans and worms. In the water, a variety of different species of fish have settled. A 2004 study has identified 360 species of invertebrates and fish in the Emscher system, some of which are rare. Moreover, the rich vegetation on the river banks provides a natural habitat for birds and mammals. Thus, despite having been used for wastewater management for such a long time, the waterways of the Emscher system offer prime conditions for a broad ecosystem with major benefits for both humans and nature.

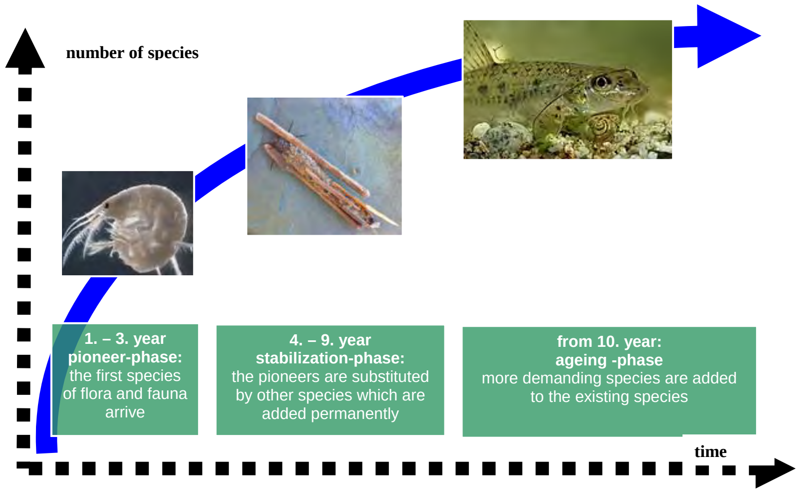

Figure 2 – Time schedule of the restoration phases

5. CONCLUSIONS

The multidisciplinary planning approach proved to be very successful. The constant sharing of work steps between the various disciplines lead to an efficient planning process.

It is important to monitor the development of an extensively restored stream; in particular, technical structures need a constant revision to check if they are fulfilling the function they were originally planned for, in order to be able to intervene in a case of malfunction.

Because the development of a stable biocoenosis that reflects the reconstructed stream morphology and external pressures needs quite some time, monitoring needs to be continued in order to show whether the restoration was a success or further complementary measures need to be taken.

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RIVER RESTORATION IN SYDNEY, AUSTRALIA

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ABSTRACT

Restoration of rivers in the Sydney (Australia) basin faces many challenges arising from both its natural environment and the impacts of urbanisation.

The city of Sydney is home to 4.1 million people living in an area of 2000 km^2. The natural environment includes eight catchments comprised of Sydney Harbour, Parramatta River, Botany Bay, Cooks River, Georges River, and the Hacking River. It also includes the northern beaches catchments for Manly, Dee Why, Curl Curl and Narrabeen Lagoons as well as the eastern beaches and catchments between Botany Bay and Sydney Harbour. This totals over 2,800 km of waterways. The geology of the catchment area is relatively simple. However, the bedrock and resultant soils have influenced the landform, hydrology, and biology of the area. The majority of the surface rock is sedimentary rock from the Triassic period. However, episodes of vulcanism resulted in the presence of a number of diatremes across the basin and a period of alluvial deposition during the Cenozoic era and Quaternary period resulted in depositional features. The interaction of bedrock type, climate and sea level rise and fall has resulted in the area exhibiting a diverse range of geomorphic forms, including; rock platforms, drowned river valleys, estuaries, elevated sandstone plateaux and low lying plains. The Sydney basin is the fifth most biodiverse region in Australia.

Alluvial streams in the Sydney basin are sensitive to natural agents of change such as periods of drought, bushfires and catastrophic floods. In addition to these natural change agents urbanisation impacts have altered hydrologic regimes, deteriorated riparian systems, changed channel morphology and reduced water quality

The Sydney Metropolitan Catchment Management Authority (SMCMA) is a regional natural resource authority responsible for managing natural resources at the catchment scale. The SMCMA has developed a Waterways Health Strategy to assess the current condition of all waterways in the Sydney basin and identify priority river reaches for restoration and/or protection. The authors and the SMCMA are identifying those priority river reaches that: 1)have high or very high recovery potential to an ancestral geomorphic type: 2)require geomorphic protection to ensure continued existence of the geomorphic type; and 3)require action *now* to stabilise a degrading geomorphic type. In addition to considerations of reach geomorphic type and fragility, the strategy also includes consideration of vegetation condition and the public access (social value) assessment for each reach.

This paper will give further details about the challenges that the range of geomorphic types, the natural change agents (drought, flood, bushfire) and the dense urbanisation presents for the selection of the highest priority river restoration project reaches in the Sydney basin.

Key words: geomorphic type, geomorphic condition, River Style, river restoration, urbanisation

1. INTRODUCTION

Restoration of rivers in the Sydney (Australia) basin faces many challenges arising from both its natural environment and the impacts of urbanisation.

The city of Sydney is home to 4.1 million people living in an area of 2000 km^2. The natural environment includes eight catchments comprised of Sydney Harbour, Parramatta River, Botany Bay, Cooks River, Georges River, and the Hacking River. It also includes the northern beaches catchments for Manly, Dee Why, Curl Curl and Narrabeen Lagoons as well as the eastern beaches and catchments between Botany Bay and Sydney Harbour – this totals over 2,800 km of waterways. The geology of the catchment area is relatively simple. However, the bedrock and resultant soils have influenced the landform, hydrology, and biology of the area. The majority of the surface rock is sedimentary rock from the Triassic period. However, episodes of vulcanism resulted in the presence of a number of diatremes across the basin and a period of alluvial deposition during the Cenozoic era and Quaternary period resulted in depositional features. The interaction of bedrock type, climate and sea level rise and fall has resulted in the area exhibiting a diverse range of geomorphic forms, including; rock platforms, drowned river valleys, estuaries, elevated sandstone plateaux and low lying plains.

The Sydney Metropolitan Catchment Management Authority (SMCMA) is a regional natural resource authority responsible for managing natural resources at the catchment scale. The SMCMA has developed a Waterways Health Strategy to assess the current condition of all waterways in the Sydney basin and identify priority river reaches for restoration and/or protection.

This paper reveals details about the challenges that the range of geomorphic types, the natural change agents (drought, flood, bushfire) and the dense urbanisation presents for the selection of the highest priority river restoration project reaches in the Sydney basin.

2. GEOMORPHIC STREAM TYPES IN THE SYDNEY METROPOLITAN AREA

Maps of the geomorphic types for 2808 km of stream have been recently produced for the Sydney metropolitan area (Earth Tech, 2007). The type labels and identification methods were adapted from those used in the River Styles® framework (Brierley and Fryirs, 2005). This framework contains a method for classifying and mapping stream reaches for their geomorphic type, condition and recovery potential. However, to date, only the reach geomorphic types have been mapped for Sydney. Field data will be collected for future production of the geomorphic condition and recovery potential maps.

The Sydney stream geomorphic type maps show a wide variety of types, totaling 17 natural ones plus 5 highly modified ones such as concrete channels. The natural stream geomorphic types range from resilient bedrock types with no floodplain such as the gorge type to those that are very fragile alluvial systems with floodplains such as the chain of ponds type (Table 1). The mapping also revealed a high variability in the proportion of natural to modified streams from one catchment to another. The average is 66% natural streams with the Cooks River catchment (all urban) having the lowest proportion of natural channels (13%) while the Hacking River catchment (mostly national park) has the highest proportion (99%).

Information on the behaviour and fragility of each natural stream geomorphic type (Style) shown in Table 1 will allow the SMCMA to assess reach geomorphic condition and recovery potential by comparing each stream reach to a good condition reference reach for its type. In addition, it allows the prediction of each type’s responses to agents of change and the selection of rehabilitation works to suit the type and target condition. For example, bank erosion control works are not needed on the confined types because the banks are bedrock. Knowledge of the behaviour of natural types is needed when restoring highly modified reaches back to the natural ancestral type that was present before development, as was done in a few places in Sydney. This tells the designer what characteristics such as shape, sinuosity, geomorphic units and vegetation need to be returned to the restored reach.

Table 1 - Description of the Good Condition State of the Natural River Styles in the Sydney Metropolitan Area (Geomorphic types mapped by Earth Tech, 2007, with type labels translated to NSW standard and Style description by authors).

River Style	Character	Behaviour	Fragility
1. Confined			
Headwater	V shape (gentle to steep) bedrock valley. No floodplain.	Laterally and vertically controlled.	Low
Occasional Floodplain Pockets	As above but with floodplain pockets at valley bulges.	Bends controlled but floodplain pockets can be reworked.	Medium
Gorge	Channel confined by cliffs. No floodplain	Laterally and vertically controlled but affected by sediment slugs.	Low
Valley Fill	Confined alluvial fan. No channel.	Slow aggradation from sediment and organic matter. Sensitive to vegetation condition.	High
Chain of Ponds	As above but with small ponds linked by a low swale.	As above. Highly sensitive to vegetation condition in swale.	High
2. Partly Confined			
Bedrock Controlled	All of each bend against the valley margin. Crescent of floodplain inside bends.	Laterally and vertically controlled but can adjust by expansion or contraction of floodplain.	Medium
Planform Controlled Meandering	10% to 50% of channel against the valley margin. Discontinuous floodplains. Meandering.	Bends migrate down-valley but not laterally.	Medium
Planform Controlled Low Sinuosity	As above. Straight.	Avulsive. Sensitive to channel obstruction.	High
3. Unconfined			
Channelised Fill	Shallow channel. Flat featureless floodplain.	Formerly Valley Fill or Chain of Ponds that has been incised. Slowly filling with sediment and organic matter.	Medium
Floodout	Alluvial fan. Swamps.	Slow aggradation from sediment and organic matter. Sensitive to vegetation condition.	High
Low Sinuosity Fine Grained	Deep narrow straight channel. Muddy bed.	Low lateral migration rate. Reworking of benches.	Medium
Low Sinuosity Gravel	As above. Gravel bed.	Low lateral migration rate, high if vegetation lacking. Avulsive.	High
Low Sinuosity Boulder	Wide straight channel. Cobble and boulder bed.	High energy. Low lateral migration but has avulsions and floodplain stripping.	Low

Meandering Fine Grained	Variable sinuosity channel. Muddy bed. Floodplain has extensive channel migration features.	Low rates of meander migration. Channel capacity decreases downstream.	High
Meandering Sand	As above. Sand bed.	Laterally active and avulsive.	High
Meandering Gravel	As above. Gravel bed.	As above plus frequent bend cutoffs.	High

3. AGENTS OF CHANGE

3.1 Natural

The major natural agents that can affect the geomorphic condition and recovery potential of stream reaches in the Sydney area are:

- Flooding – that can cause channel expansion, bed erosion, bank erosion, avulsions, floodplain stripping and floodplain deposition.
- Drought – that allows streams to recover from flooding by giving enough time for bed, bank and floodplain vegetation to re-grow. (Native riparian vegetation is drought tolerant). In addition, the vegetation re-growth can trap the sediment carried by low flows and thereby rebuild in-channel sedimentary units.
- Bushfire – that destroys riparian vegetation and produces slugs of sediment and ash.

Other natural agents of change can have minor local effects such as wind storms causing wave erosion along reaches with a long fetch.

3.2 Artificial

Riparian vegetation removal for development is a major cause of poor stream geomorphic condition in Sydney. Many of Sydney's stream types would have had extensive vegetation on the bed, banks and floodplain before development. Vegetation in the bed is important for channel roughness which reduces shear stress and thereby controls bed erosion. Vegetation on the banks also reduces channel roughness but is most important for controlling bank erosion and stability. Vegetation on the floodplains controls avulsions and floodplain stripping. In addition, all vegetation provides habitat, shade, windbreak, visual amenity and major effects on water quality. Accordingly, vegetation condition maps were produced for the Sydney metropolitan area (Earth Tech, 2007) to help prioritise conservation/protection, regeneration and revegetation projects by the CMA. The categories on the maps are: near intact – inside reserve; near intact – outside reserve; good – high recovery; good – moderate recovery; moderate – good/moderate vegetation; moderate – little/no vegetation; degraded – good/moderate vegetation; degraded – little/no vegetation; no vegetation/flood control. As expected, the catchments with the most park area have the best vegetation condition (93% in near intact or good condition for the Hacking River) and the catchments with the densest Urbanization have the worst vegetation condition (0% in near intact or good condition for the Cooks River).

Other major artificial agents that can affect the geomorphic condition and recovery potential of stream reaches in the Sydney area are numerous and include:

- Stream lining (with concrete etc) – that stops erosion but destroys the natural functions of streams
- Diversion – that changes the natural path of the stream into an artificial channel that may have higher velocities and minimal natural function
- Flood mitigation (levees) – that concentrates flood flow in channels which increases shear stress and subsequent major channel erosion
- Straightening – that increases stream slope and can initiate bed incision
- Piping – that destroys natural functions
- Weirs – that obstruct fish passage
- Inter-basin transfer (via stormwater piping) – that increases flow in some streams while decreasing flow in others
- Hard surface runoff increase – that increases flood peaks and can cause channel expansion
- Deepening and widening (for flood mitigation) – that destroys flora and fauna habitat
- Filling (reclamation) of channels and floodplains – that destroys natural stream and floodplain functions
- Sediment extraction – that can cause sediment starvation downstream and headcutting upstream
- Water extraction – that reduces or eliminates flow for the environment
- Sediment excess – that smothers habitat and blocks channels
- Weed invasion – that reduces habitat and the natural functions of native vegetation communities

It is essential that the river restoration strategy for Sydney deals with all of the natural and artificial agents of change described above.

4. FORMULATING THE WATERWAYS HEALTH STRATEGY

In order for both the natural and artificial change agents to be considered, the SMCMA commissioned Earth Tech (2007) to use a GIS for prioritising each 10 m reach of the catchment for river conservation/restoration. The GIS assigns a priority rehabilitation/conservation action based on the concept that preserving the best or most fragile has highest priority, as illustrated in Table 2. Where the geomorphic type is very fragile (*High*) and the vegetation condition is *Good*, the geodatabase assigns the "highest" value which is "conservation". Conversely, where the geomorphic type fragility is low and the vegetation condition is *Poor*, the resultant rehabilitation priority value assigned is "lowest". These are reaches that are stable without vegetation (eg due to bedrock bed and banks) so they can be left alone and will not get any worse. The methods and criteria used for categorization are described in detail in Earthtech (2007).

Table 2 - Rehabilitation priority based **only** on geomorphic fragility and vegetation condition (as a surrogate for geomorphic condition) using the concept that preserving the best or most fragile has highest priority.

Vegetation Condition (grouped) →	**Good**	**Moderate**	**Poor**
Geomorphic Fragility ↓			
High	Highest (Conservation)	High	Medium
Medium	High	Medium	Low
Low	Medium	Low	Lowest (will not get worse if left alone)

Finally, the GIS was used to aggregate the public access (social value) assessment (described in detail in Earthtech, 2007) to each reach to assign the overall priority management action category. These are summarised in Table 3 (below). With these categories, the framework for management of the waterways can be established at the regional scale.

Table 3 - Rehabilitation management action categories aggregating the physical assessment (Table 2) and the public access (social value) assessment for each reach.

	Management category	**Actions**
1	Focus on conservation/protection	• Maintain natural or environmental flow regime • Limit riparian corridor crossing to maintain connectivity • Incorporate into local reserve system • Community access should not negate ecological values
2	Focus on assisted regeneration	• Maintain natural or environmental flow regime • Limit riparian corridor crossing to maintain connectivity • Remove exotic vegetation to promote native vegetation regeneration
3	Focus on revegetation	• Revegetation with local indigenous vegetation to control erosion and bank stability • Plant at appropriate numbers of species to ensure

		diversity while maintaining assisted succession
4	Focus on geomorphic stability	• Formalise bank and bed tabilize ion appropriate to geomorphic type • Flow energy managed to achieve pre-development levels • 'soft' engineering designs or revegetation employed to recreate or maintain a natural system • Locate new stormwater structures outside riparian zone
5	Focus on geomorphic protection	• Maintain natural or environmental flow regime to stabilise erosion • Identify key agents of change and address with most appropriate action (e.g. bed control or flow control)
6	Focus on recreation	• Provide managed public access • Improve water quality for recreational activities
7	Focus on flood control	• Create off-line tabil • Implement water sensitive urban design (WSUD) in the catchment

The resultant GIS data layer or thematic map of the 7 categories in Table 3 identifies the management categories and strategies for all stream reaches within each subcatchment of the SMCMA area. This work forms the Sydney Metropolitan Catchment Management Authority Waterways Health Strategy (WHS). As additional data are obtained, these can be incorporated into the WHS GIS. It is intended that information be collected on the trajectory of change (positive or negative) for each reach. This can assist the SMCMA in identifying those priority reaches that: 1) have high or very high recovery potential to an ancestral geomorphic type; 2) require physical protection to ensure maintenance of the existing type in good geomorphic condition; and 3) require physical action *now* to stabilise or reverse a degrading trajectory.

Figure 1 – GIS map of Middle Harbour subcatchment showing management categories. Scotts Creek, the site of one of the projects, is in the middle of the map.

5. EXAMPLES OF REHABILITATION PROJECTS

5.1 Henty Creek – channelised fill – moderate condition vegetation

A reach of Henty Creek is the channelised fill geomorphic type. Historical aerial photography indicates that the ancestral geomorphic type was chain of ponds. Subsequently, channel incision occurred and fill was placed to create playing fields. This type is geomorphically fragile and the vegetation condition is poor. This places the reach in the high priority category (see Tab. 2). The CMA is working with local council in a project to return permanent ponds without significantly increasing flood levels for adjacent housing. Works include rock bed controls to create permanent ponds with extensive replanting of the natural native vegetation community.

Figure 2 - Before: Looking upstream showing a temporary high flow pond in the channelised reach and remnant native riparian vegetation. Note the proximity of dwellings to the top of the bank.

Figure 3 - During works: Looking upstream along the same reach at the completed rock ramp bed controls. The permanent ponds are starting to fill. Riparian zone replantings are yet to commence.

5.2 Scotts Creek – bedrock controlled, partly concrete-lined – good condition vegetation

A reach of Scotts Creek is the bedrock controlled geomorphic type. The type is naturally geomorphically stable. However, due to artificial straightening, filling and incomplete concrete lining, some of the filled banks are eroding and endangering buildings. This project involves stabilisation of the filled banks, in-stream planting and extensive bush regeneration to connect good condition riparian vegetation patches.

Figure 4 - Before: Looking upstream showing the left hand filled bank eroding and collapsing. Note the close proximity of the buildings to the bank.

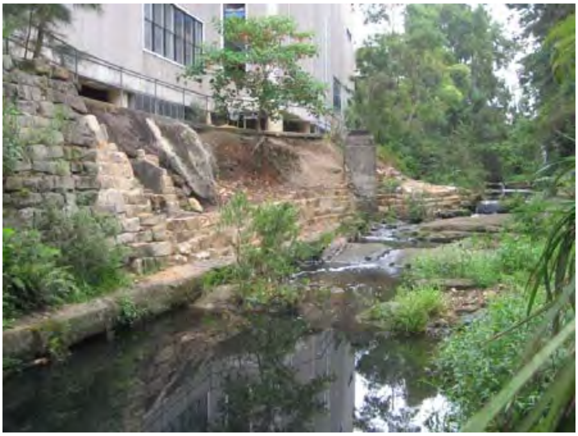

Figure 5 - During works: Looking upstream along the same reach showing the completed left bank stabilisation works.

6. CONCLUSION

Restoration of rivers in the Sydney (Australia) basin faces many challenges arising from both its natural environment and the impacts of urbanisation.

The Sydney Metropolitan Catchment Management Authority Waterways Health Strategy uses a GIS to categorise each reach for priority management actions. There are seven management action categories based on analysis of reach geomorphic type/fragility, riparian vegetation condition and public access (social value). This provides the SMCMA with an easy to use methodology to prioritise and monitor progress on activities and projects to conserve and/or rehabilitate the waterways of Sydney.

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RESTORATION OF SMALL URBAN STREAMS IN FINLAND

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ABSTRACT

In Finland almost every ditch and stream has been modified. Because of drainage needs many natural streams in Finland have been widened, deepened and straightened mostly for agricultural reasons but the situation in urban streams is not any better.

Urban streams have become increasingly important in the planning of urban ecology and green areas in Finnish towns and cities in recent years. Where urban streams have been modified as a part of urban planning, attempts have been made to create suitable conditions for fish and to make watercourses to be attractive features in residential areas.

Helsinki City program on small water bodies, including all small urban streams and the most valuable swamps, springs and ponds in Helsinki City area, was published in 2007. Restoration goals for urban streams are recommended. The program has been a good example for other cities in Finland to follow.

New planning methods for river restoration have been implemented in the past few years. One of the easiest methods, and the most cost-effective for small streams is to take landscape pictures and draw the plans on the pictures. This reduces the required measurements to minimum, which are one of the largest costs compared to the whole planning cost.

This method was used in restorations of the Longinoja stream and the Matapuro stream in Helsinki. Planning aimed to restore natural conditions and at the same time maintain good drainage level. The results are encouraging. Before the restoration, the abundance of brown trout (*Salmo trutta*) populations in the restored area of the Longinoja stream varied between 4─7 trouts per 100 m^2. Habitat survey in 2007 revealed increases in trout population to 128─155 trouts per 100 m^2. This shows the importance and potential of a small urban streams for salmonid fish and the environment.

Key words: restoration, urban streams, trout, fish

1. INTRODUCTION

Almost every ditch and stream in Finland has been altered: Many natural streams have been widened to increase drainage, deepened and straightened for agriculture. However, the situation of urban streams is not any better.

Many ecological problems are related to physical degradation. Increased difference between high and low flows leads to stronger erosion and siltation which causes loss of habitats**.**

Urban streams have become increasingly important in the planning of urban ecology and green areas in Finnish towns and cities in recent years (Niemelä et al., 2004). Goals for restoration of rivers, which took into account also small urban streams and stormwater management, have been developed (Jormola et al., 2003; Järvenpää, 2004). Attempts have been made to create suitable conditions for fish and to make watercourses attractive features in residential areas.

2. HELSINKI CITY PROGRAMME ON SMALL WATERS

Helsinki City programme on small waters (2007) includes guidelines and recommendations for restoration and management of all streams and the most valuable swamps, springs and ponds in Helsinki City area.

The program is targeted to meet the expectations of the EU Water Framework Directive in the Helsinki City area by 2015. The vision of the program is ambitious and challenging, and authorities already started the implementation process. The first results are encouraging.

3. PLANNING METHODS

New planning methods for river restoration have been implemented in the past few years. Especially for the smaller streams in Finland, planning costs can easily rise up to 30─35 % of the project funding when using traditional methods.

One of the easiest, and the most cost-effective method for small streams is to take normal or landscape pictures and draw the plans on the pictures. This reduces the need to take measurements to the minimum which represents one of the largest costs compared to the whole planning costs.

With this method, planning costs are reduced by 15─25 % of the project funding, thus allowing more concrete restoration work with the same amount of resources. Another benefit is also that pictures are more illustrative when introducing a plan to the authorities and landowners.

Figure 1 –Picture from the restoration plan for the Longinoja stream.

3.1 CASE LONGINOJA STREAM

The picture method was used in planning the restoration of the Longinoja stream in Helsinki. Restoration was part of the project where modern environmental hydraulic engineering methods were studied in an areas with fine-grained soils. The planning aimed to enhance natural conditions and at the same time maintain sufficient drainage level (Näreaho et al., 2006).

The restoration section was 150 m long and the work was implemented in snowy conditions in March 2006. More than 100 m^3 stones and 50 m^3 gravel were added and restoration was completed in five days. Total costs were 11500 € including planning, with a costs per meter of 77 €. The planning costs were 13 % of the total project cost.

Voluntary organizations havw introduced brown trout (*Salmo trutta*) into Longinoja stream since 2000 and restored some sections of the stream co-operating with the authorities. A new trout population, which migrates to the Baltic Sea through the Vantaanjoki River and returns again to Longinoja stream has developed.

Figure 2 – The Longinoja stream during the restoration.

Figure 3 – The Longinoja stream before and after the restoration.

3.2 CASE MATAPURO STREAM

The picture method was also used in restoration of the Matapuro stream in Helsinki. The planning aimed to remove a small dam which caused an obstacle for fish migration and at the same time to keep upstream water levels and flow rates at the original levels. A sedimentation pond was also created in the upper part of the restoration area. Restoration was recommended in the Helsinki City program on small waters.

The restoration area was 130 m long and it was implemented in December 2007. Nearly 70 m^3 stones and 40 m^3 gravel were added and the restoration was completed in five days. Total costs were 12200 € including planning. The cost was 94 € per meter and planning costs represented 27 % of the total project cost.

As in Longinoja, volunteers have restored some sections of Matapuro stream and introduced trout. A population migrating to the sea has developed.

Figure 4 – The Matapuro dam and the stream before the restoration.

Figure 5 – The Matapuro stream after the restoration, low flow condition.

4. RESULTS

The results for the trout population are encouraging. Before the restoration, brown trout population varied between 4 and 7 trouts per 100 m^2 in the Longinoja stream. Habitat survey in 2007 revealed increase in trout population which varied between 128 and 155 trouts per 100 m^2. Urban streams seem to provide good spawning habitats and living environments for trout after restoration.

Because the restoration in the Matapuro stream was implemented in December 2007 results for the trout population are yet to occur.

Voluntary organizations have been actively involved in the restoration and they are committed to maintain and to further restore the area. As more people have become aware of the value of such streams for fish, the local authorities have also become more interested in applying watercourse restoration methods in the management of urban streams.

The results show clearly that remarkable ecological enhancement can be achieved with small and cost-effective methods. At the same time landscape improvements as well as the feedback from the local people have been purely positive. New planning methods for river restoration open up more possibilities for small stream restoration planning and allow more restoration work with the same amount of resources.

5. CONCLUSIONS

Urban streams can provide living environments for diversified flora and fauna. Municipal programs on small waters, like in Helsinki City, are important in considering the value of urban streams. Such program is a useful tool for urban planning and should be introduced in other cities. The results of the restoration cases clearly demonstrated that even small-scale restoration measures can substantially increase the reproduction of salmonid fish in urban streams. Small urban streams can be important breeding areas for adult fish and living environments for juveniles, having also value for larger watercourses.

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NATURALIZING STRAIGHT URBAN STREAMS USING GEOMORPHOLOGICAL PRINCIPLES

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ABSTRACT

Many urban streams around the world have been transformed into straight, trapezoidal channels to promote maximum flow conveyance. Changes in attitudes toward the value of urban streams have led to efforts to "naturalize" these straight channels to enhance geomorphological and ecological diversity and to improve water quality. This study describes an approach to implementing pools and riffles in straight urban streams to achieve these goals in cases where realignment of the channel planform is impractical because of the close encroachment of urban infrastructure upon the stream. The approach draws upon geomorphological understanding of the form and function of pools and riffles in natural channels to promote self-maintenance of the implemented structures. It also modifies the form and function of natural pools and riffles to ensure that channel banks remain stable, an important consideration where infrastructure is in close proximity to the channel. The design was thoroughly tested using physical and numerical models and was implemented in a low-gradient stream with a relatively limited sediment load in Northbrook, IL, a suburb of Chicago. Five years of post implementation monitoring reveal that flows through the system have sustained the pools and riffles and that channel banks remain stable. Further testing is being conducted to modify the design for adequate performance in a stream near Champaign, IL, USA, which has a higher sediment load than the stream near Chicago.

Key Words: fluvial geomorphology, stream restoration, channel design

1. INTRODUCTION

The dominance of drainage considerations in urban stream management is evidenced by the prevalence of straight trapezoidal or rectangular channels in cities and towns around the world. Historically, the primary concern has been to ensure that urban streams have adequate conveyance to accommodate the abundant runoff produced by widespread impervious surfaces. The exacerbation of flooding in urban environments is well-documents (Rhoads, 1995), leading to a heavy emphasis on flood control in channel management. Thus, many pre-existing streams in urban environments have been transformed into straight channels with flat bottoms and uniform cross sections to maximize flow conveyance.

Recently, concern has arisen about the environmental consequences of approaches to urban stream management that focus mainly on flow conveyance. Numerous studies have documented the deleterious effects of stream channelization on ecological, geomorphological and water-quality conditions in urban streams (Brookes, 1988). In response to concern about these effects, community-based environmental groups are advocating for multi-objective approaches to management that include consideration of environmental aspects of stream systems. In many cases, these approaches are seeking to at least partially undo the channelization schemes of the past to produce more "naturalized" fluvial environments. Such efforts still involve the need for the design of stream channels; however, environmental-friendly designs are not based solely on hydraulic considerations, but also draw upon ecological and geomorphological principles.

The purpose of this paper is to show how geomorphological principles can contribute to the naturalization of straight urban streams. In particular, it focuses on situations where cost constraints or extant infrastructure surrounding the stream precludes reconfiguring the channel alignment through practices like remeandering. The particular design presented here is aimed at the establishment of sustainable pool-riffle sequences within straight, flat-bottomed urban channels.

2. WHAT IS STREAM NATURALIZATION?

Before probing the geomorphological aspects of pool-riffle design for straight urban channels, it is relevant to examine what is meant by the concept of stream naturalization. This concept, which has been developed as a specific perspective on stream management that traditionally has been subsumed under the amorphous, wide-ranging umbrella of the term stream restoration, refers to attempts to enhance the environmental quality of highly modified fluvial systems in human-dominated environments (Rhoads and Herricks, 1996; Rhoads et al., 1999). An important component of the stream-naturalization perspective is that all stream-management efforts, but particularly those that are community based, are fundamentally social in nature. Under the best of circumstances, environmental management of streams is merely guided by scientific input, not determined by this input – a detail scientists and technical experts often fail to recognize. Attempts to "naturalize" streams in urban settings typically are driven by an environmental vision that has more to do with aesthetics and the perceived benefits that an attractive stream environment has for economic growth and community pride than it does with ensuring that geomorphologists and ecologists are satisfied with the design. In other words, the very notion of “natural” in an urban context is socially determined, rather than it consisting of some objective standard defined by technical experts. Naturalization in this sense is very place-based – what one community views as natural another may see as unnatural, or artificial.

Under such a viewpoint, desired target states for naturalization are highly variable. In particular, the classic notion of restoration – or the return of a system to its undisturbed state (i.e. its pristine condition) often becomes meaningless in urban contexts given the extensiveness of human modification of the landscape. Because the goal commonly is to undo deleterious environmental effects of past human modification, the reference state, if one can be defined at all, becomes the extant, channelized condition of the stream, which has been homogenized in form and function. The goal is not to move toward the reference state, as it is in classic restoration, but to move the system away from this state towards alternative conditions that establish sustainable, morphologically and hydraulically varied, yet dynamically stable fluvial systems that are capable of supporting healthy, biologically diverse aquatic ecosystems (Rhoads et al., 1999; Wade et al., 2002). Alternatives are defined on the basis of social negotiations within the community of relevant stakeholders. It is important that scientists and technical experts be involved in these negotiations to help define how objectives derived from an environmental vision can be met, while still operating within the realm of technical feasibility and cost constraints.

3. POOL-RIFFLE DESIGN IN STRAIGHT URBAN DRAINAGE CHANNELS

The development of a pool-riffle design for straight urban channels was motivated by a stream-naturalization project along the West Fork of the North Branch of the Chicago River (WFNBCR) in downtown Northbrook, Illinois – a suburb of Chicago. Details on this project and the integration of geomorphological, ecological and engineering expertise that provided the rationale supporting it can be found in Wade et al. (2002) and Rhoads et al. (2008). The overall effort involved a considerable amount of reshaping of the channel banks and protection of the bank toes along the project reach, which consisted of two segments of straight channel connected by a gradual bend. The total length of the project reach was about 900 meters.

As part of the project, environmental groups and municipal officials decided - through consultation with the author and other technical experts - that the establishment of pool-riffle sequences in the reach would help achieve an environmental vision of enhanced aesthetics, water quality, and habitat for fish. The key was to develop a design for the sequences that would promote self-maintenance of these structures, yet not produce hydraulic conditions that would lead to erosion of channel banks within the reach, which was flanked closely on each side by parking lots and roadways (Fig. 1).

Figure 1 - West Branch of the North Fork of the Chicago River in downtown Northbrook showing conditions before (left) and after (right) naturalization.

Pools and riffles occur both in straight and in meandering streams (Knighton, 1998). These structures, along with alternate bars (straight channels) and point bars (meandering channels), have been identified as components of a coherent morphological feature of the channel bed known as the bar unit (Dietrich, 1987). The development of bar units in straight channels has been linked to the initiation of river meandering (Rhoads and Welford, 1991). Bar units deflect flow laterally, leading to the establishment of a meandering thalweg and the potential for systematic erosion of the channel banks. Thus, implementation of bar unit structures in a straight urban channel could promote bank erosion. In braided channels, double-row bar units develop, which deflect flow into the center of the channel to promote scouring of pools and allow the flow to widen and shallow over riffles (Dietrich, 1987). Although the WFNBCR does not lie within the stream-power domain of a braided river (Leopold and Wolman, 1957) and was meandering prior to channelization (Rhoads et al., 2008), an adaptation of the double-row bar unit concept provided the basis for a sustainable pool-riffle design within the straight channel that would not induce thalweg meandering. The goal was to have flow converge in the center of the pools to promote scouring at high flows and to diverge over riffles. Convergence within pools was achieved by narrowing the channel cross-section within the pools and directing the flow into the center by placing arcuate rock ribs across the channel halfway between the riffle crest and bottom of the pool (Figs. 2 and 3).

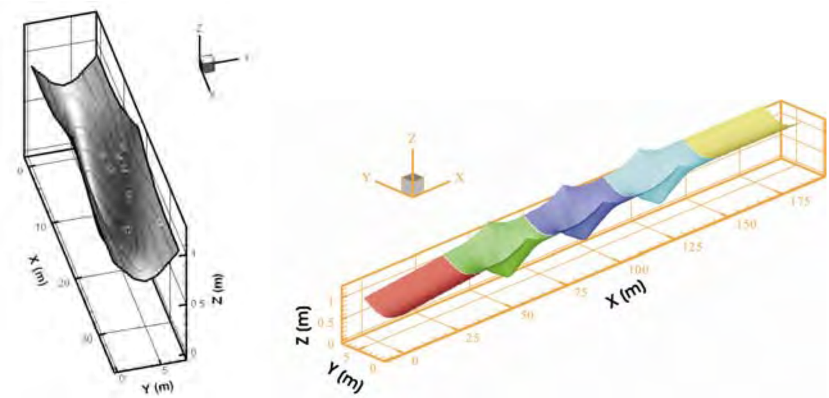

Figure 2 - Three dimensional view of a single pool-riffle unit (left) and a series of three pool-riffle units (right).

Figure 3 - Arcuate rock ribs across the channel (left) and digging of pools within the project reach (right).

Testing of the geomorphic-based design involved: 1) numerical modeling of flow through the structures at different stages using a three-dimensional computational fluid dynamics model, 2) numerical modeling of the influence of the structures on flood stages in the project reach using a 1-D step-backwater model, and 3) measurements of 3-D flow structure within a 1:7 Froude-scale physical model of the pool-riffle structures (Rhoads et al., 2008). Overall, these evaluations confirmed that the structures should produce the desired hydraulic conditions for pool-riffle maintenance. In particular, the numerical and physical modeling indicated there is a reversal of bed shear stress between riffles and pools as discharge increases. At low discharges, bed shear stress is highest at the riffles and lowest at the pools, but at moderate to high discharges the shear stress is greatest in the pools. This condition, which has been documented in natural pool-riffle sequences, should flush any accumulated sediment out of the pools during moderate to high-discharge events. Moreover, the numerical simulations indicated that dual helical cells within the pools should also promote maintenance by sweeping sediment laterally away from the center of the pool (Rhoads et al., 2008).

Construction of the pool-riffles structures took place between November 2001 and May 2002. Eleven structures were built within the project reach. Maximum relief between riffle crests and pool bottoms was about 0.75 m. A monitoring program consisting of annual surveys of the longitudinal profile along the reach was initiated in the spring 2002. Results of the repeat surveys show that the pools have maintained their form over a period of five years, indicating that the self-scouring design has been successful (Fig. 4). The implementation of the pool-riffle structures has also increased fish abundance, biomass and diversity within the reach (Schwartz and Herricks, 2007). However, fish metrics are still in the low range compared to rural streams in the area, indicating that local habitat enhancement has only a limited capacity for improving fish-community composition given the influence of intense urbanization on watershed-scale conditions, such as water quality, hydraulic stresses and barriers to fish movement.

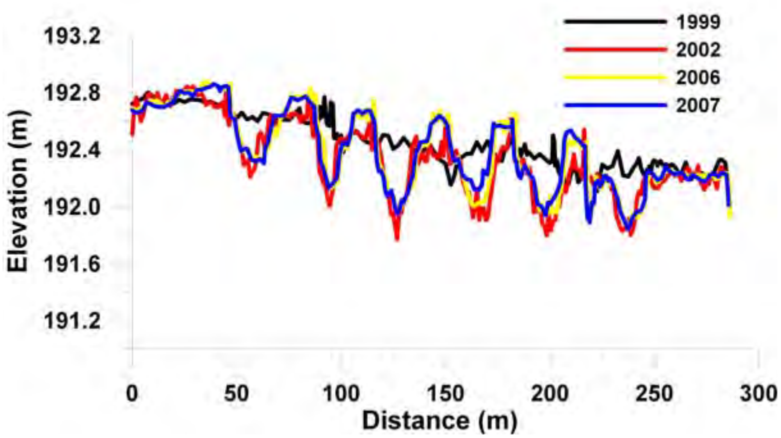

Figure 4 - Longitudinal profile through part of the project reach along the WFNBCR before (1999) stream naturalization, immediately after naturalization (2002) and several years after naturalization (2006, 2007).

Another application of the pool-riffle design is being considered for the Copper Slough – a drainage channel on the urban-rural fringe of Champaign-Urbana, Illinois. Implementation of the structures in this setting is being considered to mitigate the loss of fish associated with a chemical spill. The current channel consists of a trapezoidal drainage channel with a flat bottom, much like the situation along the WFNBCR. The Copper Slough transports abundant sand and fine gravel, whereas the amount of sand and gravel in the WFNBCR is rather limited. To ensure adequate performance of the design in a fluvial system that transports abundant sediment, it is important to generate adequate acceleration of flow within the pools as discharge increases so that the increase in bed shear stress relative to the riffles is sufficient to produce flushing of the pools over a broad range of flows. Currently, numerical experiments using a 1-D step backwater model are being conducted to evaluate various modifications of the basic design. Another variant of the basic design involves modification of the upper banks adjacent to riffles to create habitat “shelves” that could provide slackwater areas for fish refuge during high discharges.

4. CONCLUSION

Geomorphological principles related to the form and function of pools and riffles in natural streams have been used as the foundation for development of a design for implementation of pools and riffles in straight urban channels. The purpose of the design is to enhance stream aesthetics, fish habitat and water quality. The hydraulic performance of the design was tested extensively using numerical and physical models. The design was then implemented in an urban channel in a suburb of Chicago, Illinois, USA. Repeat surveys of the channel longitudinal profile over a period of five years following implementation indicate that the pool-riffle sequences have been stable and that, as designed, the pools are self-scouring. The pools and riffles have enhanced local habitat for fish, but it is valid to question the ecological value of local, isolated naturalization projects situated within stream systems that have been impaired by watershed-scale urbanization. Increased attention must be given to watershed-scale stream naturalization efforts in urban settings.

ACKNOWLEDGMENTS

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ENVIRONMENTAL RESTORATION OF FLOOD CONTROL CONCRETE CHANNELS IN URBANIZED CITIES

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ABSTRACT

Many rivers and streams throughout the world were severely affected in the past century by human activities including water abstraction, watershed land use changes, power generation, dam and levee construction, etc. In highly urbanized cities, engineering practices advocate straightening, enlarging, and converting the natural rivers and streams into concrete channels to minimize flooding and erosion problems. These engineering design approaches destroy the natural equilibrium of the fluvial systems and eliminate aquatic and riparian species in the watercourse. The objective of this research is to develop a general stream restoration approach for flood control concrete channels in highly urbanized areas, e.g. Hong Kong. The restoration goals are: 1) to create a natural and self-sustainable river system in order to re-establish the aquatic species on the flood control channel; 2) to provide appropriate in-stream covers, pools and riffles features for fish spawning and rearing; and 3) to maintain the flood control function after stream restoration. In order to achieve the first two restoration goals, the low-flow channel will be modified using a stream tube model to include meanders and deflectors. The Generalized Stream Tube model for Alluvial River Simulation program (GSTARS) will be used to investigate the hydraulic and sediment transport relationships of the modified low-flow channel. GSTARS has the capabilities to simulate flow conditions in semi-2D and sediment transport in semi-3D using stream tubes within a 1D backwater model. The rate of sediment transport will be estimated based on the information of the incoming sediment properties from the upstream. Physical model experiments will be conducted to validate the numerical model results. The restoration approach will be applied to a concrete flood channel in Hong Kong that drains into a nature reserve, namely the Mai Po Nature Reserve, in Deep Bay.

Key words: Stream restoration, flood channel, sediment transport, deflectors, meanders, Deep Bay, Hong Kong.

1. INTRODUCTION

Many natural rivers and streams in highly urbanized cities were converted into concrete channels to maximize the efficiency of conveying the floodwaters away from populated areas. Figure 1 shows a section of a concrete channel in Yuen Long, Hong Kong. The channel drains into a semi-enclosed bay called Deep Bay. This engineering design approach disrupts the natural equilibrium of the fluvial systems and eliminates the macroinvertebrates, aquatic and native vegetation habitats in the natural streams. With a growing awareness of the value of natural ecosystems, a global awareness has started in the past decade to change from manipulation and control of rivers to restoration and conservation (Bockelmann, 2003; Ness and Joy, 2002). The purpose of this practice is to achieve a self-regulating stability of form that characterizes natural rivers and streams which would reduce the surrounding temperature, improve the air quality and the aesthetic value, and the ecosystem function of the watercourse (Rosgen, 1994; Doll et al., 2003). The objective of this research is to develop a general stream restoration approach for flood control concrete channels in highly urbanized areas, e.g. Hong Kong. The restoration goals are: 1) to create a natural and self-sustainable river system in order to re-establish the aquatic species on the flood control channel; 2) to provide appropriate in-stream covers, pools and riffles features for fish spawning and rearing; and 3) to maintain the flood control function after stream restoration. In order to achieve the first two restoration goals, meanders and deflectors will be applied to the low-flow channel (Fig. 2). The Generalized Stream Tube model for Alluvial River Simulation program (GSTARS) will be used to investigate the hydraulic and sediment transport relationships of the modified low-flow channel, and to verify whether the modified channel design can provide a suitable environment for the targeted fish habitats.

Figure 1 – A typical flood control concrete channel in Yuen Long, Hong Kong.

Figure 2 – Modified low-flow channel.

2. STREAM TUBE MODEL

The GSTARS program was originally developed by Molinas and Yang for the U.S. Bureau of Reclamation in 1986. It has the capabilities to simulate flow conditions in semi-2D and sediment transport in semi-3D. By using stream tubes within a 1D backwater model, GSTARS can be applied to solve complex river engineering problems and predicts the changes of river morphology caused by man-made and natural events with limited data and resources (Molinas and Yang, 1986).

GSTARS consists of four major parts. The first part is the use of both the energy and the momentum equations for the backwater computations. This feature allows the program to compute the water surface profiles through combinations of subcritical and supercritical flows and handles irregular cross-sections regardless of single or multiple channels separated by small islands or sand bars (Yang et al., 1998).

The second part is the stream tube concept used in water and sediment routing computations. Hydraulic parameters and sediment routing are computed for each stream tube in order to provide a transversal variation of the cross-section in a semi-two-dimensional manner. Although no sediment or flow can be transported across the boundary of a stream tube, the position and width of a stream tube can change after each time step of computation. The scour or deposition computed in each stream tube gives the variation of the channel geometry in either vertical or lateral direction. GSTARS applies Bennett and Nordin method (1977) for bed sorting and armouring. Estimation of the sediment transport rate will be based on the properties of the incoming sediments and the fluvial morphology at the upstream of the natural river in the case studies (Fig. 1).

The third part is the use of the theory of the minimum energy dissipation rate in its simplified version of minimum total stream power to compute channel width and channel depth adjustments. The fourth part is the inclusion of channel bank side stability criteria based on the angle of repose of bank material and sediment continuity (Yang et al., 1998).

2.1 Limitations of GSTARS (Yang et al., 1998)

Although GSTARS is intended to be used as a general engineering tool for solving fluvial hydraulic problems, its limitations from a theoretical point of view are listed below:

1. GSTARS is a quasi-steady flow model. Water discharge hydrographs are approximated by bursts of constant discharges. Consequently, it should not be applied to rapid, varied, unsteady flow conditions.
2. GSTARS is a semi-2D model for flow simulation and semi-3D model for simulation of channel geometry. It should not be applied to situations where a truly 1D or truly 3D model is needed for detailed simulation of local conditions. However, it should be adequate for solving most river engineering problems.
3. GSTARS is based on the stream tube concept. The phenomena of secondary current, diffusion and superelevation are ignored.

3. METHODOLOGY

A river restoration approach for flood control concrete channels is proposed and the flow chart illustrating different phases of the approach is shown in Fig. 4. In the first phase, stream assessment will be conducted along the study area to collect information such as flow rate under dry weather condition, channel geometry, sediment size distribution, water quality, existing aquatic and riparian habitats, etc. For testing purposes, it is proposed to modify a small section (about 20 m in length) of the existing low-flow channel by manipulating the existing meander patterns nearby the study area. The cross-section area of the low-flow channel will be adjusted in order to hold the proposed bed material and decrease the existing velocity until the design velocity is within the range of the swimming velocity of the targeted fish. The information collected in the stream assessment phase and the morphological patterns observed in the modified low-flow channel will be used to calibrate and verify the GSTARS program. Once the program is proven accurate, GSTARS will be used to investigate the hydraulic and sediment transport relationships for different design scenarios. It is planned to apply the river restoration approach by the end of 2009.

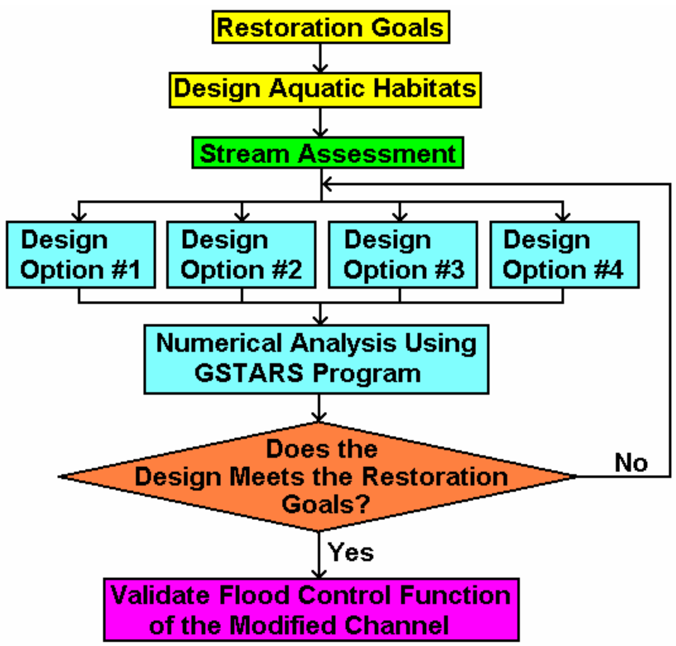

Figure 4 – Flow chart of environmental restoration approach for flood control concrete channel.

There are four design scenarios developed for the restoration approach of the flood control concrete channel: 1) modified low-flow channel with bed material; 2) modified low-flow channel with deflectors and bed material; 3) modified low-flow channel without bed material; and 4) modified low-flow channel with deflectors and without bed material. For the first two scenarios, twenty centimetres of bed material will be inserted into the modified low-flow channel at the initial condition to speed up the restoration process. The last two scenarios simulate the situation after a huge thunderstorm which all the bed material has been flushed out by the large runoff. The GSTARS program will be used to determine the recovery rate for the incoming sediment to re-establish the bed form again. Deflectors are applied in scenarios 2 and 4 to investigate its effects on maximizing the pools creation and provide some shading areas for the aquatic habitats. Different flow rates will be also tested in each scenario to cover the dry weather and various storm events conditions.

4. CONCLUDING REMARKS

By using the GSTARS program to conduct a series of numerical analysis, hydraulic and sediment relationships will be developed including: 1) distance between meanders; 2) sizing and locating of deflector; and 3) sizing of the low-flow channel with respect to the targeted aquatic habitats.

Additionally, physical model experiments will be conducted to validate the numerical model results. Strategies and measures of the flood control concrete channel restoration will be also identified and implemented to the concrete channel in Yuen Long, Hong Kong.

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TOWARDS SUSTAINABILITY IN REHABILITATING URBAN RIVER LANDSCAPES. CROSSING ECOLOGY WITH SOCIAL CONCERNS

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ABSTRACT

Urban rivers are complex systems to manage in the current context of the search for sustainability. The rehabilitation and restoration of urban watercourses is a demanding challenge for planners, scientists, experts, decision makers and urban citizens. The methods, lessons learned and outcomes of river restoration processes in less disturbed areas, such as rural or natural landscapes, are not transferable to highly urbanized landscapes, where impervious surfaces and disturbance cause major changes in the geomorphologic, hydrological and ecological characteristics of the catchment. The EU WFD requirements are more difficult to achieve, due to strong human pressures, requiring the application of "highly modified water bodies" status.Rivers bring added values to urban areas, such as amenity, aesthetics, recreation, heritage, spatiality, identity, restorative capacity and influence urban pattern and uses. Recent interest for urban riverfronts calls for new approaches for urban river management, which take into account ecological, spatial, social, economic, aesthetic and institutional issues, and use multidisciplinary approaches which require public participation.

Building on a previous research developed under the European research project URBEM (www.urbem.net), an in-depth study has been undertaken on city-rivers relationships and how a river can contribute to urban sustainability. This study is conducted under an ongoing project called "Ri-Pro-City, opportunities for urban sustainability". A set of indicators of sustainability which can be applied to fluvial cities and urban river corridors has been developed, aiming to assess progress in river rehabilitation projects. The indicators are based on the evaluation of: sustainable urban land use, flood risks, water quality, river corridor habitats, contribution to amenity and microclimatic balance, access and use of riverfront facilities, public satisfaction towards the river and the river corridor, and institutional arrangements for these specific projects.

Some case studies in Portugal have been selected, where river rehabilitation has been part of larger projects of urban regeneration. In these cities, those projects have been assessed using several indicators, aiming to evaluate strengths and weaknesses of the rehabilitation process. The lessons learned can contribute to ameliorate and improve urban rehabilitation techniques and processes, leading to more ecologically-balanced urban river landscapes, which are socially experienced and valued by citizens and local stakeholders.

Key words: urban river, sustainability, rehabilitation, evaluation, indicators.

1. INTRODUCTION

In the context of urban landscapes, a better balance between natural components and the built environment is seen as an important target for urban development, correlated with a better human quality of life. Water is a key natural resource for sustainability and plays an important role in the urban environmental quality. The relationship city/water is a complex and demanding issue, requiring special management procedures affecting all the levels of urban management.

The presence and crossing of rivers in cities bring additional concerns to the urban environment. Besides the historical, geographical and morphological features, several specific aspects should be considered, such as water quality, flood vulnerability, accessibility, increased aesthetic and landscape value and contribution to urban attractiveness and identity, among many others.

The presence of nature in urban areas may contribute to an increase in perceived quality of life. Thus, various sets of indicator have been developed for the purpose of assessing urban sustainability, including indicators considering the presence and accessibility of green urban areas (e.g., Urban Audit1). Even though not explicitly considered, rivers provide an unique opportunity to introduce nature into urban areas.

Two main characteristics of rivers might contribute to a more sustainable urban development: its continuity and the presence of water. Continuity and connectivity are key issues in promoting quality of ecological system and in the conservation of biodiversity (Hellmund and Smith, 2004) because they enable fluxes of species, matter and energy (Forman, 1985) and create habitats for urban fauna.

These linear continuous structures (corridors) also provide opportunities for movement of people by increasing access to open areas, as advocated by the ‘greenway’ concept (Jongman and Pungetti, 2004). In the light of climate change and the need to reduce CO_2 emissions, these corridors may set the basis for more sustainable modes of mobility and a shift in urban lifestyle,

[1] http://www.urbanaudit.org/

where proximity, a sense of community and social interaction may gain a new realm.

Water is recognized as being of fundamental importance for all species. The presence of water bodies is thereby of special relevance to people by creating more attractive and relaxing environments, valued for their aesthetic qualities (Kaplan, 1989; Ulrich, 1991). Rivers are also of great potential for recreational and outdoor activities linked to water. Notably, in Mediterranean cities, due to the combination of high temperatures and absence of rainfall in summer, water becomes very attractive. The presence of water is an essential factor in fighting the ‘urban heat island’ (Hough, 2004) and thus provides an increased climatic comfort to the residents. Taking into account climate change the presence of water may play an even more relevant role in the future.

Rivers in urban areas provide important ecological and social benefits and thereby show a great potential for forming the backbone of the ecological structure of cities. River corridors should be addressed in order to create spaces where “residents can enjoy beautiful surroundings that are more suitable for wildlife” (UNEP, 2007).

2. CONTEXT OF URBAN RIVER RESTORATION AND REHABILITATION

The increasing interests in the restoration and rehabilitation of rivers and watercourses is motivating an emergent trend of river restoration programmes, all around the world (Palmer et al., 2005). The specific case of urban rivers calls for increased complexity, either on the physical and ecologic domains, as well on the social dimensions, related with the public, the experts and the decision makers that experience, promote or conduct the rehabilitation schemes (Kondolf and Yang, 2008). So, physical and ecological processes, as well as social processes, need to be both identified and studied, in order to achieve a successful project, which takes into account the several domains involved.

According to Bernhardt and Palmer (2007), the restoration of urban rivers is a demanding process due to the changes of land use and urbanization of catchments, along three main axis: a) The geomorphic simplification in habitat heterogeneity and reduced floodplain connectivity; b) the ecological simplification with decline in stream biodiversity and sediment transport; c) the diminished social value of rivers, becoming unattractive for social uses and recreation. The level of intensity of these disturbances creates very different situations, where a continuum of cases can occur, from a non-disturbed catchment processes into a highly urbanized urban land uses (Kondolf and Yang, 2008). So, different objectives and targets can be established, from a more restoration-oriented project to others which could be more adequately classified as “rehabilitation” or even “improvement”.

When planning actions on urban rivers and streams, it is then important to state the level of the intervention, according to the degree of existing constraints and the potentiality to restore some natural processes and functions. The distinction of concepts can be useful in order to analyze the constraints and establish the potential targets and aims (Schanze et al., 2004): "Restoration is directed towards recreating the pristine physical, chemical and biological state of rivers. In its purest sense it means a full structural and functional return to a pre-disturbance state (Wade et al. 1998; p.2, in Schanze et al., 2004). Renaturalisation or naturalisation describes the naturalistic way of bringing (river-) ecosystem back to a natural state but without targeting the really pristine, pre-disturbance state (cp. Mendiondo, 1999 in Schanze et al., 2004). Rehabilitation indicates a process which can be defined as the partial functional and/or structural return to a former or pre-degradation condition of rivers or putting them back to good working order (Wade et al., 1998; p.2 in Schanze et al., 2004). It is dedicated to the ecologic state (biological, hydromorphological and physico-chemical) by structural and partly non-structural measures. Enhancement means an improvement of the current state of rivers and its surroundings. It aims at a general valorisation of the ecological, social, economic and aesthetic properties".

According to these concepts, it can be accepted that in mostly urban landscapes interventions are commonly related with improvement and rehabilitation, based on the existing constraints and the potential for achieving process-led schemes rather than form-led projects. In both cases, social concerns and motivations can also be assessed through similar approaches.

3. APPROACHES TO URBAN RIVER REHABILITATION

During the last decades urban rehabilitation and regeneration programmes have been carried out in major urban areas in order to promote better urban environments, find solutions for degraded areas and to improve city image. Also in Portugal, for the Lisbon World Exhibition (EXPO 98), an urban area was subject to a regeneration process. This process was disseminated throughout 28 Portuguese cities by the application of a public supported urban rehabilitation programme, called "POLIS".

The POLIS programme established, as main goals, the improvement of life quality, through urban and environmental interventions, increasing attractiveness and competitiveness in the national urban system.

Since the rehabilitation programme favoured the creation of public open space, water played an important role in the choice of the intervention sites. Among the projects in the 28 cities, 17 of the sites included intervention on the river and river corridor.

The nature of these interventions depended on the relative position of the river in the city (central or peripheral), which restrained both the space available, but also the relation with the city and the citizens.

Interventions ranged from a very localized creation of green urban areas in the river corridor that did not address rivers at all, to intervention on the whole river corridor that crosses the city, to intervention on reaches of rivers, mostly located in degraded or neglected urban areas, as for example, in Cacém (Figs 1 and 2) and in Bragança (Figs 3 and 4).


Figure 1 - River Jardas at Cacém (before the intervention).


Figure 2 - River Jardas at Cacém (after the intervention).


Figure 3 - River Fervença in Bragança (before the intervention).


Figure 4 - River Fervença in Bragança (after the intervention).

For instance, the success of the intervention on the river Fervença in Bragança, was systematically assessed by Vaz (2008), by using a set of success indicators based on the dimensions of sustainability, according to ecological, social and economic targets (Tourbier and Gersdorf, 2005). Results showed that mainly the social dimension had been successfully addressed. The river, which before was isolated in the periphery of the city, turned in a recognized and used space that now belongs to the city. However, the rehabilitation on the river itself showed deficiencies. The creation of artificial riverbanks and the construction of a dam downstream to ensure the constant presence of water to increase visual quality of the site, heavily constrained the ecological dimension.

4. INDICADORS ADDRESSING THE CONTRIBUTION OF RIVERS TO URBAN SUSTAINABILITY – THE 'RIPROCITY' APPROACH

Any intervention in highly variable systems, such as river systems, necessarily implies consequences, not only for the intervention area, but also for upstream and downstream areas, depending on the degree of intervention developed. Thus, the assessment of the success of a rehabilitation activity can be conducted by selecting an appropriate set of indicators. The use of indicators allows to perceive the advantages and disadvantages of a particular option and to understand if the strategy was successful or not, supporting the decision for future projects of similar nature.

Monitoring, evaluation and management are thus essential components for a successful implementation of any rehabilitation project of river systems, particularly in the urban context, which entails greater complexity of analysis and understanding. In this case, the selection of the types of indicators to be used creates greater difficulties. The monitoring and evaluation process requires integrating different aspects including the economic, social, environmental, ecological and aesthetic ones.

That was one of the objectives of the European research project URBEM - "Urban River Basin Enhancement Methods", (www.urbem.net) on rehabilitating urban rivers in the perspective of sustainability, to which our research group had the opportunity to collaborate. Its main aim was to conduct a study on the state of the art of rehabilitation of urban rivers in Europe, including the experience of some countries from other continents. The following topics were selected: the process of planning and intervention, rehabilitation techniques, environmental impacts, social and economic, aesthetic evaluation, community involvement and monitoring of performance through the application of indicators to assess the success of interventions (Tourbier and Schanze, 2005; Silva et al., 2005).

This methodology was applied to the assessment of river rehabilitation process to the river Fervença in the city of Bragança, under the POLIS Programme, as refered above. The use of the set of indicators of success developed in the URBEM project (Tourbier and Gersdorf, 2005) showed some limitations, due to the difficulty in data acquisition, the absence of reference values to assess the indicators significance in many cases, and the lack of information concerning institutional issues that were relevant for the process implementation.

In order to encompass the gaps identified in the previously described methodology and in an attempt to further develop the research, our research group has undertaken another research project called "RiProCity, opportunities for urban sustainability." The main issue was to analyse multiple relationships between cities and rivers under the perspective of intervention and enhancement of both systems, in the context of sustainable development.

The various dimensions of the relationship between rivers and cities has been explored by an expert panel, to answer the question “To what extent does the river contribute to urban sustainability?”. During a ‘post-it’ session of two hours, 15 experts produced 177 contributions that have been organized into a set of 5 dimensions: (1) ecological/environmental; (2) spatial/urban; (3) psychological/social; (4) economic and (5) institutional/governance.

The discussion of the content of these contributions and the typology of related issues has directed the choice of a set of indicators to assess the path towards sustainability in urban river rehabilitation processes. The level of integration, their representativeness and the capacity to express the multiple dimensions involved, were the main criteria required. The team’s choice was the adaptation of a set of indicators already tested for assessing urban sustainability – the “common indicators” (EEA 2000) to the city-river context and to the multiple dimensions emerging from the outcome of the expert panel.

Then, a set of indicators of sustainability, applicable to fluvial cities and urban river corridors were developed, aiming to assess progress in river rehabilitation projects., These indicators address sustainable urban land use, flood risks, water quality, river corridor habitat, contribution to amenity and microclimatic balance, riverfront access and use of facilities, public satisfaction towards the river and the river corridor, and institutional arrangements for these specific projects.

Table 1 summarizes the set of indicators chosen, called ‘RiProCity indicators’. Their designation, objectives and methods of measurement are briefly described. The current phase in the research is their application to two case studies, the cities of Coimbra /river Mondego and Leiria/river Lis.

Table 1 – List of Riprocity indicators for assessing sustainability in urban river rehabilitation programmes.

RIPROCITY INDICATORS	OBJECTIVES	MEASUREMENT
Citizen satisfaction with the local riverfront	Recognizing that welfare of citizens and their satisfaction with the city are important elements for sustainability.	Satisfaction Level of the citizens in relation to the intervention area.
River contribution to local bioclimatic	Comparative analysis of climate in the river water body adjacent	Measurements of climatic variables (temperature,

change	green area, with other green areas without influence of the river.	relative humidity, wind speed (direction), solar radiation).
Ecological quality of the river corridor	Evaluate the ecological quality of river corridors, integrating also through citizens' perception of the quality of their rivers.	Riparian corridor conservation status; Ecological status of water bodies.
Flood risk	Analyse land uses in the area vulnerable/exposed to flooding; Evaluate the area vulnerable to flooding in the city of Leiria and set levels of risk.	Risk = Probability (probability of chain of events from origin to impact) x Exposure x Vulnerability (consequences/damages).
Sustainable land use	Establish a strategy for protecting urban rivers and sensitive areas from a hydrological point of view.	% of impervious surfaces in urban watersheds (Schueler, 1995) ; % of soil sealing and its impact on the hydrological cycle in ecologically sensitive areas .
Mobility and river accessibility	To promote an increased accessibility to the water and allow a better public appropriation of the banks, as well as stimulate enhanced connection between banks.	River crossing by pedestrians**;** Accessibility to the river by public transportation .
Availability of local public spaces and services	To determine the quality of the urban setting, services and leisure areas provided on the riverfront.	Social facilities area on the riverfront per inhabitant**;** Percentage of open public space on the riverfront**;** Area occupied by restaurants, commerce and other services available for recreation over total surface area of the riverfront.
Governance and sustainable management	Management models' efficiency (towards sustainability) of the river's banks.	Stability of the land-use management system ; Existence of projects or programmes with influence over the riverfront; Compatibility/conflicts between different management instruments.

5. CONCLUSIONS

The application of these indicators is in an early stage, and requires the collection of data and the integration of information from different sources. However, the discussion undertaken has contributed to define an interdisciplinary approach, where ecological, social and institutional issues have been crossed and approached in an integrated way.

The possibility to overcome conflicts and uncertainties, common to almost any river restoration and rehabilitation processes, increases with this 'crossed' vision that enlarges the scope, the effects and the role and involvement of different stakeholders. We expect that, in the near future, the lessons learned through this methodology will contribute to bridge the gap between distinct and opposite professional sectors and ways of conducting such projects.

Public acceptance and involvement are key issues for the success of river restoration projects. Notably in urban areas, this aspect is of major relevance due to the multiple issues at stake. Therefore, bringing together social expectations with the achievement of healthy ecological processes and ecosystems can be viewed as a progress towards sustainability.

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MEXICO CITY: FROM WATER AVENUES TO ASPHALT RIVERS. CURRENT CONDITION AND FUTURE PERSPECTIVES OF MEXICO CITY RIVERS

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ABSTRACT

Mexico City developed in a hydrological basin occupied by a natural lake system. This situation made the city vulnerable to floods caused by its overflowing lakes. Thus, Mexico City and its relation to its lacustrine environment have been conflictive ever since the Spaniards conquered the city in the XVI century, and through our present day and age. Successive generations over four centuries built hydraulic works that aimed to empty the basin's lakes through different tunnels. The war against water has characterized this city over the centuries. Once the Valley of Mexico dried up in the XX century, the city's growing population polluted its rivers and the best solution consisted of confining the waters to pipes and transforming their beds into vehicular roadways.

In this present day and age, all recovery or rehabilitation of a urban Mexico City river demands taking its hydraulic history into account; that history structured the huge drainage system that collects and expels lake water from the basin, as well as the rivers confined in pipes, and the city's rain and wastewater. The rescueing of an urban Mexico City river is faced with the challenge of overcoming the prevailing cultural and technological inertia.

We entered the XXI century with the idea of shifting paradigms and recovering an urban river on the southwestern side of Mexico City. This project intends to amend the historically conflictive relationship that has existed between water and the capital city's residents, and thus start to support sustainability in one of the world's largest cities.

Keywords: Mexico City, hydraulic history; draining lakes, rivers confinement; river rehabilitation.

1. INTRODUCTION. MEXICO CITY AND WATER: A GREAT PARADOX

The Mexico basin was a natural endorrheic basin, i.e. a closed basin in a valley with a vast system of lakes formations, but it has become an artificially-open and semi-deserted basin. The Mexico Basin has been exploited by successive generations that succeeded in drastically modifying its hydrological operation over the last four centuries.

The war against flooding has been a constant since the city of Tenochtitlan was founded and in the current Mexico City metropolitan area. This constant battle waged against the excess of water over the centuries, produced a great paradox in the XX century: while Mexico City succeeded in overcoming its flood and full outlet nightmares, the valley lacks enough water to meet the growing demand of its explosive urbanization. We must bear in mind that Mexico City population increased from two to 20 million inhabitants in just six decades. In principle, the efficient removal of rain water from the Valley of Mexico allowed urban and industrial development of the metropolis through the extraction of groundwater. However, when these groundwater sources were found to be insufficient in the 1940s, city authorities built an aqueduct to carry water from a neighboring basin. Later on, in the 1980s, the city built a second aqueduct to transfer water from another neighboring basin. These two aqueducts (the Lerma and Cutzamala systems) supply approximately 30% of the potable water that Mexico City requires.

Rivers did not represent a possible water supply solution for the city throughout the XX century. On the contrary, because these are seasonal rivers, polluted by the cities that were incorporated into the capital metropolitan area, they are perceived as a health hazard for the population. The solution to the problem consisted of laying pipes to confine and discharge the contaminated waters and transform the structures left by their old channels into roads for vehicular transportation purposes. Hence, the different drainage works caused rivers to be classified as wastewater. The city condemned the rivers to a murky death: their mild currents were reduced by concrete and asphalt.

The present is charged with history. Any project to rescue the urban rivers within this context demands a full understanding of the long-term processes that have impacted the hydraulic history of the Mexico City Valley, the cultural history of the type of urbanization and its relation with the environment. The rescue of an urban river in Mexico City represents a serious challenge that is limited not only to technology and methodologies, but is affected primarily by historical, social and cultural factors.

2. FROM AN AMERICAN VENICE TO A THIRSTY MEGALOPOLIS

The Mexico Basin is an endorrheic formation on the Tertiary geological horizon, i.e. close to 9,600 square kilometers were hydrologically enclosed to house lake lowlands 2,250 meters above sea level. Five lakes were then formed and trapped among mountains and hills that became one great lake during the rainy season. The lakes known as the Zumpango and Xaltocan lakes flowed on the north side of the city; while the Xochimilco and Chalco flowed on the southern side of the Valley, each at a different altitude, but each intercommunicated as they flowed into the Texcoco River at the center of the valley. The lakes were fed by the runoff that flowed from the elevated areas through torrential rivers, and the summertime precipitation that ranges between 1500 mm and 600 mm.

Figure 1 – Rivers and Lakes of the Mexico Basin in the 16th Century

The Mexican civilization faced cyclical floods that decimated its population. Nonetheless, the solutions proposed to face these catastrophes never questioned the cultural strategy of leveraging the benefits the lakes provided. Once the Europeans conquered the Mexico City Valley, they modified the attitudes and the practices regarding the ecosystem. The complex lacustrine life became a problem for the Spaniard's conception of a city. The chronicles report floods of great magnitudes in 1555, 1580, 1604 and 1607. The New Spain policy with respect to the valley's water did not contemplate its retention, rather the radical modification of the Valley's ecosystem. The city's first ambitious project to artificially discharge the waters of the Cuauhtitlán River through a tunnel drilled in the northern part of the basin was completed in 1608. This first artificial solution is known as the *Tajo de Nochistongo* (Nochistongo Tagus). This hydraulic work in the XVII century started a approach that has been maintained through this day, i.e. to banish the lakes and rivers from the Mexico Basin. In the year 1900 General Porfirio Díaz undertook a second drilling in the Tequixquiac Mountain to drain the basin; however, flooding continued during the first half of the XX century, inundating the downtown area of the modern capital city for weeks at a time. The revolutionary government built a third artificial drainage system 200 meters from the previous system in 1947 and the fourth drainage system, the largest one to date, was finally initiated in 1975, which consists of a 200-meter deep tunnel that flowed into the El Salto River. Tthanks to these four artificial drainage systems, the Mexico City Valley is no longer a closed basin, as from 1607 to date it has been discharging its surface waters, into the neighboring Tula River basins.

After the drainage of the five lakes of Mexico Basin conducted for three-and-one-half centuries, the landscape was drastically modified and the superficial waters started to be in short supply. It was then that engineers of the revolutionary state designed and built the first infrastructure to bring water from a neighboring basin: the Lerma System that initially collected the springs from the Almoloya River and later on extracted groundwater from the Toluca and Ixtlahuaca valleys. However, the city's explosive demographic growth in the following three decades caused the imported water from the neighboring basin to be insufficient. Thus, a second system was inaugurated in 1982 with the same objective: "import" superficial water collected in dams at the Cutzamala River Basin, over 100 kilometers away from the capital city, overcoming a 1,000 meter difference in elevation.

3. URBAN MODERNITY AND RIVERS CONFINEMENT

The use of rivers was never an option for the modern Mexico City, as people in the 1930s perceived the streams and rivers as discontinuous and hard to control: "*The streams that feed the Federal District flow in from the surrounding mountains; most are classified as torrential waters and of a passing nature. They include the Consulado, Los Remedios, Tlalnepantla, Churubusco, and the Piedad rivers, although none of these are important streams and some overflow and flood portions of the surrounding land at certain times of the year."* (DDF, 1930:18).

As the rivers flooded the new suburbs, the government started to apply a policy that consisted of containing them through a system of dams in the west of the city. The solution was to collect the waters in small dams and create underground tunnels to bring them to the north through the drainage systems, remove them from the city and finally remove them from the basin. Six dams were built between 1937 and 1941 The Mixcoac, Tacubaya, San

Joaquín, and San Joaquín-Tornillo dams were built in 1937-1941, 1936-1938, 1935-1936, and 193-1938 respectively; the Mixcoac-Becerra and the Tacubaya-Tecamachalco tunnels were built in 1937-1940 and 1937-1937, respectively.

In summary, during the thirties, the transformation of the social representation of the rivers was consolidated, and changed from viewing them as a local source of water and peripheral irrigation to viewing them as responsible for floods and sources of infection.

Despite all the protective hydraulic works, Mexico City continued to suffer from severe flooding during the 1940s. A second set of river taming work was then undertaken, beginning with the Viga Canal that was enclosed in 1941. A portion (10.4 kilometers) of the Consulado River was piped between 1944 and 1960, as the river was seasonal and with low discharge and its basin has been occupied by human settlements that constantly felt threatened by the flood and by the fact that it transported large amounts of wastewaters from the capital city's thriving industry. People held negative perceptions of the Consulado River: *"These channels, which frequently overflow in times of heavy rainfalls cause dangerous floods in large areas; they are also unhealthy centers because they do not have a continuous current flows, they are dry most of the year and encouraged the accumulation of trash and all kinds of filth. The greatest damage was caused by the Consulado Rivers, which flowed through populated colonies [neighborhoods] such as Cuauhtémoc, San Rafael, Santa Julia, and Santa Maria, Nonoalco, Peralvillo, Vallejo and numerous other neighborhoods to the East."* (DDF, 1942:113). Communication between the Santa Maria, San Jacinto and Tacuba colonies improved once the river was confined to pipes (DDF, 1975), and a new layer of asphalt was laid over its bed, thus creating a paradigmatic example of the new river urbanization strategy.


Photos 1 and 2 – Magdalena river confined in 1960

A portion (11.3 kilometers) of the Piedad River was piped between 1945 and 1960, in parallel with the construction of the network of collectors and improved drainage systems; this long process included a variety of different public works. A portion (21 kilometers) of the Churubusco River was channelized between 1950 and 1975.

Urban development used the riverbeds as borders between different neighborhoods, and for the construction of highways, thus resolving automobile trip needs. The modern city model involved the design of large avenues to connect the different regions of the capital city; thus another 1.9 km of the Piedad River were piped between 1947 and 1957, to connect the Becerra River and the Miguel Alemán Viaduct and create an expressway to drive from the eastern to the western side of the city. During this same period, the city piped 542 meters of the San Joaquín River and thus the rivers were gradually transformed into the mute asphalt avenues of the city.

In the ’50s, the city’s government and residents continued to fight their rivers, and in 1951 the waters of the Churubusco River were diverted to the National Canal to maintain the decreasing water levels of the Xochimilco, Tláhuac and Mixquic Lakes. In 1953, the Los Remedios River overflowed and flooded several surrounding settlements. The first floods in the ’50s were clear proof that the drainage system was insufficient, and certain areas of the city started to cave in. The solution had to have a wide approach and in 1953, the Head Office of the Federal District’s Hydraulic Works Department introduced the “*General Plan to resolve the sinking and flooding problems in Mexico City and supply running water in Mexico City*.” The plan permanently modified the riverbeds that ran through the capital city and finished piping of the Consulado River and about 80 kilometers left of the Churubusco, Magdalena, San Angel, Mixcoac, La Piedad, Becerra, Tacubaya, Dolores, Barrilaco, Tecamachalco and San Joaquín Rivers. The works were completed with the construction of the so-called Western Interceptor that was built to collect the waste and rain waters. The interceptor was 17 kilometers long and divided the Magdalena River, running through the Chapultepec hills until it poured into the Remedios River (Casasola, 1967).

Work was started on the Grand Canal in 1960, to help carry waters from the rivers that were now combined and undivided from wastewaters generated by the different neighborhoods. The Grand Canal was built to flow down the Hondo River and into the Vaso de Cristo River. Between 1963 and 1964, the Western Interceptor was extended to the Cuauhtitlán River, the Zumpango Lake and the Nochistongo Tagus. The Western Interceptor opened an outlet for the rivers to flow to the western and southwestern sides of the city, which represented a health and aesthetic problem for the settlements,. And also allowed for the waters to flow and drain towards the north.

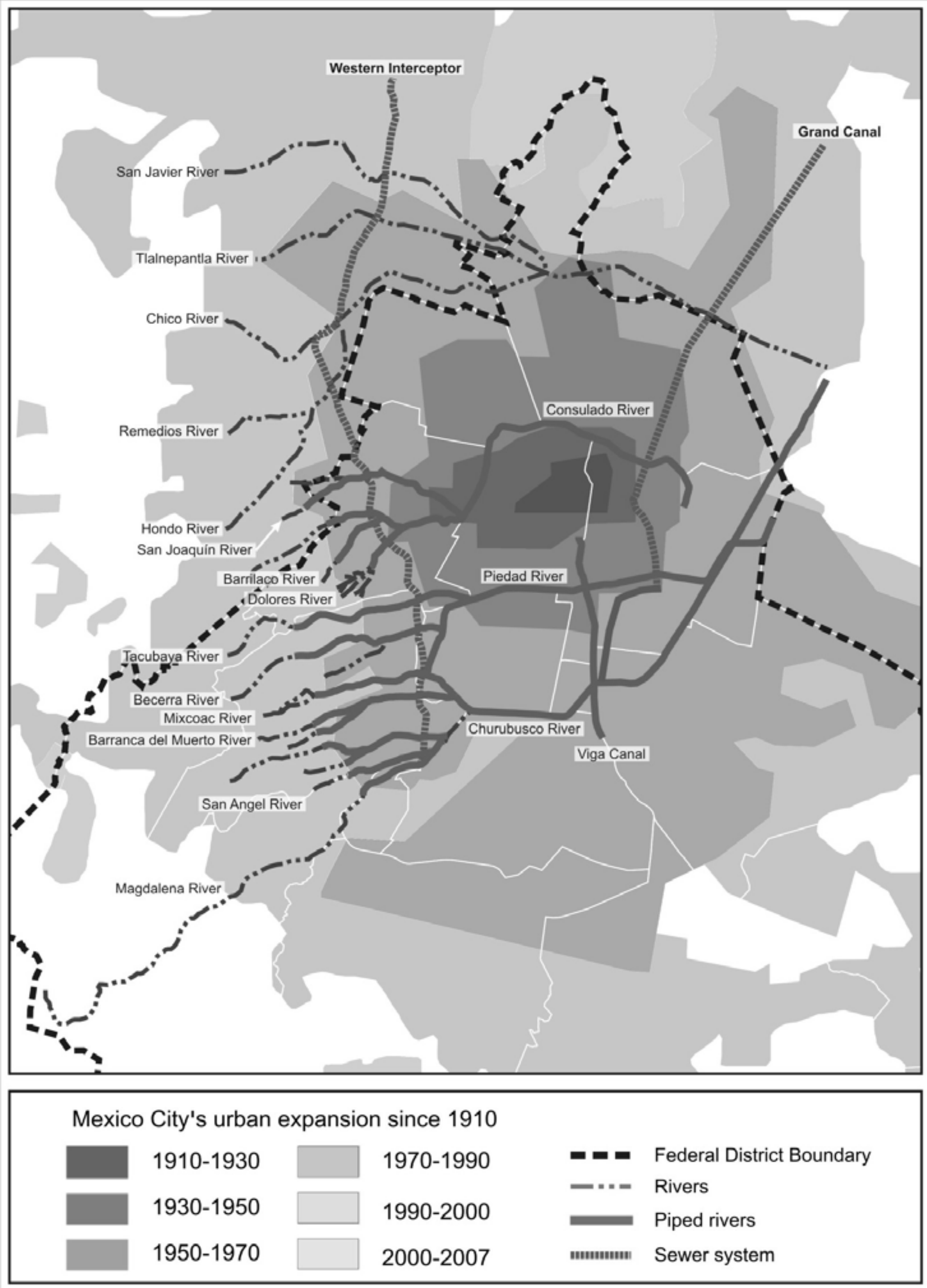


Figure 2 –Rivers and urban expansion in Mexico City

Between 1960 and 1970, a good part of the north and northeast of Mexico City was industrialized, leading to explosive population growth, which grew to nine million citizens in 1960, and 14 million residents by the ’80s, which caused a rapid growth in metropolitanization. The needs and services had to correspond to the modern dimensions of the large city and its population in such a manner that the authorities decided to create a Deep Drainage system. The sewer system was modernized during its construction, and the river problem was finally resolved and controlled to improve the city’s “roadway, sanitary and aesthetic aspects". This system confined 620 meters of the San Juan de Dios River, 1.7 kilometers of the Miramontes Canal, 200 meters of the San Buena Ventura River, 1 kilometer of the Tacubaya River, 1.3 kilometers of the Hondo River, 1.6 kilometers of the San Angel River and 300 meters of the Barranca del Muerto River and also dredged part of the Churubusco River, piping it up to Zaragoza (DDF, 1975:231).

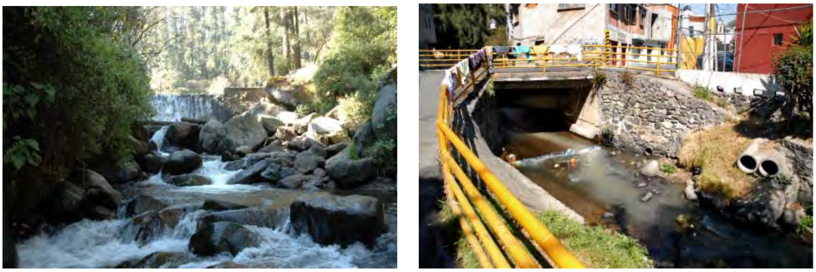
4. REHABILITATING THE MAGDALENA RIVER AGAINST THE HISTORIC INERTIA THAT PREVAILS IN THE MEXICO BASIN

All of the rivers in the Mexico Basin are today fragmented by dams, artificial outflows and other types of hydraulic works. It is important to note that some rivers on the east of the basin still run in their natural course, they are approved for local agricultural activities and flow into the remainder of the Texcoco Lake.

People have raised their voices within this context to change the treatment and management of the river basins by building an alternate model that demonstrates the benefits of incorporating a river into the urban environment. These types of proposals have been concentrated to rescue the Magdalena River in the southwestern side of the city.

There are several reasons that play a role in choosing the Magdalena River to create a new paradigm: the excellent quality of the water in its upper portion, the eminently young forest and good conservation conditions of its non-urbanized area, its entrance with an open riverbed to the urban area, its contributions to the water supply (210 L/s) and its historical heritage and cultural relationship with the city. Thanks to this great natural and socio-cultural potential, the Magdalena River symbolizes in the social imagination the chance of changing the hydrological history of our city.

The *Master Plan for the Comprehensive Management and Sustainable Use of the Magdalena River Basin* has been in process since November 2007 and is expected to be announced to the population in the summer of this year. The *Plan* has a multipurpose focus that will promote the eco-systemic services this river provides for the city and will create a cultural, social and urban development with the river as the focus of one of the largest linear parks in Latin America.



Photos 3 and 4 – Magdalena River in Mexico city

If this plan were to succeed in a short-term harmonization of the results derived from an integral vision for the long-term, we will be able to ponder on the relationship we have kept with our rivers. Instead of considering them as a threat and a weakness in our surroundings, we will be able to transform them into spaces that offer multiple environmental, social, cultural and economic opportunities.

5. CONCLUSIONS

Mexico City can be considered as a metropolis that overpoweringly transformed its urban rivers into vehicular roadways, driven by a vision for progress and modernization. In 40 years, the city erased almost 83 kilometers of rivers, which is three times the size of the largest avenue in the world (*Insurgentes* located in Mexico City).

Mexico City's present day challenge consists in readdressing the relationship between our society and the environment. Water sustainability implies changes in the manner in which we formulate the problem itself: it is no longer a matter of trying to dominate nature to our own benefit; that is to say, this no longer has to do with bringing water from far regions or mixing rain water with wastewater and expelling it to even more remote sites; neither is it a matter of confining the rivers that still flow under the open skies, to pipe flows. From now on, the problem's formulation is not based exclusively on the construction of dikes, dams, aqueducts and channels; that is to say, this is not a matter that is exclusive to civil and hydraulic engineering. The XXI Century is now faced with the challenge of taking action on our own selves; on the need for society to regulate itself to its own benefit, as the protection and efficient management of water resources –and environmental resources, in general– will guarantee its future viability.

We expect to change the manner in which we have related to our rivers through the city's sustainability and the future of the 51 rivers that still remain in the basin and refuse to disappear.

ACKNOWLEDGMENTS

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CHAPTER 13

Session 10

Large dams and River Restoration

Chairperson

D. G. DE JALÓN

Introduction
LARGE DAMS AND RIVER RESTORATION

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In a world of increasing pressure on the use of water resources the construction of large capacity reservoirs in order to be able to stock exceeding waters from floods and rainy seasons, for being used at the dry seasons, is one of the most important impacts that have rivers nowadays. Large dams have a direct impact in fluvial ecosystems through the effects of river fragmentation (population isolations, loose of resilience) and the 'lenthification' of natural habitats.

This session was rather heterogeneous including six oral presentations and a poster, that deal with cases of restoration and mitigation measures for regulated rivers, the proposal of methods for restoration design, together with the analysis of the ecological effects.

The restoration cases include a holistic one with a dam removal implemented (unfortunately not a large one). Mitigation cases were dedicated to avoidance of the sedimentation effects in the by-passed river channel using the floods removal capacity. Another case for the mitigation was the revegetation and cleaning of levees along river reaches below dams.

Proposal of methods for restoration design include: flow regime analysis for hydrological alteration evaluation, Ecohydraulic habitat simulations for the evaluation of designed fish passes, and sociological analysis for fish habitat improvement implementations.

Finally, a long term study of the effects hydropower regulated flow regime and their improvement through the answer of the macrobenthic community.

4th ECRR Conference on River Restoration
Italy, Venice S. Servolo Island
16-21 June 2008

WIDENING BY-PASSED REACHES OF THE RHONE RIVER, FRANCE, REMOVING SEDIMENT DEPOSITS. INTERDISCIPLINARY STUDIES AND PROCEDURES.

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ABSTRACT

The Rhône River upstream of Avignon is a high-energy, large river which has been trained (1) for navigation between 1860 and 1939, and (2) for the production hydropower between 1892 and 1986. The first engineering works were dykes built inside the river bed; the second generation consisted of dams, canals and power plants, and by-passing some reaches (National Rhone River Company. The by-passed reaches are called "old Rhone" because they drain a minimum ecological discharge, except during floods when discharge is almost natural (flood discharge may last from several days to several weeks).

River dynamics in the by-passed reaches has resulted in the deepening of the gravel riverbed and in deposition of sand and silts behind the low dykes which restricted the width of the former braided active tract. During recent floods (1993-1994, 2002-2003), it has been proved that the flood level has increased since the mid-19th century, which can be detrimental to riverine floodplains and requires compensation works complementing the restoration of former arms.

An interdisciplinary study is in progress since 2004 through different programs involving several partners. An innovative methodology has brought together into a GIS : (1) the historical changes of land occupation in the former active tract since 1860, (2) all the dykes and levees, (3) the delineation of homogeneous land units prone to sedimentation, (4) the estimation of the thickness and volumes of deposits, (5) the grain size analysis and the content in heavy metals of the sediments to assess the possibility of removing them, (6) the computation of tractive forces in selected areas to assess the possible erosion during floods.

Indeed, this project aims at removing sediments by using the energy of the floods after limited preparation work. A first project limited to two by-passed

reaches is presently submitted to State authorization, while a master plan is being prepared for extending the widening to the complete set of by-passed reaches.

Key words: Impacts of water diversion, dams, by-passed reach, restoration, Rhône River

1. INTRODUCTION

Since the 18th century and even earlier, the rivers of Europe, as others over the world, have been experiencing heavy development works aiming at the protection of riparian land, stabilization of the channel by reducing its width and increasing its depth. These engineering works have promoted deposition of sand and silt on the banks and adjacent areas, as well as the encroachment of alluvial forests, thus reducing the hydraulic capacity of rivers during floods. The aging of the riparian landforms, which creates a progressive decrease in the ecological richness of side channels and lateral landforms, is an increasing problem along many rivers, which experience worsened conditions during floods. These changes have been widely documented across Europe were rivers have been trained in a period of high rate sediment delivery from rural areas and mountains, and have been prone to drastic changes and to fluvial metamorphosis in some cases.

Restoration procedures have been implemented along some river reaches to compensate for river constriction and associated detrimental impacts. The reopening of side channels is common along rivers such as the Rhône, the Danube River. Along the downstream Muse (Netherlands), silt deposits have been excavated to widen and restore channel capacity during floods to improve the protection of adjacent lowlands. In the Northern Alps, these procedures are implemented using the "erodible corridor concept", usually along reaches which have not been trained and whose mobility should be preserved (Piégay et al., 2005).

This contribution presents innovating studies and procedures along selected reaches of the Rhône. Considering the recent worsening of flooding, their goal is to widen the former channel by removing the old embankments. The concept is to use the energy of the floods for eroding the sand and silt deposits with a minimal energetic cost.

2. GENERAL SETTING

2.1. The Rhône River

The Rhône River is a 9th order, 812 km long stream, flowing from the western Alps, and draining a watershed of 98 500 km^2. Its discharge reaches 1700 m^3.s^{-1} at the mouth. The floods with 100 ys return period have a discharge close to 11 500 m^3.s^{-1} and the minimum annual levels can be as low as 400 m^3.s^{-1}. In the late 19th century, most of the river course was actively braiding due to heavy coarse sediment inputs from the tributaries flowing from the Jura Mountains, the Alps and the Central Plateau. However, during periods of the Holocene characterized by weak slope erosion, by low inputs of sediment, and by a quiet hydrology, the Rhône was meandering for its entire course. The unit stream power around 1860 was comprised between 5 and 210 $W.m^{-2}$; these differences in value may be explained by upstream-downstream changes of the slopes which are in equilibrium with the transit of coarse sediment or locally with the transit of sand, and may be influenced by quaternary tectonics.

2.2. The development of the Rhône River since 1840

The Rhône River, France, has been trained from the 18th century at least. At first, rural estates were protected by discontinuous earthen levees, while braided channels were constricted using spur dykes. From 1840 onward, the State begun to train the river to improve the conditions of navigation. Longitudinal dykes were erected along the concave banks, and then, from 1878 to 1930, a “system” of submersible and transverse dykes was built in order to dam the side arms, and to constrict the braided channels into a unique navigation channel that had to be deepened.

The Rhône River has been trained for hydropower from 1892 to 1986. The first scheme has been completed in 1899 in the vicinity of Lyon. All the other development schemes have been constructed by the National Rhône C° from 1937 to 1986. Except two dams built across the upstream gorges, all the development schemes belong to the “run of the river” type. Most of them are diversion dams with a narrow reservoir, a canal with the power plant and locks, and a by-passed reach. During floods exceeding the capacity of the power plant, water flows into the by-passed reach called the “old Rhône River”. In normal times, these reaches have a minimum flow.

Fig. 1: Map of the Rhône river with the CNR hydroelectric power plant of Montélimar. Photo: a view of the by-passed reach

2.3. The river "margins", relicts of the former embanked zones preserved along the by-passed reaches

For about 170 years, the training projects have successfully modified the river, as expected by their designers. Behind the low dykes, floods have deposited fine sediments, promoting the deposition of sand and silt into the side channels, over the former bars and islands, as well as on the banks, which have been raised up to 5 m above the former gravel bars. In these zones, the former braided tract has been converted into a smooth surface drained during floods by residual channels flowing across the alluvial forest. This former tract, called the "river margins", is preserved along the by-passed reaches and elsewhere has been flooded by the reservoirs. Its ecological status has been progressively deteriorating, due to the increased depth of the water table (accumulation of fines and incision of the gravel bed), and to the drying up of side channels (Fruget, 1992, Olivier *et al.*, submitted).

Recently, i.e. following the publication of the “Global Rhône Study” (2000), the impacts of the changes affecting the “margins” have been correlated with an increase of flood levels along some reaches, to the detriment of local communities. For instance, in Montélimar reach, the 1 in 100 years flood (1856 flood) should be ca 1 m higher than in the natural conditions, due to new hydraulic conditions. It was then necessary to study these changes and to propose engineering solutions aiming at restoring flood capacity while improving the ecology of the river tract.

3.METHODOLOGY FOR ASSESSING CHANGE IN THE BY-PASSED REACHES AND SELECTING SITES FOR TESTING THE WIDENING PROCEDURES

Since 2004, a methodology adapted to mitigate these problems has been progressively implemented by the National Rhône C° with the scientific contribution of the department of geography of the University Lumière-Lyon 2. The methodology was first applied to Montélimar, Bourg-lès-Valence, Donzère-Mondragon, and Péage-de-Roussillon by-passed reaches. This experimental methodology is progressively enriched by new developments.

3.1. Change in land use since 1860

A historical GIS on Arcview allows the diachronic comparison of maps (the 1860’s map drawn by the Bridges and Roads Service at the detailed scale of 1:10 000) and air photos taken by the Institut Géographique National (photos dated 1954, i.e. before the CNR development and 2003). It shows that the former braided tract lost its gravel bars since the training of the river, even if the reduction of flow in the by-passed reaches after dam completion has reduced the surface occupied by water. Forests and agriculture have encroached over the area, since erosion by floods has stopped, thus increasing sediment deposition and reduction of overflow through the increased relative elevation of the land.

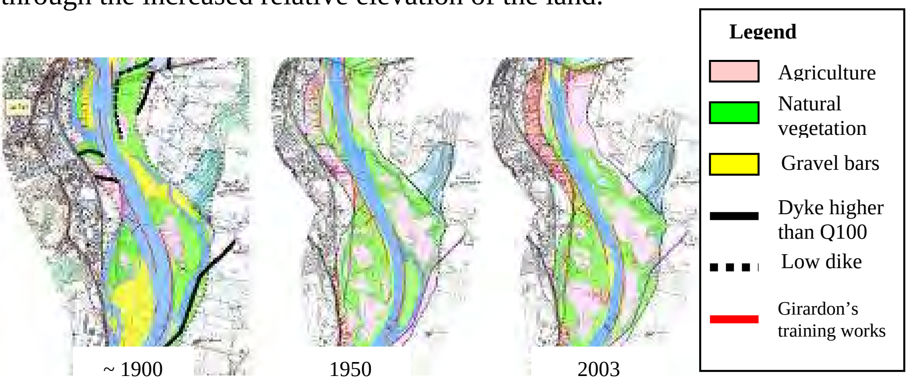

Figure 2 – Maps of changes in land use from 1860 to 2003, Roubion confluence

From river embankment to sediment deposition

The changes in the elevation of the active channel and of its margins may be traced since 1860 using a limited number of precise bathymetric surveys. Transects document the thickening of the top layer of fine sediments. These results are confirmed in the field, using the “penetrometer Panda” and excavations.

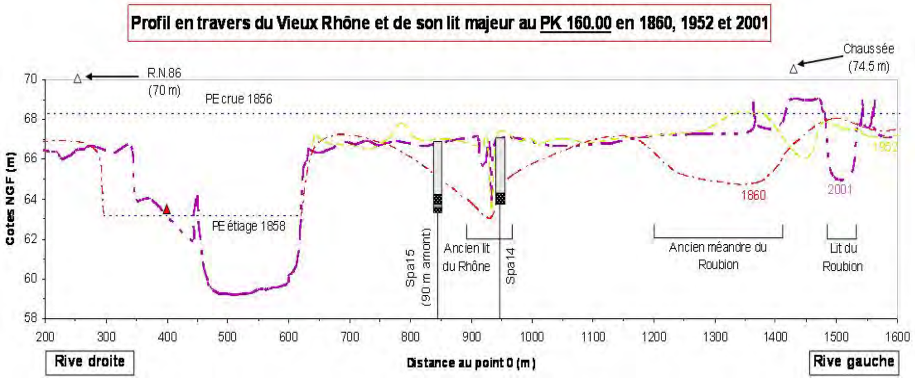

Figure 3 – Transect showing the accumulation of fine sediments on the river margins

The thickness of fine sediments depends on their location along the river corridor. The type of embankment controls the volume of discharge flowing over the margins, the water depth, the velocity, and the turbulence of the water column. Then maps drawn at different key dates delineate discrete land units according to their hydraulic conditions and to their ability to store suspended sediments.

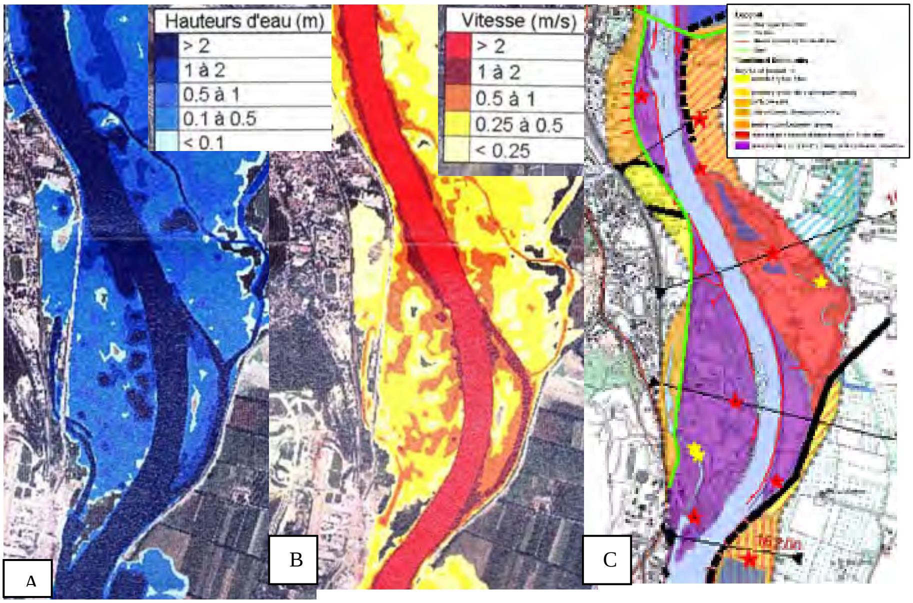

Figure 4 – A and B: Hydraulic model of flow across the river margin. C: Map of space units delineated according to their ability to the deposition of suspended sediments, Roubion confluence

3.3. Granulometry of fine sediments

In each land unit, the grain size of the sediments depends on the turbulence during the overflow and on roughness controlled by vegetation. Backhoe trenching allowed detailed studies of grain size in selected sites. Between 25 and 85 % of the total volume of fine sediments are sands coarser than 200 microns, a threshold value for sediments considered as "useful" for the stability of the shore in the Camargue delta. This is a justification for using floods to remove the fine sediments from the margins, and to transport them downstream to the mouth.

Moreover, the CM image technique was used to assess the degree of cohesiveness of fine sediments, and their capacity to be eroded (Bravard & Peiry, 1999). Samples with a value of the median (D50) exceeding 100 microns are prone to erosion, the closer they are to the C = M line (perfect sorting) the higher the erosion.

3.4. Ecological interest of alluvial forests

The evolution of the forest cover since 1856 has been analyzed for each land unit. There are few forests dating back to the 19^{th} century and most of them must have been cut by local people and thus are today secondary forests. More than two thirds of the present alluvial forests are located in land units open to floods and autogenic successions prevail. Sediment deposition has raised the land and promoted the development of hard wood trees.

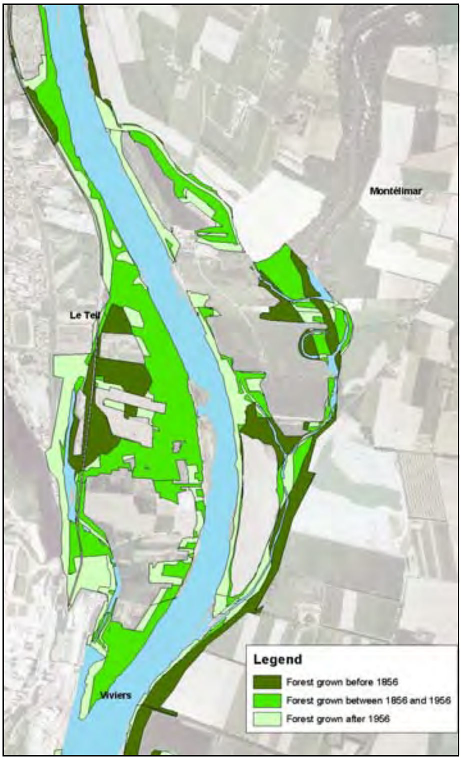

Fig. 5: Map of alluvial forests in 2003, Roubion confluence (Motchalova, 2007)

3.5. Heavy metals

In the median Rhône River system, heavy metals are present in post-1850 sediment and the level of contamination can reach 300 ppm of lead for the deposits. Two drilled sequences provided a high resolution record of sedimentation for the last hundred years. Lead concentration was measured with spectrophotometry.

In site A, analysis were performed every 20 centimers from 0 (recent times) to 420 cm (contact with the submersible dyke built around 1870 AD). For the upper 350 cm, lead content ranges from 60 to 100 mg/kg of Pb. An important enrichment is observed from 350 to 420 cm. The absence of correlation with grain size demonstrates the independance of the lead signal inside the fluvial sequence.

In order to provide a more detailed record, site B was drilled on the left side of the old Rhône. The 2.70 m sequence has been sampled every two centimeters. Three units can be distinguished : from 0 to 50 cm and 200 to 250 cm, lead concentration is comparable to the one measured upstream on the right side (FIG. 6, site A). The maximum contamination is present between 150 and 200 cm. No chronology is currently available but we suspect a contemporaneous contamination of Rhône sediments by lead.

Other types of pollution, such as radionucleids, pesticids and PCB, will be traced to be sure that sediments can be removed safely.

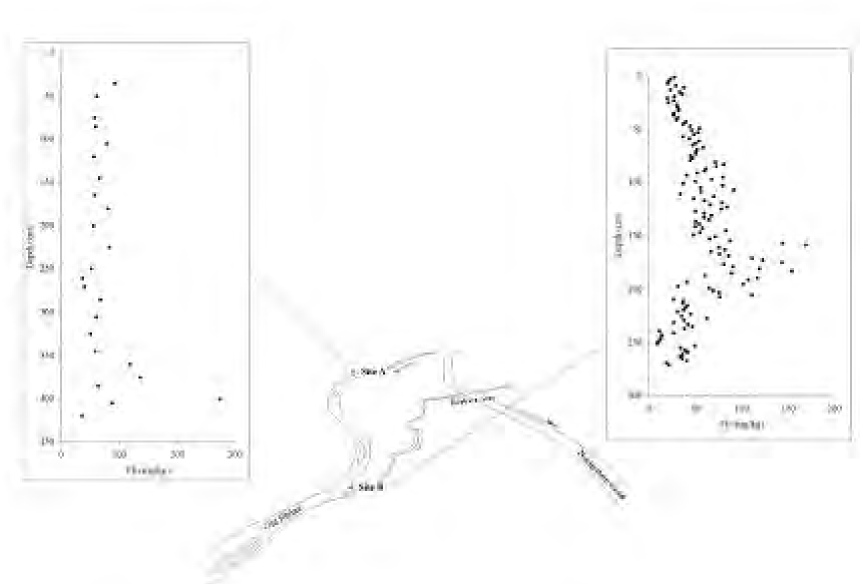

Figure 6 – The old Rhône of Montélimar redrawn from Google earth (non linear scale due to projection). Site A: lead sediment concentration from 0 to 420 cm. Site B: lead sediment concentration from 0 to 270 cm.

4.METHODOLOGY FOR RESTORING BY-PASSED REACHES

4.1. Hydraulics at the reach and site scales, and possible erosion

While pre-dam discharge of the Rhône was 4600 m^3/s for the 1 in 2 years flood for the period 1920-2005 (morphogenic flood), present discharge in the Old Rhône is limited to 2750 m^3/s due to the diversion into the canal and through the power plant. For characteristic discharges, water depths have been computed in each site of the river margins. Tractives forces and critical tractives forces as well as sediment transport using Meyer-Peter formula have been computed for different discharges. The volume of sediments prone to erosion in the selected sites of Montélimar is comprised between 150000 and 200000 m^3 and should be removed on a period of 3 to 5 years according to hydrological conditions.

4.2. Restoration procedures in selected sites

For each site, restoration procedures were designed in order to maximize the efficiency of the removal of sediments. Part of the old embankments will be removed, stretches of land will be clear-cut. It was demonstrated that it will be necessary to dig a narrow channel to increase the velocity of processes and the rate of sediment removal. An original design is adapted to each of the selected site.

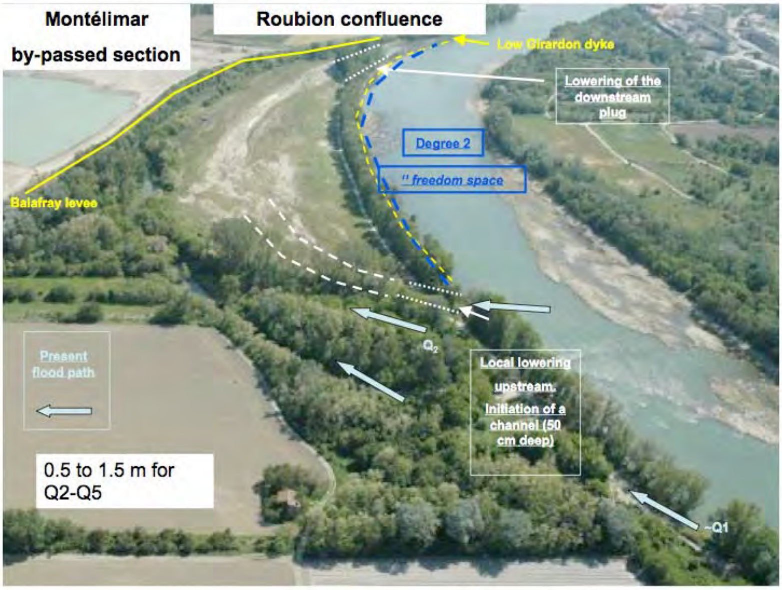

Figure 7 – Photography of Roubion confluence, with proposed restoration procedures

4.3. Recent developments

Complementary procedures are being selected for locating valuable landscapes and zones prone to risks. A master plan for widening the by-passed reaches of the Rhône is under study.

5. CONCLUSION

The widening of the Rhône will be conducted following a set of criteria that will allow the selection of the sites to be implemented as soon as possible, other sites which will be restored in the future, and stretches which will not be widened at all. However, the question of polluted sediments is a constraint, which could impede the process. Official authorizations are required to proceed further.

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2D WATER FLOW AND HABITAT MODELING OF A NATURE-LIKE BYPASS AT MONTTA WATER POWER PLANT IN RIVER OULUJOKI

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ABSTRACT

The river Oulujoki was harnessed for hydropower production after 1948. Several power plants prevent the natural migration of Atlantic salmon *(Salmo salar)* and brown trout *(Salmo trutta)*. Currently, the river Oulujoki is very effectively used for power production and it lacks spawning and rearing habitat, as former rapids have disappeared after dam construction. In 2003, a fish pass was built at the lowest dam at Merikoski located in the city of Oulu. This allows migration of salmon and trout to the next dam, 30 km upstream. However, suitable spawning sites are missing in the river and they are few in the tributaries.

A nature-like bypass including spawning sites was planned at the Montta dam. In this paper we present how modeling was applied in the planning. A first screening of potential solutions was done with a 2D water flow modeling for short sections with gradient varying from 0.1 % to 5.0 % and discharges from 0.3 m^3s^{-1} to 10.0 m^3s^{-1}. A full length 2D water flow model was created based on cross sections from the first phase and run with four different discharges ranging from 0.3 m^3s^{-1} to 2.5 m^3s^{-1}. The objective was to find general cross sections to create good spawning and rearing habitat for salmon and trout. The area and suitability of habitat was determined with habitat modeling for different bypass discharges.

The habitat modeling proved that over half of the bypass channel area will be good for spawning of salmon and trout and more that 40 % is considered as excellent areas for spawning. With 0.5 m^3s^{-1} and 1.0 m^3s^{-1} discharges almost the whole bypass channel will be good rearing habitat for juvenile salmon and 55 % for trout. With the highest discharge (2.5 m^3s^{-1}) the suitable areas are smaller than the planned profile, and mainly the shallow side areas are suitable for juvenile salmon. By applying the results for all planned bypasses at the other power plants, 11 hectares of spawning and rearing habitat can be created. This would significantly help the return of self-reproducing fish stocks.

Key words: water flow, habitat, modelling, fish pass, bypass, nature-like, spawning, rearing.

1. INTRODUCTION

The river Oulujoki was harnessed for hydropower production after the second world war 1948, thus preventing the natural migration of Atlantic salmon *(Salmo salar)* and sea run brown trout *(Salmo trutta)*. Currently, the river is very effectively used for power production and lacks spawning and rearing habitat. A technical fish pass with a partly nature-like section was built in 2003 at the lowest dam at Merikoski, located in the city of Oulu. This allows migration to the Montta dam, 30 km upstream. To bring back salmon into the river, fish passes have been planned also at Montta and the remaining five power plants (Fig. 1). However, suitable spawning sites are missing in the river and they are few in the downstream tributaries. If further fish passes are constructed as gently-sloped bypasses, they are expected to provide excellent spawning and rearing area for salmon and trout. Good spawning and rearing areas are also found in tributaries upstream (Laine, 2008).

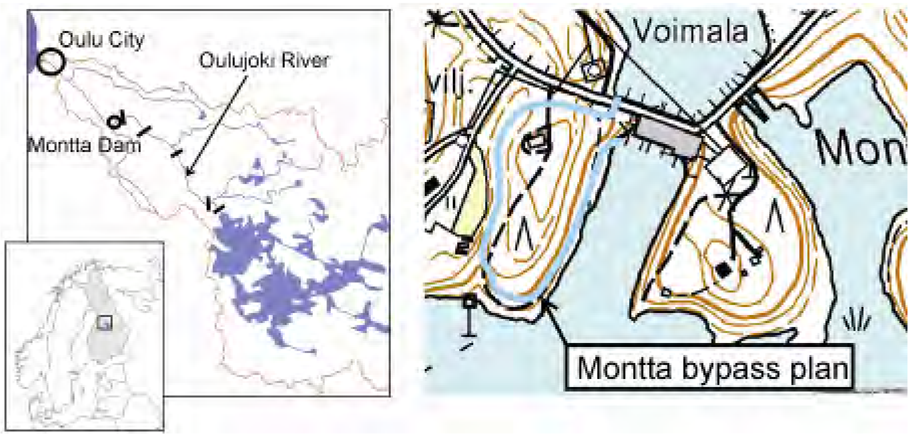

Figure 1. Oulujoki River and the planned Montta bypass.

Water flow and habitat modeling are tools for planning river restoration or new channels and also for evaluating restoration success. Reproduction areas have been created in several nature-like fish passes in Europe, but modeling has not or seldom been used in planning. Artificial spawning and rearing channels have been commonly used in Canada to enhance reproduction of Pacific salmon species. In this project the creation of habitats was combined with the planning of fish pass for the Atlantic salmon and the brown trout.

In Finland, Fortum Power and Heat Oy (previously Imatran Voima Oy) has developed a habitat modeling program (Lahti, 1999). It was used for the first time to evaluate the restoration of Laukka area in river Oulujoki (Yrjänä et al., 1999). Weighted usable area (WUA) was calculated at two discharges and 17 to 206 percent increase in WUA was achieved (Lahti, 1999). Later on the model has been used by Lahti & Kyykkä (2006), Lahti et al. (2006) and Lahti et al. (2007) to design habitat restoration. Habitat modeling has also been used in much smaller scale in Lauttaoja river, a tributary of Iijoki with a watershed of 7.06 km^2 (Sutela et al., 2002). Water flow modeling has also been used by Tammela (2006) in restoration planning.

2. COMBINING BYPASS PLANNING AND MODELING

The objective of the bypass planning and modeling was to find general cross-sections to be used in nature-like bypasses and to demonstrate in which extent new habitats could be created to mitigate lost spawning and rearing habitat for salmon and trout in Oulujoki and other regulated rivers. Different discharges were studied to demonstrate how discharges affect the habitat area and value.

As a case study, modeling was applied for the Montta bypass planning. The mouth of the bypass is placed near to the turbine flow on the bank where telemetry monitoring had shown salmon mostly migrate. The length of the bypass is 650 meters with 12.5 m height difference by a mean gradient of 1.9 %. To reduce velocities, maximum gradient in the steep section is 5 % (1:20). The discharges to the bypass had to be limited for energy saving reasons. Discharges are planned to be 1 m^3s^{-1}in the summer, reducing the discharge to 0.5 or 0.3 m^3s^{-1} in the winter. The mean discharge of the Oulujoki river is about 250 m^3s^{-1}. To ensure to attract the fishes, 2.5 m^3s^{-1} through the bypass during main migration should be possible. Additionally, conditions at 5 and 10 m^3s^{-1} were studied to evaluate velocity increase for safety and flush maintenance.

2.1 Water flow modeling

Water flow modeling is used to predict water depths and water flow velocities. The modeling is based on basic equations of potential and kinetic energy and friction (Froehlich, 2002). The water flow model used was FESWMS-2DH programmed by Federal Highway Administration of United States (Froehlich, 2002) and the graphical user interface SMS 9.2 (Surface-water Modeling System), developed by the Environmental Modeling Laboratory at Birmingham University (www.emrl.byu.edu). Mass transfer was calculated with Surfer 8.0. Water flow models are often calibrated by Manning’s roughness coefficient n and water viscosity. Higher roughness coefficient causes more resistance to water flow, increases water depth and decreases flow velocity. Water viscosity affects flow patterns in corners and where the channel suddenly changes its shape.

Elevation contours of the modeling area were digitized to produce a digital land surface map. The modeling network (mesh) has nodes and elements. Each element has corner nodes and a mid-side node in the middle of each side. If any node has a negative water depth, the node and all elements connected to it are set to be dry. The mesh points along the designed alignment were interpolated to produce the bypass channel. In the first section, a third of the channel was designated as spawning area. It has a 0.3-0.35 % gradient with small gravel (16-64 mm) steps, pools and one larger pool. An area for juveniles is located in the following section, with a 1.5 % gradient. This section also has a small step-pool formation to add depth and flow velocity variation with 32-256 mm grain size. This section ends into a pool located at a forest road (maintenance road) crossing the channel. The section is followed by a steep section (4.0-5.0 %) with one larger pool. The steep section has 265-512 mm stones as primary bottom material. This ends in a riffle-pool section with 2.5-3.0 % gradient with 64-512 mm grain size; it was designed as a suitable area for larger juvenile salmon and trout. Both ends of the bypass are technical fish pass sections. The different selected materials and gradients have different Manning roughness coefficients (Tab. 1). The channel construction requires 11 000 m^3 excavation and 3 000 m^3 filling.

The model sensitivity was studied varying the Manning's roughness n with 1 m^3s^{-1} discharge. All Manning roughness coefficients were changed by +0.01 and -0.01. When decreasing all roughness values by 0.01, the resulting lowest roughness values were only 0.02, which is a normal value for smooth surfaces. Sediment transport was not necessary to be included in the model.

Table 1. Material classes and grain sizes used in the Montta bypass with Manning roughness n according to Cummins (1962).

Material		Depth	
class	Grain size	< 0.3 m	> 1.0 m
4	16 - 32 mm	0.05	0.03
5	32 - 64 mm	0.06	0.04
6	64 - 128 mm	0.07	0.05
7	128 - 256 mm	0.08	0.06
8	256 - 512 mm	0.09	0.07

2.2 Habitat modeling

In habitat modeling, flow and channel variables are given values from 0 to 1, where 0 is a not suitable and 1 a perfectly suitable habitat for fish which are investigated. Flow velocity and water depth are typically divided into 0.1 ms^{-1} and 0.1 m sections. Each species has characteristic habitat preferences which vary with the age of fish and the time of the year. Habitat preferences are created from extensive research on fish distribution and behaviour. The most commonly used variables are flow velocity, water depth and bottom material. Bank properties, vegetation and cover can also be used. Spawning habitat preference curve data was described in Louhi et al. (2008) and all other habitat data in Mäki-Petäys et al. (1997, 2004). The researcher also gave us some advices about habitat modeling and a biologist's view of it.

Values are combined into CSI (Composite Suitability Index) by multiplying all habitat values. Habitat values can be weighted with an exponent. The sum of exponents has to be 1. The so called geometrical mean method was used as it compensates the effects of variables (Gan & McMahon, 1990). In this method the weight exponent is 0.33 for each three variables. Habitat data was processed with Microsoft Excel and graphically presented with SMS. Flow velocity, water depth, surface elevation and habitat contour maps were created. The areas were measured with SMS.

3. MONTTA WATER FLOW MODEL

In the first modeling step, short hypothetical straight sections with different gradients were modeled to establish general cross sections for different flows: gently sloping sections (0.05 % and 0.1 %) for long, low gradient parts of the bypasses; spawning sections (0.25 % and 0.5 %) for placement of spawning gravel to create an ideal spawning habitat; juvenile section (1.0 % and 2.0 %) for juvenile salmon and trout and steep sections (5.0 %) to dissipate the energy of water and to allow migration with higher discharges. Modeling was done with discharges 0.3 m^3s^{-1}, 0.5 m^3s^{-1}, 1.0 m^3s^{-1}, 2.5 m^3s^{-1}, 5.0 m^3s^{-1} and 10.0 m^3s^{-1}.

After the initial modeling, the full length natural bypass was modeled and fitted to the terrain at Montta. The same cross section from the first modeling step was used, except for the steepest sections. In the bypass model the steep sections had a constant cross section. The final modeling was done with 4 lowest discharges 0.3 m^3s^{-1}, 0.5 m^3s^{-1}, 1.0 m^3s^{-1} and 2.5 m^3s^{-1}, which were the designed flows for the bypass.

4. RESULTS

The modeling contours from the upper part of the bypass are presented in Fig. 2 for the 1 m^3s^{-1} discharge. Winter habitat was studied for salmon only (Tab. 2) with 0.3 m^3s^{-1} and 0.5 m^3s^{-1} discharges. The CSI maps show only small spots of suitable areas located mainly in spawning and rearing areas where water is deep and the flow velocity low. The bottom material is too small for juvenile salmon as it prefers larger material during winter. Suitable areas are slightly increased with the higher flow as the water depth increases.

The spawning habitat area with four different discharges is given in Tab. 3. Most of the spawning and rearing areas are good or excellent spawning habitat for both salmon and trout with the two lowest flows. With the 1.0 m^3s^{-1} discharge, salmon spawning areas increase slightly due to increased wetted area. They are located at the deepest areas which stay wet when water depth decreases. Trout spawning areas decrease as the water depth increase and they are located at the sides of channel, which can dry out during winter low flows. This could reduce spawning success since a constant flow through gravel is needed. With the highest discharge, the spawning areas decrease dramatically because of higher water depth and flow velocity. The used cross section is too narrow for the highest flow and a wider section is recommended.

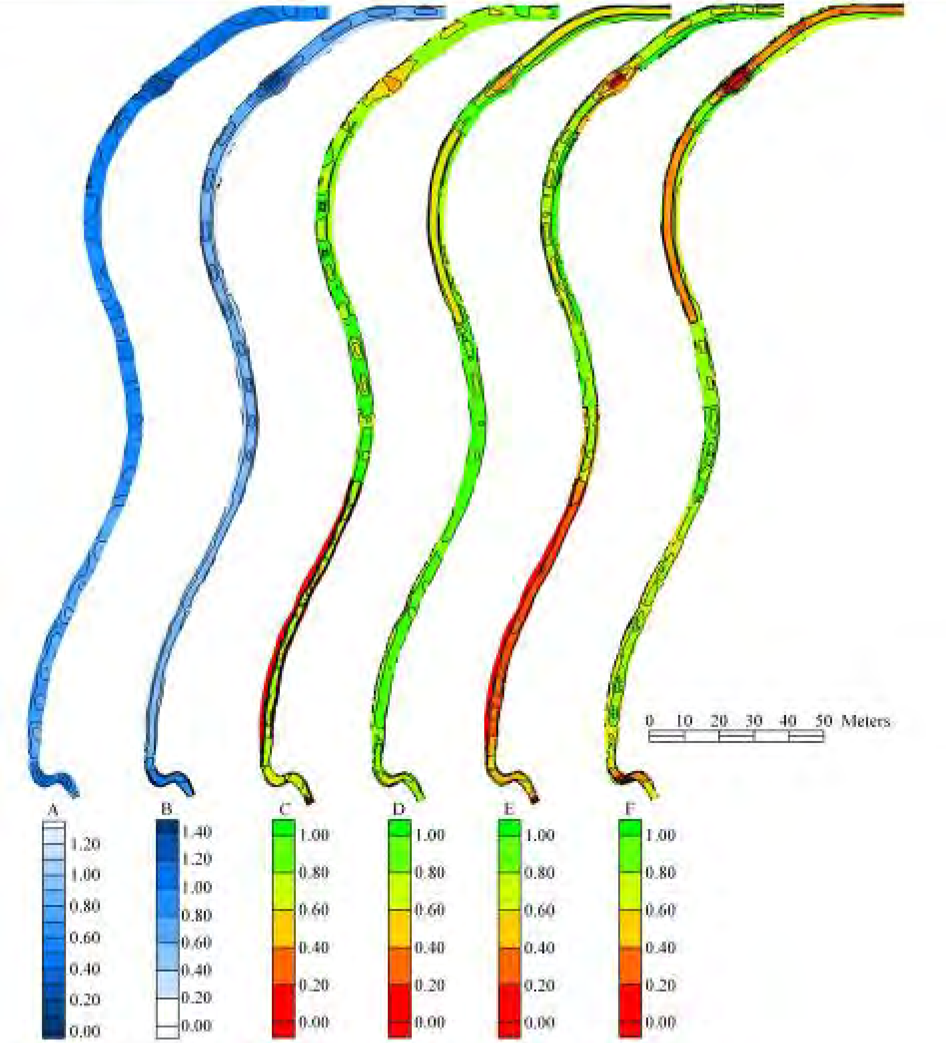

Figure 2. Modeling contour pictures from 1 m^3s^{-1} modeling: A) Water flow velocity [ms^{-1}], B) Water depth [m], Atlantic salmon spawning habitat (C) and rearing habitat (D), Brown trout spawning habitat (E) and rearing habitat (F).

Table 2. Juvenile Atlantic salmon habitat areas (left) and percentage of the total wet area (right) for winter.

Flow m^3s^{-1}	Wet area m^2	Atlantic Salmon							
		Winter habitat > 0.5				Winter habitat > 0.75			
		< 11 cm		> 11 cm		< 11 cm		> 11 cm	
0.3	1577	15	1.0	161	10.2	0	0.0	16	1.0
0.5	1842	178	9.7	409	22.2	29	1.6	80	4.3

Table 3. Good (> 0.5) and excellent (>0.75) spawning areas (left) and percentages of the total wet area (right) for Atlantic salmon and brown trout.

	Flow m^3s^{-1}	Wet Area m^2	Atlantic Salmon Spawning		Brown Trout Spawning	
> 0.5	0.3	1577	1252	79.4	921	58.4
	0.5	1842	1358	73.7	961	52.2
	1	2265	1396	61.6	947	41.8
	2.5	2745	824	30.0	205	7.5
> 0.75	0.3	1577	580	36.8	808	51.2
	0.5	1842	749	40.7	810	44.0
	1	2265	557	24.6	340	15.0
	2.5	2745	196	7.1	34	1.2

Table 4. Good (> 0.5) and excellent (>0.75) rearing habitat areas (left) and percentage of the total wet area (right) for Atlantic salmon.

	Flow m^3s^{-1}	Wet Area m^2	Atlantic Salmon			
			< 10 cm		> 10 cm	
> 0.5	0.5	1842	1748	94.9	1800	97.7
	1	2265	1874	82.7	2071	91.4
	2.5	2745	1215	44.3	1868	68.1
> 0.75	0.5	1842	895	48.6	857	46.5
	1	2265	939	41.5	1108	48.9
	2.5	2745	296	10.8	406	14.8

The rearing habitat area was studied with three flows (Tab. 4 and 5). For 0.5 m^3s^{-1} and 1.0 m^3s^{-1} discharges, almost all the bypass is classified as good or excellent area for juvenile salmon except the steep parts. However, for juvenile trout a smaller reach area is classified as good or excellent, as juvenile trout has a narrower preference curve regarding flow velocity and water depth compared to salmon. With 1.0 m^3s^{-1}, the deepest and fastest flowing areas are not suitable for trout. With the highest discharge, the rearing areas are decreased due to deeper and faster water flow. Flow velocities still allow salmon and trout migration.

Table 5. Good (> 0.5) and excellent (>0.75) rearing habitat areas (left) and percentage of the total wet area (right) for brown trout.

	Flow m^3s^{-1}	Wet Area m^2	Brown Trout					
			< 10 cm		10 - 15 cm		> 15 cm	
> 0.5	0.5	1842	1104	59.9	1090	59.2	841	45.7
	1	2265	1027	45.3	1314	58.0	1250	55.2
	2.5	2745	288	10.5	436	15.9	654	23.8
> 0.75	0.5	1842	500	27.1	309	16.8	264	14.3
	1	2265	290	12.8	307	13.6	416	18.4
	2.5	2745	22	0.8	43	1.6	37	1.3

4.1 Sensitivity of the model

Increasing roughness increased water depth only by 2-3 cm and decreased water flow velocity by 3-7 cm s^{-1}. Decreasing roughness caused water depth to decrease by 2-15 cm. The water flow velocity increased by 3-8 cms^{-1}. The largest changes were caused by damming, as elements dry out narrowing the bypass, forming a pond upstream of the element and riffles downstream. As a consequence, flow conditions changed over fairly large areas.

Changes in habitat areas were studied for salmon spawning habitat and for summer habitats for salmon over and under 10 cm length, and for trout spawning habitat and as habitat for 10-15 cm long trout. Increasing roughness increased good habitat areas by 0.2-2.8 % and increased excellent areas by 5.2-17.3 %. The variation caused by roughness decrease was from -14.5 % to +3.4 % in good areas and -34.5 % to +36.1 % in excellent areas. A large variation was caused by element drying.

5. DISCUSSION ON FURTHER NEEDS AND DEVELOPMENT

In order to create better winter habitats with lower flow velocities, the upper half of the fish pass should have deeper pools with 256-512 mm stones. This would reduce the CSI value of spawning and juvenile areas for all flows. Unwanted reduction of spawning areas with too high flow velocities could be solved by widening the channel, and loss of spawning area observed for too shallow depths could be avoided by constructing more pool sections.

If the lowest discharge were 0.5 m^3s^{-1} instead of 0.3 m^3s^{-1}, the minimum flow channel could be designed to provide even better conditions for spawning and winter habitats. Also, if only one discharge would be used during the summer and the migration period, the cross section could be made even simpler, thus providing the best possible conditions for both seasons and discharges.

In the present habitat modeling only primary grain size was considered. This has the largest effect on winter habitats. For wintering juvenile salmon, water flow velocity and depth are good in large areas. If larger stones were placed in these areas, winter habitat area would further increase.

The steep section requires steps, large stones and pools. This would provide more flow vorticity and head loss with resulting decrease in flow velocity and increase in habitat quality. Deeper pools would be created, they would be used by migrating salmon and trout to stop and rest in the bypass. This would increase the amount of summer and winter habitat for juvenile salmon and trout. Juvenile trout can use nature-like step-pool fish passes as rearing habitats (Kuvaja, 2007).

By applying the results for all planned bypasses at the other power plants in Oulujoki river, 11 hectares of spawning and rearing habitat could be created, in addition to habitats in the main river and tributaries (Järvenpää et al., 2008).

6. CONCLUSIONS

The modeling showed that large areas of habitat of excellent quality for spawning and juveniles can be created into power plant bypasses, making significant juvenile production possible in connection with regulated main river stems. Many regulated rives totally lack reproduction areas and bypasses are promising possibilities to (re)create these areas. Artificial reproduction areas would significantly help the return of self-reproducing fish stocks.

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THE MANZANARES RIVER RESTORATION (NORTHERN MADRID –SPAIN-): DEMOLITION OF AN OBSOLETE DAM AND REHABILITATION OF A RIVERINE ECOSYSTEM

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ABSTRACT

Manzanares River, in the Tajo basin, has its source in the mountains of the Sistema Central chain, located in the northern part of Madrid region. For the first few kilometers the river flows across an area with such an interesting and unique geology (granite rock) and pristine nature, that it was declared as a Regional Park as well as a UNESCO Biosphere Reserve in 1992.

In the heart of this area, a dam was built on the Manzanares River in the '40s in order to supply water to the village located downstream. Year by year the dam has accumulated such a big amount of sediments coming from the granite banks and slopes, that by the end of the century it was completely filled with sand, in such a way that it became useless and an ecological disaster.

The Confederación Hidrográfica del Tajo (the River Basin Authority) in collaboration with other authorities, settled as an achievement the demolition of this dam. The target was to restore the natural features the river had before the dam construction.

As the dam was located in a protected area, one of the goals was to preserve -as far as possible- all the natural values of the surroundings, trying to complete all the work without damaging the river bed, the banks and the areas nearby, preserving at the same time flora and the landscape features. The works were carried out in three stages: in each one the target was the demolition of a part of the dam through different controlled detonations and then the waste removal. This task was carried out with the aid of a helicopter, as the path between the river bank and the granite slope was so narrow that a heavy machinery would have caused a significant destruction.

The last goal was to restore the river bed and banks that had been affected by the dam -while existing- and the demolition works. For this stage, the tasks consisted only in light reforestation and not much more, as the river flow was able to remove the last sand particles that had been retained near the old dam.

Key words: Dam demolition, Manzanares River, Hydromorphological recovery.

1. INTRODUCTION

The Manzanares River has its source in the mountains of the *Sistema Centra*l, located in the northern part of Madrid region. The river is part of the Tajo basin, one of the large catchments of Spain. For the first few kilometres, the river flows across a zone called "*paraje de el Tranco*", situated in the middle of an area where the granite geology and the pristine nature are so interesting and unique, that it was declared as a Regional Park (*Parque Regional de la Cuenca Alta del Manzanares*) and as well as an UNESCO Biosphere Reserve in 1992. This Park has an extension of 528 Km^2, i.e. 7% of the whole surface of Madrid region.

In this area the granite substrate has been shaped for ages by the erosion of the atmospheric agents, in such a way that the resulting landscape has an astonishing richness of different shapes, tors, rounded massifs, rocky labyrinths made out of huge round polished granite blocks, and large natural stone sculptures. All this natural area is crossed by many rivers (among them, the main one is the Manzanares, the river that some kilometers downstream crosses Madrid city) and other small waterbodies, surrounded by well preserved and characteristic flora and fauna.

Because the most important and representative elements of the Regional Park are its rivers and streams, the main goal in nature preservation of this area is river protection and, if needed, river restoration.

2. GENERAL SETTING

In the '40s, a small dam (9 meters high, 23 meters wide) was built on the Manzanares River, in a site placed inside the Regional Park, in order to supply water to a village –Manzanares del Real- located few kilometers downstream. Year by year the dam has accumulated such a big quantity of sediments coming from the granite banks and slopes, that by the end of the century it was completely filled with of sand, in such a way that it became useless. This abandoned dam full of sediments and partially damaged, turned into an ecological disaster that was responsible of the decrease of the natural values of the riverine ecosystem, a disruption of the longitudinal and transversal river continuity, a barrier for trout and other species, a nutrients trap, an obstacle to normal flow and hydrodynamics, as well as a serious danger for the Park visitors if a sudden collapse should have occurred.

The River Basin Authority-Confederación Hidrográfica del Tajo-, that belongs to the Spanish Ministry of Environment in collaboration with other authorities (the local Council and the Madrid Autonomous Community), declared a main goal the removal of this dam, in order to solve the problems created by this structure to the riverine ecosystem. The main target was to restore the natural features that the river had before the construction of the dam, and to recover the longitudinal and transversal continuity.

Figure 1 – Manzanares dam before the demolition

3. WORK PLANNING

Because the dam was located in a protected area, one of the goals was to preserve -as far as possible- all the natural values of the surroundings, trying to complete all the work without damaging the river bed, the banks and the areas nearby, preserving flora and landscape features as well. On the other hand, the area is part of a Regional Park situated near a large city sich as Madrid, so it was important to take into account the large amount of daily visitors (walkers, trekkers, climbers…) which could have been affected by the work and by the consequences of an intervention within a heavily used route (as the dam access is part of a long path that connects different and very popular areas of the Park).

In order to accommodate all these requirements one of the problems was to decide how to accomplish the dam demolition: it was important not to destroy the river banks nor the pedestrian path that goes along them, limited on both sides by the riverbed and the granite slopes. So, it was impossible to use heavy equipment to remove the dam mechanically, as the transport of them from the car parking up to the dam would have ruined the narrow path and affected the river banks and slopes.

The same problem had to be solved in order to remove the concrete blocks once the demolition had been carried out.

4. WORK STAGES

The decision of which demolition and removal techniques should have been followed, was taken after an analysis of the situation and an economical assessment: it was more profitable to use explosive material to break the wall into big pieces and then remove the demolition waste with an helicopter.

The work was carried out in three stages: in each one the target was the demolition of a section of the dam through different controlled detonations and then remove the rubble and sand. Once the detonations had split the dam wall into big pieces, it was necessary to obtain smaller sized blocks in order to allow the helicopter to carry them into big bags. This task was accomplished by a relatively small mechanical digger, which was chosen because of its “spider-legs” that could allow its access trough the river bed with minimum impact due to the reduced footholds. For this works 500 hours of spider excavator were needed to fill 3.500 bags (1.600 m^3 of waste).

Figure 2. Mechanical digger

The most difficult and expensive task was the removal of the demolition waste once each part of dam was split into small pieces. This task was carried out with an helicopter because the use of a truck for the waste transport was unfeasible, as the path between the river bank and the granite slope was so narrow that a heavy machine would have caused a significant destruction. For this stage 110 hours of helicopter were needed.

Finally, once the removal was achieved, the following goal was to restore the river bed and banks that had been affected by the dam -while existing- and the demolition works. This stage included the removal of the sand in order to give more uniformity to the surrounding banks and soil were it was needed, as the river flow was able to remove the last sand particles that had been retained near the old dam. A light reforestation was carried out as well to give more stability to the slopes and enhance the riverine vegetation recovery. At the end, all the artificial elements used during the work, such as metallic fences or other material, was were removed,. For the whole works, from the very beginning to completion, a total of 1.100 day's wage was needed.

Figure 3 – Manzanares dam after the demolition

5. CONCLUSIONS

After several months of works and with the aid of the hydraulic dynamics, the Manzanares River has regained the appearance, the longitudinal and transversal continuity and the ecological dynamic that it should have had if the dam had not been built.

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IAHRIS: NEW SOFTWARE TO ASSESS HYDROLOGICAL ALTERATION

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ABSTRACT

Indicators of **H**ydrologic **A**lteration in **RI**ver**S** **(IAHRIS)** is a software designed to:

1. Use parameters to characterize the natural or regulated flow regime, in a section of the river. These parameters evaluate those aspects of the flow regime with the highest environmental meaning (magnitude, variability, seasonality and duration). For their definition, priority was given to the singular characteristics of the Mediterranean regimes.
2. If the user enters data of the natural flow regime and data for any other flow regime in the same section or reach (altered regime, environmental regime, management scenario, …) the software calculates, in addition, a set of indicators that assess the degree of hydrologic alteration in comparison with the natural regime. These indicators of alteration have been defined according to the CIS-WFD recommendations for the Ecological Quality Ratios.

The software requires, at least, a data set of 15 entire years (daily average flows and/or monthly volumes).

The type of data entered in IAHRIS determines, directly, the results obtained. In particular, the results depend on the data periodicity –daily or monthly-, and the simultaneous character of the data associated to the natural and the altered flow regimes.

IAHRIS is a free software, available on the website of the Spanish Ministry of the Environment.

Key words: hydrologic alteration, stream flow regime, large dam, environmental impacts, environmental flows

1. INTRODUCTION

Why evaluating the alteration of the flow regime?

This question can be answered by focusing on three different approaches: the legal, the scientific and the management approach.

From a legal approach, the evaluation of the hydrologic alteration is necessary, as a core requirement of the Water Framework Directive (WFD). This Directive fixes, as the most important target of the water resources management, the establishment of a good ecological status of the associated ecosystems. In order to reach this target, it is necessary to use protocols that allow for an efficient and objective knowledge of the ecological status of rivers. The WFD, in its Annex V, determines a set of components of the river ecosystem that must be considered in order to assess its ecological status. Between those, the flow regime is particularly quoted.

From a scientific approach, the importance of the flow regime as a driver of the river ecosystem has been widely recognized (Richter *et al,* 1998, Arthington , 1997, Poff *et al.*, 1997): success in the conservation of the biodiversity and functioning of our rivers depend on our ability to identify, protect and/or restore the main components of the natural flow regime.

Public agencies dealing with river management need to know the status of the most relevant environmental components of the flow regime. Only from this knowledge it is possible to formulate adequate diagnoses to establish management politics that allow advances towards the achievement of the "*good ecological status*". Also for those water bodies eventually designated as "heavily modified", it is necessary to characterize both their flow regime, and their optimum hydrological potential compatible with the conditions that enhance this status.

2. HOW COULD THE MOST ENVIRONMENTALLY MEANINGFUL ASPECTS OF THE FLOW REGIME BE CHARACTERIZED?

The natural flow regime paradigm (Poff *et al*., 1997) already establishes the most environmentally meaningful aspects of the flow regime: magnitude, frequency, seasonality, duration and rates of change.

In IAHRIS, the process of characterization includes those five aspects, for both to the normal or habitual discharge (which determines of the general water availability for the ecosystem) and the extreme events – floods and droughts – (since they define the most critical conditions for the ecosystem, specially in the Mediterranean region, considering the intra- and inter-annual variability).

Tab. 1 summarizes, for every component of the flow regime, the aspects and parameters proposed for its characterization. They are explained in detail, in Martínez & Fernández (2006).

Table 1 – List of parameters used to characterize the flow regime.

COMPONENTS OF THE REGIME		ASPECT	PARAMETER
HABITUAL DISCHARGE	MONTHLY OR ANNUAL VOLUMES	MAGNITUDE	Average of the annual volumes
		VARIABILITY	Difference between the maximum and the minimum monthly volume within the water year
		SEASONALITY	Month with the maximum and the minimum water volume within the water year
	DAILY FLOWS	VARIABILITY	Difference between the average flows associated to the 10% and 90% percentiles
EXTREME EVENTS	MAXIMUM VALUES of the daily flows (FLOODS)	MAGNITUDE AND FREQUENCY	Average of the maximum daily flows within the water year Effective discharge Connectivity discharge Flushing flood (Q5%)
		VARIABILITY	Coefficient of variation of the maximum daily flows within each water year Coefficient of variation of the flushing flood series
		DURATION	Maximum number of consecutive days in the water year with q> Q 5%
		SEASONALITY	Average number of days in the month with q> Q 5%
	MINIMUM VALUES of the daily flows (DROUGHTS)	MAGNITUDE AND FREQUENCY	Average minimum daily flows within each water year Ordinary drought discharge (Q 95%)
		VARIABILITY	Coefficient of variation of the minimum daily flows within the water year Coefficient of variation of the ordinary droughts series
		DURATION	Maximum number of consecutive days in the year with q < Q 95%
			Average number of days in the month with a daily flow equal to zero
		SEASONALITY	Average number of days in the month with q<Q 95%

This characterization can be obtained for any flow regime natural or regulated (resulting from a real regulation and/or abstraction, or a simulation under different management scenarios) for which enough data are available.

3. HOW CAN THE HYDROLOGIC ALTERATION DUE TO AN ALTERED FLOW REGIME BE QUANTIFIED?

Based on the assumption that the natural flow regime is the most determinant factor of the integrity of the fluvial ecosystems, and on the tools –parameters- that allow for a quantification of the most environmentally meaningful aspects of the flow regime, a set of indicators is formulated (Martínez & Fernández, 2008). Those indicators are designed to assess, objectively, the degree of similarity of a flow regime –altered regime-, or any other –for instance, an environmental flow regime- with the natural flow, since those similarities or differences will determine the real or potential integrity of the river.

Attending to the recommendations of CIS-WDF (2003) for the EQR, most of the INDICATORS OF ALTERATION were defined as a ratio between the parameter value in the altered regime and the parameter value in the natural regime.

Table 2 shows the links between the Indicators of Hydrologic Alteration calculated by IAHRIS and the components of the flow regime whose alteration is evaluated.

All these indicators, in order to make their analysis more homogeneous and easier, range between 0 and 1 (with 0 meaning the maximum alteration and 1 the absence of alteration).

Following the recommendations for the EQR, five different levels or Hydrological Status were established, they are linearly distributed in the range of the indices (0-1), and a code colour recommended for the EQR (fig. 1) was assigned to them.

HYDROLOGIC STATUS: PARTIAL INDICATORS (IAH)				
HIGH	GOOD	MODERATE	POOR	BAD
0,8< IAH ≤1	0,6<IAH ≤0,8	0,4<IAH ≤0,6	0,2<IAH ≤0,4	0≤IAH ≤0,2

Figure 1 – Criteria used to assign qualitative categories to the Indicators of Alteration (Very low value of the Index=Very high Hydrologic Alteration=Very deficient Hydrologic Status; Very high value of the Index=Very low Hydrologic Alteration=Excellent Hydrologic Status).

Table 2 – List of Indicators of Hydrologic Alteration (IAH1 – IAH21)

ASPECT		CODE	NAME
HABITUAL DISCHARGE	MAGNITUDE	IAH 1	Magnitude of the annual volumes
		IAH 2	Magnitude of the monthly volumes
	VARIABILITY	IAH 3	Habitual variability
		IAH 4	Extreme variability
	SEASONALITY	IAH 5	Seasonality of maximum values
		IAH 6	Seasonality of minimum values
FLOODS	MAGNITUDE AND FREQUENCY	IAH 7	Magnitude of the maximum floods
		IAH 8	Magnitude of the effective discharge
		IAH 9	Magnitude of the connectivity discharge
		IAH 10	Magnitude of the flushing floods
	VARIABILITY	IAH 11	Variability of the maximum floods
		IAH 12	Variability of the flushing floods
	DURATION	IAH 13	Flood duration
	SEASONALITY	IAH 14	Flood seasonality (12 values, one for each month)
DROUGHTS	MAGNITUDE AND FREQUENCY	IAH 15	Magnitude of the extreme droughts
		IAH 16	Magnitude of the habitual droughts
	VARIABILITY	IAH 17	Variability of the extreme droughts
		IAH 18	Variability of the habitual droughts
	DURATION	IAH 19	Droughts duration
		IAH 20	Number of days with null flow (12 values, one for each month)
	SEASONALITY	IAH 21	Droughts seasonality (12 values, one for each month)

In order to make the global interpretation easier, and for any of the three main components of the flow regime –habitual values, floods and droughts-, two aids are offered.

On one side, a meshed diagram for the simultaneous comparison of the indicators associated to the aspect under analysis (figure 2). This diagram makes possible an easy interpretation of the distance of the real value of each index –in red in the figure- to its natural value (always 1, following the afore-mentioned assumption).

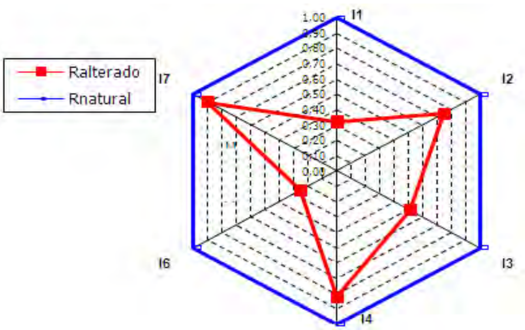

Figure 2 – Diagram for the simultaneous comparison of the indicators associated to the habitual data

On the other side, an index of global alteration (IAG) is calculated for each component –habitual values; floods; droughts-. The index combines the values of all the indicators used to evaluate any of the aspects considered for any component of the regime. The global index is calculated as the ratio between the area defined by the polygon associated to the altered flow regime (delimited by the red line in fig. 2), and the area defined by the polygon associated to the natural flow regime –logically linked to the area defined by the value 1 for all the indicators (blue-lined in fig. 2). A colour code has been established also for these global indicators, (fig. 3).

HYDROLOGIC STATUS: GLOBAL INDICATORS (IAG)				
HIGH	**GOOD**	**MODERATE**	**POOR**	**BAD**
0,64< IAG ≤1	0,36<IAG ≤0,64	0,16<IAG ≤0,36	0,04<IAG≤0,16	0≤IAG ≤0,04

Figure 3 – Criteria used to assign qualitative categories to the Indicators of Global Alteration.

It is essential to understand that the global indicators compare areas. Thus, they consider the square values of the indicators for the different components analyzed –habitual, floods or droughts-. Accordingly, the range assigned to each status is different –it follows a quadratic law-compared to the range used for the individual indicators.

4. WHICH ARE THE DATA REQUIREMENTS IN IAHRIS? WHICH ARE THE RESULTS?

4.1 Data requirement

The software was designed to generate results only when the user enters, at least, fifteen entire years of flow data, either daily or monthly values. This threshold was established on the assumption that at least fifteen years are necessary to base the analyses on a minimum set of information, so that the conclusions extracted are reasonable and correctly related to the extreme values and variability of the flow series.

Data are grouped in two types:

i) Series in the NATURAL regime: It contains data linked to the natural flow regime. A maximum of two flow series may be associated in any point of the analysis: one with monthly data and the other with daily data.

ii) Series in an ALTERED regime: It contains data linked to a flow regime different from the natural.

The software admits, for each point of the analysis, any number of altered regimes. The user should enter, for all of these, a maximum of two series: one with monthly data and the other with daily data.

4.2 Results

The type of information entered in the software determines, largely, its results (Martínez *et al.*, 2008). In particular, results depend on the data periodicity –daily or monthly-, and the simultaneous character of the natural and altered data being compared.

When the largest set of information is used in a point –natural and altered series of daily flows, with simultaneous registers-, the software offers:

a) For the characterization of the natural flow regime:
    - Interanual variability, classifying the years as wet, normal or dry, respectively if their annual water volume is situated in the upper quartile -wet-, the lower quartile -dry-, or the middle quartile -normal-.
    - Intrannual variability. For any type of year -wet, normal, dry- it calculates the monthly median volume for every month.
    - 19 parameters (numerical variables that allow the characterization of the most environmentally meaningful aspects of the flow regime): 4 for the characterization of the habitual values of the regime, 8 for the characterization of floods, 7 for the characterization of droughts.
    - Average flow duration curve.

b) For the characterization of the altered regime:

- Intrannual variability. For any type of year –wet, normal, dry, according to the criteria obtained with the natural regime- but using the dataset of the altered period, it calculates the monthly median volume for every month.
- 19 parameters (numerical variables that allow the characterization of the most environmentally meaningful aspects of the flow regime): 4 for the characterization of the habitual values of the regime, 8 for the characterization of floods, 7 for the characterization of droughts.
- Average flow duration curve.

c) For the characterization of the alteration:
- 21 individual Indicators -each of them assessing the alteration of a parameter-: 6 for the characterization of the habitual values of the regime, 8 for the characterization of floods, 7 for the characterization of droughts.
- 3 global Indicators -each of them assessing the alteration of a component; each global Indicators takes into account jointly the alteration of the parameters used for the characterization of that component-.

IAHRIS provides all these results, numeric tables and diagrams, ordered in reports, set as spreadsheets in an Excel book.

One of these reports is shown in Fig. 4.

ASPECT		INDICATORS OF HYDROLOGIC ALTERATION (IAH)							
		VALUE	CODE	DENOMINATION	HIGH 0,8< I ≤1	GOOD 0,6< I ≤0,8	MODERATE 0,4< I ≤0,6	POOR 0,2< I ≤0,4	BAD 0≤ I ≤0,2
HABITUAL DISCHARGES	magnitude	0,23	IAH1	Magnitude of the annual volumes					
		0,12	IAH2	Magnitude of the monthly volumes					
	variability	0,25	IAH3	Habitual variability					
		0,37	IAH4	Extreme variability					
	seasonality	0,54	IAH5	Seasonality of maximum values					
		0,01	IAH6	Seasonality of minimum values					
FLOODS	magnitude	0,81	IAH7	Magnitude of the maximum floods					
		0,99	IAH8	Magnitude of the effective discharge					
		0,83	IAH9	Magnitud of the connectivity discharge					
		0,54	IAH10	Magnitude of the flushing floods					
	variability	0,59	IAH11	Variability of the maximum floods					
		0,56	IAH12	Variability of the habitual floods					
	duration	0,52	IAH13	Flood duration					
	seasonality	0,80	IAH14	Flood seasonality					
DROUGHTS	magnitude	0,00	IAH15	Magnitude of the extreme droughts					
		0,00	IAH16	Magnitude of the habitual droughts					
	variability	0,00	IAH17	Variability of the extreme droughts					
		0,00	IAH18	Variability of the habitual droughts					
	duration	0,06	IAH19	Droughts duration					
		0,00	IAH20	Number of days with null flow					
	seasonality	0,00	IAH21	Droughts seasonality					

Figure 4 – Example: results of IAHRIS for an existing situation (Jarama River at Vado Dam, Spain)

5. HOW CAN IAHRIS BE APPLIED?

Time, experience and suggestions from the users will answer this question, but we hope IAHRIS will contribute to some of the following subjects, in a rigorous and objective manner.

Why using IAHRIS?

- To handle the scientific and the water management communities a tool specifically designed to help in the fulfilment of those WFD requirements associated to the characterization of the hydrological status of the water bodies.
- To quantify, objectively, the hydrological alteration caused by water abstractions on the natural flow regime.
- To interpret the impacts of the alteration of the flow regime on the integrity of the fluvial ecosystem.
- To serve as a tool for:
  - Assessing the alteration induced by different management scenarios on the natural flow regime.
  - In heavily modified water bodies, characterizing the optimum hydrological potential, i.e. the regime derived of the alterations linked to the strict consideration of the conditions that enhance the heavily modified character.
- To identify the elements of the flow regime most directly linked to the rehabilitation or recovery of the reach under analysis.
- To fix objective criteria, in order to establish priorities in the restoration of the fluvial ecosystems.

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CHAPTER 14

Workshops

BASIN SCALE REHABILITATION

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1. SUMMARY

The following is a summary of the group discussions at the Basin Scale Restoration for Fisheries Rehabilitation Workshop that followed the thematic sessions on Basin Scale Restoration for Fisheries Rehabilitation. The thematic session was very well attended with standing room only for much of the four hour period. The workshop participants included those giving oral presentations and other interested participants (see Appendix for list of workshop participants).

The objective of this workshop was to bring speakers from around the world together to discuss guiding principles on planning, prioritization and monitoring of fisheries and habitat rehabilitation at a basin scale. After a brief introduction, the workshop participants were divided into three smaller working groups to discuss key topics including assessments to identify restoration actions, methods of prioritizing restoration actions, and monitoring and evaluation. The goals of these breakout sessions were to reach some agreement as to the key challenges and guidelines for basin scale assessments, prioritization, and monitoring of restoration/rehabilitation actions. To facilitate discussion, we used responses to a questionnaire sent to workshop participants prior to the conference. In particular, a draft table (matrix) of monitoring parameters and the scale at which they were used was provided. A summary of each of the breakout groups is provided below.

The workshop, unfortunately, was cut short (<1.5 hours) due to some logistic changes in the Conference. Thus the breakout groups only had about 45 minutes to discuss these items before we reconvened and discussed as a larger group. In the end, the workshop attendees agreed that this workshop, while short, provided some initial ideas and discussion that could be used to

coordinate a more focused and longer workshop. The organizers are currently discussing a more focused follow up workshop to be held in 2009 or 2010. Below is a summary of discussions or key points of each breakout groups.

2. BREAKOUT GROUP SUMMARIES

2.1 Assessment Breakout Group (Coordinator Roni P.)

The assessment breakout group focused on filling out the table of measures, sites, reaches (Table 1). There was much discussion on what constitutes an “assessment” and we clarified that we were not trying to reinvent a rapid bioassessment protocol, but rather that our objective was to try and create a list of the types of physical and biological assessments typically used to assess conditions, and identify degraded habitat and restoration opportunities. We were also trying to determine at which scale various assessments are most appropriate.

It was noted that the table initially was not really set up quite right to achieve the above objective as the scale of measurement and the scale of inference are often different. For example, we identify barriers at a site scale, but the inference is at a reach or network scale. Thus we modified the initial table provided to reflect this with one column for the measurement scale and one for the scale of inference. We then listed types of assessments used throughout the world and indicated in each column the scale of measurement and inference. The following codes were used for scales: S= site, R = reach, N = Network, B = basin. A network refers to the stream network and contrasts to basin or watershed scale in that it does not include riparian and upland areas, but solely the stream network. It should be noted that this was an initial attempt and some follow up is needed to describe why certain scales are appropriate for specific measurements.

Table 1 - Draft list of type of assessments (measurement or parameters) and scale at which they are measured and their scale of inference (what at which results are applicable). S= site, R = reach, N = Network, B = basin.

Measurement/parameter	Measurement Scale	Inference scale
Dissolved Oxygen, Water Quality, Temperature etc.	S	R,B
Sediment	S,R	S,R,N
Geology	B	B
Gradient/stream power	S,R	S,R,B
Sinuosity	R	R
Morphology/mesohabitats	S,R	S,R
Barriers	S,N	R.N,B
Erosion/Deposition	R	R
Riparian including veg. structure	S,R	S,R
Hydrology/connectivity	N,B	N,B
Woody debris	S,R	S,R
Boulders/roughness	S,R	S,R
Land cover	S,R,B	R,B
Land use	R,B	R,B
Fish population	S,R	B
Fish abundance	S,R	S,R,B
Macroinvertebrates	S,R	S,R
Diatoms	S	S
Predators	N	N
Invasive species	S,R	S,R,B

2.2 Prioritization Breakout Group (Coordinator Steel A.)

The prioritization workgroup focused on identifying the most important criteria for prioritizing restoration actions across entire basins. We didn't discuss prioritization across smaller scales except with respect to collecting biological data.

We began with a short discussion about the role of funding in prioritizing restoration actions. Do the funding opportunities determine the priorities or do ecological priorities determine the structure of available funding? We decided to consider physical, social, and biological rationales for project prioritization.

The most important physical consideration should be connectivity and this should be combined with data on geomorphological status. Connectivity should be considered with respect to four dimensions: (1) barriers to biological migration; (2) barriers to the downstream movement of wood, sediment, and water; (3) connectivity between high quality habitats or refugia habitats; and (4) lateral connectivity. The data required for connectivity-based prioritization schemes include historical maps and remotely sensed data.

Data for analyzing the social dimension of restoration prioritization includes stakeholder inputs and identification of social constraints (such as cities). Stakeholder input might include asking stakeholders about which problems or areas they would like to see tackled first. The social dimension of restoration prioritization also includes education about the reasons for and benefits of restoration. Public education is a form of outgoing data.

Biological data are also critical for prioritizing restoration actions. Biological restoration priorities should begin with a list of species of particular concern or species historically present. There may be historical abundance records to support biological prioritization schemes. An assessment of limiting habitats, by species and life stage, should also fold into the biological restoration priorities. In many cases, life cycles models may be required to identify bottlenecks in the population performance and restoration of the habitats that support these particular life-stages should be a high priority. Maintaining and restoring biodiversity are also priorities. Prioritizing for biodiversity could happen at multiple scales and would require data on the distribution of a wide variety of species.

2.3 Monitoring Breakout Group (Coordinator Gregory S.)

The monitoring breakout group attempted to use the matrix (table) of measurements and the spatial scales at which parameters should be measured. Throughout the discussion, the connections between ecological assessment and monitoring made it difficult to focus solely on monitoring. We discussed the links between the fundamental questions being asked and the scale at which those questions are answered. Because of the shortened time available for our discussion, we were just beginning to fill out the matrix when we had to end the discussion and reconvene with the larger group and were not able to fully discuss or develop a table of monitoring parameters. The following text highlights the key points discussed by the group.

The scale of monitoring is determined by the ecological question being asked. Commonly the questions addressed by monitoring are determined by the local restoration project. In these cases, there is a tendency for monitoring to be focused more on smaller spatial scales, such as the restoration site or reach, and may overlook important contexts at larger spatial scales. Restoration or monitoring focused on a single species or process is likely to provide a one-dimensional and inherently biased analysis. It is always important to determine whether species or communities require larger scales for critical life history requirements or processes. Monitoring only at the site scale is vulnerable to the “Magnet Effect”; in which community composition or species abundance reflect local attraction rather than changes in communities or populations. In general, monitoring should be expanded to at least the next largest scale greater than the restoration project and should always address the overall goal and objectives of the restoration actions.

Independent of scale of restoration, it is important to assess existing conditions and causal factors at the scale of the catchment. Regional assessments often identify limits, barriers, or constraints. When ecological assessments of basins or large areas have provided the basis for restoration efforts, monitoring is more likely to at least acknowledge linkages to large scales and even conduct monitoring at appropriate physical or biological scales. If working in very large basins, assessment, prioritization, and monitoring may need to be based on sub-basins because of the difficulty and limitations of measurement and analyses at extremely large spatial scales.

Even when monitoring the mainstem of a large river, understanding the effects of restoration is more likely if stressors and ecological conditions in adjacent subbasins have been identified. Ecological conditions at these large scales can have major influences on the outcomes of restoration. If you have good conditions in the basin, ecological processes and immigration from the surrounding areas may accelerate and enhance the responses to restoration. In a similar manner, responses to restoration may be dampened or negated if the basin has been extensively degraded and detrimental processes continue to degrade a restoration site and colonization from the surrounding areas is minimal.

The breakout group noted that it is critical to link a restoration priority or question to the anticipated or desired outcome with an explicit mechanism. If this mechanism is not stated and addressed through the monitoring measurements, the outcomes may be misinterpreted. The scale of monitoring must be consistent with the mechanism responsible for the ecological response to the restoration practices. The group emphasized that large systems inherently are complex and the existing conditions often reflect multiple stressors. Our restoration actions and monitoring are more likely to be effective and successful if we can address multiple stressors that have caused the ecological change. The group also noted that the scale of monitoring depends on pattern of stressor and scale of the ecological response. In addition, it was noted that, to be useful, the measurements and scale need to explicitly address the objectives and key questions of the monitoring.

The group discussed the distinctions between monitoring individual restoration projects versus multiple projects versus larger collective programs of agencies or NGOs. The scale of monitoring tends to be smaller and more restricted for individual projects. This may also be true for monitoring of multiple projects and agency programs unless they have been associated with prior assessments of larger spatial scales.

The scale and complexity of monitoring depend on who you are and what resources available. It is better to do fewer monitoring projects but do them well rather than conduct many projects that are less effective or statistically less valid. It may be better to expand the scope of inference by coordinating monitoring efforts to include more project-level replicates. Leaders of the National River Restoration Survey in the Unites States suggested development of regional monitoring banks, in which small projects would contribute a small portion of their funds to a collective “bank”. This collective bank of funds could then design rigorous monitoring programs with robust experimental designs and adequate replication and spatial scales to evaluate the effectiveness of the major and most commonly implemented restoration approaches in the region. The group did not have adequate time to discuss this mechanism but noted that collective efforts may be required to develop more effective monitoring of aquatic restoration at appropriate spatial scales.

RIVER RESTORATION: A MEASURE TO DELIVER EU DIRECTIVES OBJECTIVES?

Coordinator: Fokkens B.[1]

[1] Rijkswaterstaat – Centre for Water Management NL/President of the ECRR

1. SUMMARY

1.1 Introduction by the chairman

In a number of reports the the EU has concluded, that River Restoration measures, often wetland restoration measures can contribute to the implementation of the EU directives. But at the same time a number of questions were raised about the role of river restoration for the implementation of the directives. These questions deal mainly with river restoration in relation to river basin management, protection of wetlands in relation to water quality and quantity status and the contribution of restored sites to the environmental cost recovery.

For the implementation of the Water Framework Directive, EU member states must provide an assessment of the pressure and impacts on the hydro morphology of surface waters. Water bodies identified as at risk of achieving "good ecological" status" must be restored to this standard by the year 2015 subject to derogation and designation criteria. Water bodies designated as Heavily Modified water Bodies will achieve the objective of "good ecological potential" which may require mitigation measures to improve existing habitat conditions.

1.2 Discussion round

The discussion was about the following statements or questions:

- River restoration should be based on an integrated, towards all functions, ecosystem approach
- The European Water Directives are based on an integrated, towards management, river basin approach
- The development of a coordinated approach to river restoration is a good measure to deliver River Basin Management Plans

However, if river restoration is to be used as an improvement measure for hydro morphology, a number of important knowledge gaps need to be addressed. The effectiveness of restoration and habitat creation, often in relation to reducing flood risk, or in relation to restoring environmental flows and application at the catchments scale is largely unknown. Information about the ecological benefits of river restoration is still limited. Identifying restoration priorities at the catchments scale requires a good coordination of existing delivery and funding mechanisms and close cooperation between stakeholders. There is time to address these problems before and during the process of making River Basin Management Plans.

The spatial coherence on different relevant scale levels is not covered in the EU directives. This causes local problems, concerning connectivity and isolation of sites and disturbed gradients and natural fluctuations and dynamics. And regional human influence by constructing infrastructure without sufficient mitigation measures causes migration problems. And on a larger scale the impact of constructing reservoirs and dams can be disastrous for migrating fish species. And on a fly-way scale, there should be suitable stopover points for specialised feeders.

The sustainable maintenance of biodiversity is especially the objective of the combined implementation of the WFD and the Bird and Habitat Directive (BHD), especially in the Natura 2000 sites. The WFD implementation deals strongly with the reduction of nutrients and micro pollutants. While River Restoration is based on, the integrated eco-system development approach. This difference gives obvious nice opportunities, but also some threats with respect to an effective joined implementation of both River Restoration Measures and the EU directives.

River restoration sites need not always exactly overlap Natura 2000 sites. And for that reason the ecological and physio-chemical targets may differ in one (protected) site. For example natural nutrient levels in shallow water bodies are often higher then the EU standard levels, with a high carrying capacity as a food source for fish and water birds. Furthermore groundwater habitats or species are not included in WFD targets and the unsaturated groundwater zones are insufficient covered in the WFD.

There was concluded that the WFD/BHD and ecological river restoration measures are mutually very much supportive to each other. The WFD water quality restoration to ecosystem targets is unique. While the implementation of many river restoration measures experiences can be quite well used for the WFD implementation at policy (strategy) and practical level (management plans). But “blind” implementation of the WFD measures can harm the functioning of an ecosystem. But there are also other For example groundwater habitats, in relation to, both the unsaturated and saturated zone, might be badly affected by implementing the WFD. There where the EU directives have a strong legislative basis, there is quite some flexibility possible in the implementation River Restoration Measures.

2. ROLE OF THE WORKSHOP

The workshop was held to get recommendations and ideas for implementation of these ideas by:

1. The ECRR for further development of their strategy, plans and activities
2. The EU and Member States for the development of River Basin Management Plans

3. PARTICIPATION

There was an active participation by all participants in the discussion and in formulating the recommendations. This active participation was strongly based on the recognition of the implementation tasks of the EU directives and the conviction that river restoration (projects) can be of a great help for this. Most participants were from EU-countries. But there were also a few participants from countries neighbouring the EU and one participant from Malaysia.

4. CONCLUSIONS AND RECCOMANDATIONS

1. The role of the ECRR should be to form the link between the EU and the professionals who have to apply the WFD and related directives. The ECRR should collect questions and the problems from the different member states of the EU and should reflect on these by reports to the EU, but also by disseminating information on good experiences with river restoration (projects) as a possible solution to these problems.
2. The role of the ECRR: an advisory body, not a decision making body. Therefore the ECRR should assist EU member states in implementing the WFD using river restoration where it is the most cost effective way to obtain good ecological quality. At the same time the ECRR should service a wide audience, including NGO's and the public on the wide benefits of river restoration (biodiversity etc.).
3. The ECRR should look for more and stronger cooperation with NGOs in order to assure implementation of projects through commitment of local communities and stakeholders towards river and wetland and floodplain restoration
4. The ECRR should prepare a document to be send to the EU commission presenting selected good river restoration projects (practices) which can prove the achievement of the WFD's goals in the light of socio-economic benefits they can provide to the society

(economic evaluation as a pillar to prove the goodness of river restoration.

5. The ECRR could identify tools and project files needed for river, floodplain and wetland restoration activities, which at the same time could be used for the implementation of the program of measures for implementation of the IRBMP.
6. The ECRR should stress that river basin management plans should be developed in accordance to the priorities of the region and therefore can and must include wetland restoration activities as a part of river restoration. Wetlands restoration could contribute to the regulation of nutrient balance and thus support habitat development. Flood protection management activities, including river restoration activities on the base of selection of relevant sites suitable for wetland restoration, should be included in the management plan for the river basins.

5. OPPORTUNITIES FOR FUTURE CO-OPERATION

Most participants had the opinion that the ECRR is a perfect platform for a more intensified cooperation. This can be in different ways. Within the framework of the present strategy and activities of the ECRR or with an adjusted strategy, that should focus more on the implementation of the WFD PoM. More intensified could f.e. mean a bi-annual river restoration conference, more regional seminars, working groups for specific topics, (pilot) demonstration projects, best practices data base, toolkit on river restoration and river management techniques etc.. And through the ECRR organised meetings between countries, organisations, institutions and individuals other contacts will develop easier.

WORKSHOP PARTICIPANTS: About 15

HOW MUCH SEDIMENT IS NEEDED FOR A WELL FUNCTIONING RIVER SYSTEM?

Coordinators: White S.[1], Brils J.[2]

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1. SUMMARY

Within the Water Framework Directive (WFD) there is little explicit mention of sediment and the role it may play in achieving good ecological and chemical status. However, at a round table event organised by SedNet in 2006 river basin managers from 4 river basins around Europe (the Elbe, the Danube, the Humber and the Douro) identified sediment related issues as crucial to successful achievement of the WFD objectives. The issues in each river basin were different – from concerns about lack of knowledge of sediment budgets, to sustainable extraction rates, to remobilisation of contaminants in sediment deposits and the impacts of managed retreat to allow for increasing sea levels.

There is a need for more evidence (system understanding) to support sediment management decisions in relation to both WFD and other legislative drivers such as the Birds and Habitats Directive. A review of all UK river basins, carried out by ADAS in the UK (Collins & Anthony, 2008) identified that most passed the Fisheries Directive guideline value of 25ppm mean annual suspended particulate matter (a form of sediment) concentration – based on available data. However, it is known that many of these river basins have sediment related issues and problems. There may be at least three reasons for this:

1. Inadequate temporal scale of data – routine monitoring is at 4-week time steps, whilst bulk sediment transport is highly skewed to high flows.
2. Inadequate spatial resolution of data – data may not be collected at places most relevant for increasing our system understanding.
3. Meaningless guideline value in terms of whole ecosystem functioning - if any numerical target is to be set then it may need to

take into account the highly dynamic nature of rivers. Furthermore it needs to be differentiated by river type, to be inclusive of the whole river ecosystem and may need to look at the continuum of sediment quantity gradient and biological response.

So, given the complexity of sediment supply and transfer, should we be monitoring sediment load at all – or should we first rather look more fundamentally at the role of sediment quantity – in relation to quality – in river system functioning (to increase our system understanding)?

The workshop in Venice set out to address these themes through a sharing of experience and practice from an international group of participants. Key points from the workshop were:

- In Europe, White and her team (White et al, 2005 and Becvár, 2006) have looked at sediment load in relation to flow exceedance values for 44 major river basins. Those rivers which are not predominantly groundwater fed show a clear tendency to transport the majority of sediment in high flows. On average for the European rivers studied, 62.9% of sediment moves in the top 10% of flows. The exact percentage changes from year to year, from river to river and even from location to location on one river. **Monitoring should reflect this, but does not currently do so.**
- Work has been done in the USA on characterising sediment concentration in relation to different flow exceedance values. Analysis has been done by ecoregion and by stable versus unstable reaches (Simon et al, 2004, Simon & Klimetz, 2008, Simon & Klimetz, in press). **It is clear that great variation in sediment concentration is seen for rivers in different environmental contexts and this must be borne in mind when considering sediment "target values"** (see for example, Cooper et al, 2008).
- Sediment is just one of a number of stressors which affect the ecological status of our water bodies. An integrative approach is needed if we are to achieve WFD goals. **Sediment MUST be included in this integrative approach.**
- We do not understand the cause-effect linkages between sediment and ecosystem health. Should we be looking at dose-effect response relationships? Or is it more important to think about exposure duration? Can we define an exposure time for which a certain sediment concentration should not be exceeded for a certain river or location? **Further research is needed on the sediment quantity related implications for ecosystem functioning.**
- Sediment is a natural and necessary part of healthy functioning aquatic systems. The problems largely arise when there are anthropogenically driven changes in sediment supply, which can

either increase or decrease load. **Work is needed to enable quantification of natural versus anthropogenic sediment flux.**

- Sediment has historically largely been considered as an end of catchment issue (the catchment sediment yield or sediment flux) in relation to e.g. sedimentation of reservoirs, dredging. **We need a much clearer understanding of sediment budgets across river basins, including variability in supply over the short, medium and long-term** (see for example White et al, 2006; Walling and Collins, 2008).
- There is little evidence that historical monitoring of sediment concentration internationally has provided the information required to make informed management decisions on sediment management in relation to ecosystem functioning. **Well designed and focused monitoring is required in which sediment forms part of an integrated monitoring programme.**
- The predicted changes in climate for much of the world suggest that the channel forming flow is likely to change in the short to mid-term. This means that many rivers will begin to remobilise, cutting into deposited alluvial material in flood plains. Such river bank erosion will enhance sediment concentrations at least locally and will change sediment load and flux budgets. **The implications of changing river flow patterns on sediment supply and transfer are not well understood and require further research.**
- The focus of this workshop was largely on sediment quantity. However, it was acknowledged that we probably know even less about the role of sediment in binding, storing, releasing and recycling pollutants. **The remobilisation of historical sediment deposits and associated contaminants from floodplains was considered to be a particular issue of concern**.

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ASSESSMENT OF RIVER ECOLOGICAL STATUS: SHADOWS AND LIGHTS OF THE WFD

Coordinators: Boz B.[1], Schipani I.[1], Bizzi S.[1]

[1] Italian Centre for River Restoration (CIRF)

1. WORKSHOP ORGANIZATION

Considering the number of participants (10 persons), the discussion has been organized following these steps:

1) a member of CIRF introduced the main issue with a very short (not more than 5-8 minutes) presentation (plenary session)
2) every issue was discussed by all participants comparing directly each others experiences.

2. MAIN ISSUE

Considering the complexity of the argument the discussion was limited to 2 main issues (spending about 1,5 hour for each).

2.1 Importance of hydromorphology elements in WFD

According to some interpretations, the ecological status classification system introduced by the WFD gives marginal importance to hydromorphology, in particular because the hydromorphological elements are considered only for surveillance monitoring and for the "high" status class of the ecological classification system (WFD, All. V, sec. 1.2). The assignment of water bodies to the "good status (or potential)" class is only made on the basis of the biological and physico-chemical monitoring results (while the classes "sufficient", "poor" and "bad" status only rely on biological quality elements). Such approach might leave rivers defenceless in front of hard engineering interventions and undermine the integration between the WFD and the Floods Directive (2007/60/EC).

According to other interpretations, instead, the limited role of hydromorphological quality elements in the classification procedure does not constitute a problem because all morphological alterations are assumed to be recoded by the biological communities and, in particular, because biological indicators presently used are sensitive enough to detect these impacts.

Questions

To what extent, this second assumption can be assumed to be true? Or does the risk of a misleading assessment exist?

If it does, what kind of solutions can be proposed?

Output

According to the majority of participants, even if it does make sense to measure biological, hydromorphological and physical chemical indicators separately, the limited role of hydromorphological quality elements in the classification procedure does not constitute a real problem. In fact, in general, all morphological alterations are assumed to be recoded by the biological communities and biological indicators can be sensitive enough to detect these impacts.

On the other hand, the scientific community and the WFD implementation working groups have to be very careful in choosing and defining the right biological indicators and, in particular, their reference conditions.

About the kind of biological indicators to use there was not agreement between participants:

- some of them underlined that biological indicators response differently to environmental pressures and that it’s not easy to discern the causes of impacts. So the approach of WFD, that establish to consider fish fauna, bentic macroinvertebrates and acquatic flora, seems to be correct;
- according to other, if correctly defined, only one biological indicator, like in particular fish fauna, would be able to detect most of hydromorphological alterations.

Consistently with the idea that biological indicators can be sensitive enough to detect impacts, according to this group of participants the effort required by WFD to define hydromorphological indicators to use only for surveillance monitoring and for the "high" status class of the ecological classification system (WFD, All. V, sec. 1.2), have to be considered quite excessive.

Other participants though theoretically agreed using biological indicators as the main descriptors of the ecological status, stressed the risk of misleading assessment due to poor monitoring techniques related with biological survey. They are not always relevant description of a river stretch as they are based on site-specific survey. Eventually the pointed out how remote sensing data used to develop hydromorphological indexes can cope better with this issue.

2.2 Integration approach in the WFD classification system

Another interesting point to discuss is the potential WFD's low propensity to integrated assessment in the classification of the ecological status: it could be argued that integration in the classification system is lacking both among the three quality elements - biological, physico-chemical and hydromorphological - and among specific sub-elements of each quality element. A " worst-wins" (OO-AO: One-Out All Out) approach was chosen (WFD, Annex V, 1.4.2.i) in the assessment, entailing the risk of imposing recovery costs not proportionate to the achievable ecological improvement and significantly increasing the risk of misclassification.

<u>Questions</u>

What are possible pros and cons of the OO-AO (One-Out All Out) principle in the assessment of the ecological status? Might a compensatory approach be a valid alternative? Would it be practicable within the WFD implementation process? To what extent has this issue been discussed so far?

<u>Output</u>

According to the majority of participants the use of OO-AO (One-Out All Out) principle in the assessment of the ecological status according to WFD can be justified.

In fact, even if the risk of misclassification exists, this approach is consistent with the *principle* of *caution* and can be very stimulating to solve immediately the worst problems; it's a good instrument to focus the most important ecological problems and to give them priority during the construction of the action plans.

There was agreement anyway to recognize the need to compare different assessment methodologies. Analyzing how dissimilar assessments can drive differently the implementation of management and restoration policies.

So, the use of this principle have to not to be extended to the integration of all the sub-elements of the classification system and it's not necessary the only approach to follow.

Also the compensatory approach can be useful, in particular for the integration of specific sub-elements of each quality element.

USEFUL DOCUMENTATION

- The Water Framework Directive: a soup bubble? An integrative proposal: FLEA (FLuvial Ecosystem Assessment) (Nardini *et al. 2008*).
- 'Natural' rivers, 'hydromorphological quality' and river restoration: a challenging new agenda for applied fluvial geomorphology (Newson and Large 2006).

WORKSHOP PARTICIPANTS: 10

CHALLENGES TO STAKEHOLDER ENGAGEMENT IN DECISION-MAKING PROCESSES IN RIVER RESTORATION IN EUROPE

Coordinators: Nardini A.[1]*, Baker C.*[2]

[1]Italian Centre for River Restoration (CIRF)
[2]Wetland International

1. INTRODUCTION

Here below is a very synthetic summary and additional remarks from the following Workshop on stakeholders' engagement which further built upon the presentations of the morning sessions.

I adopted a telegraphic language because time is very limited and we need to read a lot of material just capturing the essence. I hope this does not prevent readers from adequately understand contents.

2. KEY FINDINGS

- Engage, entrust stakeholders, but don't lose their trust, otherwise the process will break down and hardly recover. Hence it is advisable not to set too challenging goals.
- A DM participatory process needs funding to be successfully conducted and to be kept alive afterwards: a good practice is to draw them from who is damaging the river ecosystem while taking advantage of it (e.g. hydropower plant).
- The "public" needs to see that their inputs are indeed taken into consideration; if not, trust is lost.
- People can wait to see actions implemented, but ….not too much.
- A structured process may possibly overcome the un-satisfaction of stakeholders if actions are not implemented as planned, by examining and explaining the underlying reasons.
- But different cultural and socio-economic contexts have different needs. In particular, in developing countries institutions are typically weak and have little power; grass root participation is strong, but the time horizon of people is very short: one year may seem an excessively long time period. Participatory process need to be fully geared to the context.

- Uncertainty: the prediction of effects of a given course of actions is affected by uncertainty; sometimes, people prefer “experts” who make credible statements based on their long time experience, rather than “objective” scientific statements based on the concept of confidence intervals which may give the impression that …everything is possible and prediction useless. However, uncertainty needs not to be hidden; rather, developing good ways of communicating is key. And some nice ideas have been shown in the presentations.
- Uncertainty also affects the participatory dimension of the DM process itself: receiving reasonable assuring information about the future of the process stimulate people to get engaged, while an obscure future is a strong des-incentive.
- There still is a weak link between the participatory and the systemic/scientific based dimensions.
- Alternative solutions: they are an unavoidable feature of DM process that almost always involve conflicting objectives-interests. A key stage of DM process is hence the evaluation of alternatives. This should be based on a Multicriteria approach. Cost-benefit approach can complement it, but the pitfalls of economic valuation must be carefully avoided.
- Before evaluation can be undertaken, objectives must be specified in such a way that their achievement can be measured, while in practice they are often not well identified, as sometimes conflicting objectives are mixed up (e.g. rehabilitating a river to enhance the ecosystem and ….navigation!). It is probably impossible to actually measure all non monetary values associated with RR projects; however, it is possible to specify each objective (by building a value tree) in terms of attributes and indicators so that different situations (present or future) can be described to such a degree that the involved stakeholder becomes able to preferentially rank them, in view of that objective, and trust his own ranking.
- In different cultural contexts, there is however need for a two ways daring communication effort: first, understand and speak the language of stakeholders (possible based on emotions, visual expressions,….), then lead stakeholders to face a choice problem where different alternative solutions are compared under several points of view, and then again translating into their language the predicted effects.
- The scope of river restoration definitely is to enhance rivers (“Nature” objective); but… need for, and advantage in, looking at other VERY important objectives: Hydro-geomorphological Risk reduction, Recreation enhancement, Costs minimization, and others.

3. FURTHER REMARKS

We need to convince Decision Makers on the desirability of River Restoration; this means:

- showing a positive balance between pros (“Benefits”) and cons (“Costs”)
- tackling interest conflicts: this calls for developing and applying a significant negotiation capability
- showing that RR is KEY to solve the risk problem (i.e. improving Nature objective may lead to improving the Safety objective as well), provided that an integrated, multiobjective, transdiscplinary design is undertaken from the beginning.

There still is a deep lack of experiences on overall projects evaluation: we need key “simple” questions, not only on the achievement of objectives; e.g. something that goes on the following lines:

- Have we done what was planned?
- The stated objectives have been (or will be) achieved?
- Identified problems have been (will be) solved? (or new problems created?)
- Was it worth?

Perhaps, the conclusion is that for many RR projects Costs simply exceed Benefits; but this can be reversed if we spend less in works and exploit more the self-rescuing ability of rivers (approach already applied for instance in Australia).

Figure 1 – The case of Sangro river (Castel di Sangro, Abruzzo, Italy): completely artificialized in the '80s, after just one significant flood in 1991 almost dismantled most of works and, after a few years, recreated interesting habitat and geomorphological diversity with no interventions at all (these are however envisaged to accelerate the renaturalization process).

In the end, values awakening, Stakeholders involvement is key; but not enough:

- We need a comparative, conflict-resolution-oriented, evaluation of Alternatives and this requires the capability to represent Stakeholders' satisfaction associated with alternative courses of action: yet, there is too little experience in this!
- While planning, there is need to address how actions will be implemented (e.g. allow diffused flooding: who will pay damages?), otherwise decisions will remain on the paper…..

FLOOD AND GEOMORPHOLOGICAL RISK ALLEVIATION MEASURES AND RIVER RESTORATION – A GOOD AND EFFECTIVE DUO?

Coordinators: Negri P.[1], Bakonyi P.[2], Goltara A.[3], de Jalón D. G.[4], Menke U.[5], Nijland H.[6]

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[6] Ministry of Transport, Public Works, and Water Management , Rijkswaterstaat, Programme Directorate "Room for the River", Utrecht, The Netherlands

1. BACKGROUND

Between 1998 and 2004, Europe suffered over 100 major damaging floods, including the catastrophic ones along the Danube and Elbe rivers in summer 2002. Severe floods in 2005 further reinforced the need for concerted action. Since 1998, floods in Europe have caused some 700 deaths, the displacement of about half a million people and at least €25 billion in insured economic losses.

In addition to economic and social damage, floods can have severe direct environmental consequences, for example when plants storing large quantities of toxic chemicals are inundated.

At the same time, especially in Mediterranean rivers, damages related to the geomorphological processes of rivers, both natural and induced by morphological alterations (e.g.: gravel abstraction and interruption of sediment transport inducing deep riverbed incision) are a major concern. Together with floods they are on the one side a cause of heavy economic losses, on the other of severe impacts on river ecosystems, due to the traditional approach of risk control through defence works and "hard" engineering interventions. This approach has clearly shown its limits, both under ecological and economical points of view, and climate change adds to the urgent need of different solutions.

Some significant experiences have been carried out, integrating river restoration and risk alleviation, adopting what was labelled as the “more room for the river” approach. Nevertheless, this is still far from being a standard approach in basin planning and management. There is a need for a clearer assessment of its benefits, further dissemination of knowledge and best practices and also the development of new tools and methods to overcome critical implementation problems. This appears to be strategic for river restoration in Europe, since, despite the WFD requirements, “stand alone” restoration/rehabilitation projects are very rarely financed, whereas most funds are allocated to risk alleviation measures. This is especially true in the case of densely populated river catchments where the implementation of river restoration measures for flood and hydromorphological risk alleviation is probably the only way of attaining a better ecological status of water bodies.

2. EXPECTED OUTCOMES

This workshop would like to give a contribution towards a more widespread and effective integration of river restoration into river basin planning and management measures for flood and geomorphological risk control. As a result of the discussion, we would like to highlight what are the positive aspects and successful experiences of this integration and what are the difficulties and main challenges still to be solved when trying to combine river restoration and risk alleviation measures, implementing a “more room to the river approach”.

3. STRUCTURE OF THE WORKSHOP

The workshop is divided in 4 steps:

1) Introduction
2) SWOT analysis
3) SWOT recapitulation (during coffee break and informal presentations of case studies)
4) From SWOT to strategies

Step 1 - Introduction

The first part of the workshop will be devoted to an introduction of the subject “river restoration and flood/geomorphological risk management”. Main issues and some examples will be concisely illustrated, also taking into account discussion and results of the preliminary Italian-Spanish workshop on the same subject carried out in June 2007.

Step 2 – SWOT analysis

The participants will be divided by the facilitators in 4 small groups in order to foster the expression of ideas and opinions by everybody. Ideally, there will be cross-functional teams that represent a broad range of perspectives (e.g.: biologists, engineers, planners, public managers, politicians, farmers). The 4 groups will be sitting around a table together with a facilitator and a reporter in charge to write down the minutes. Every table will represent one (or two) aspect(s) of the SWOT analysis (Strength, Weakness, Opportunity, Threat) and every working group should work separately on a specific part of the SWOT analysis for 15 minutes. The facilitator will lead the discussion and the reporter will write the key outcome of the analysis. At the end of the 15 minutes, the groups will be swapped to a different table i.e. to a different SWOT component. The facilitator and the reporter will remain seated at the same table in order to collect the results of the discussion by the 4 groups on the identical issue.

Step 3 – SWOT recapitulation

The facilitators together with the reporter will summarize the results of the SWOT analysis. The objective is to identify the most important and significant issues emerged during the discussions with the 4 groups. This will be done preparing a slide with a bullet point list for each aspect of the SWOT.

Step 4 – From SWOT to strategies

There will be a presentation of the 4 slides of the main topics of the SWOT analysis in order to reach a common agreement. After that the SWOT will be used as input to the creative generation of possible strategies, by asking and answering each of the following four questions:

- How can we use each strength?
- How can we overcome each weakness?
- How can we exploit each opportunity?
- How can we defend against each threat?

The debate will be open but moderated by the facilitators, in order to keep the discussion on topic. For each question, in fact, only 10-15 minutes will be available. The facilitators will draw up the conclusions for common understanding and agreement.

4. RESULTS

The discussion conducted among more then 20 people participating in the ECRR conference has been very fruitful and different vision and ideas have been shared and debated. The main results are described using a table divided according to the 4 keywords of the SWOT analysis. The table summarised the main issues identified and some possible answers.

Issue	Strengths	How can we use each strength?
Strengths:. **Aspects that are helpful**	o Water Framework Directive 2000/60/CE and Floods Directives o Climate change awareness (easier to convince people and to obtain funding) o There are good examples of successful integrated projects o Several funding opportunities for RR and flood mitigation projects, EASIER to obtain for integrated projects o Higher awareness of the need to give more space to rivers, especially just after catastrophic events	o More efficient and more effective working (or project) teams o Better selling of the message to the audience o More recognition at (EU) policy level o Thrust-building and changing attitude towards other disciplines; better start for future projects.

Issue	Weakness	How can we overcome each weakness?
Weaknesses **Aspects that are harmful**	o Communication: - social perception and different languages o Different priorities and goals o Tradition engineering approach has more weight	o Proper information to be delivered to the right audience and with the right attitude o Need for an adequate communicator; thrust and continuity are important issues here. o Good education is needed right from the beginning e.g. this includes teaching social sciences to engineers. o River Basin Management gives priorities, but consensus-finding is important at the catchment level o RR cannot stand a failure in recent times; we need to plan and implement good projects that get a broad support from the public. (This means that exchange information on small or even failed projects is also important in order to not repeat the same mistakes twice). o Broadening of project teams and searching for an integrated approach instead of a sector one is essential. To achieve this, education is a pre-requisite.

Issue	Opportunities	How can we exploit each opportunity?
Opportunities **External aspects that are helful**	o Sustainable & no regret measures, better design o Better understanding of each other o integration of disciplines lead to more realistic and practical advice o multiple objectives lead to a better acceptance o One open transparent organisation for river management	o RR should play an important role in the implementation of national measures within the WFD; o Make projects symbolic to others e.g. by building up a European database of highlights/best practices/ failed projects or examples of smaller projects o RR should use more publicity and PR opportunities (e.g. more publications, TV programmes, and others) o Maybe the installation (development) of a quality label or trademark would be useful for addressing politicians and decision makers for funding of projects. o Society can better face climate change by jumping into the EU climate programme.

Issue	Threats	How can we defend against each threat?
Threats **External conditions which could do damage**	o Cultural. Negative perception of the people that live close to the river. Fear of public to soft measures. Overtrust on engineering Infrastructures. Lack of knowledge as people do not understand the risk of flooding o Marked driven decisions: Policy, subsidised funding (agriculture) o Economic constrains. Cost recovery is difficult (no way of giving a price to Nature). o Intensive land use. No space availability. Conflict in more developed floodplains. Urbanization and building cause increase in runoff. Corruption and lack of local control o Due to prioritisation of river restoration associated with flood mitigation measures, RR will never be an independent goal o Society thinks that RR and FD are different problems o False River restoration Projects (only words) o The possibility of not matching both objectives	o Food demand in the world will increase; at this moment about 50% of the Europeans live in floodplain areas. o Insurance agencies will play an important role on how living in a floodplain is valuated. o Flood Risk Management will be carried out also in the future, especially in order to cope with climate change. o River Restoration can deliver or delivers an extra (or added) value

5. CONCLUSION

From the workshop it is possible to draw some general conclusion. Although there are still some fears regarding “soft interventions”, it emerges from the discussion that RR can play an important role in the future especially for meeting the WFD requirements and for facing the water availability reduction due to climate change. A possible synergy between river restoration and flood defences will be possible if the land and urban planning allow more space for the rivers. A key issue would be a proper communication strategy at different levels from local communities to national and European level as there are already some successful projects. This could be one of the next challenges of the ECRR. Of course this workshop is just a starting point and the discussion is open to new debates but hopefully this is a productive contribution towards a better integration between river restoration and flood.

MONITORING OF RIVER RESTORATION PROJECTS

Coordinators: Mant J.[1], Peter A.[2]

[1] River Restoration Centre (RRC), UK
[2] Eawag, Switzerland

1. WHAT IS HAPPENING AT THE MOMENT?

Monitoring of river restoration projects in general perceived to be poor. Overall most groups (irrespective of country seemed to suggest that a maximum of 10% of projects have any form of assessment). However, it seems to be a general tendency for increasing assessment in different countries.

However, there did seem to be a discrepancy in view points depending of whether scientists or managers were being asked the questions. This may be because view points on what is appropriate monitoring can differ widely. Thus for example, manager may believe that a high percentage of projects actually have some form of post project appraisal.

There is also some variability between countries:

- China - monitoring is based around a few specific places mainly in Shanghai and Being. In general this is focussed at looking at water quality issues.
- Italy - very few restoration projects have been completed on the ground. In most cases projects are funded through LIFE money and therefore although project numbers may be limited to around 10 -15 projects perhaps as many as 80% have some associated appraisal.
- Denmark (but also many other places) there is a lot of pre-project modelling and aspirations for multi-objective projects - in reality these feasibility assessments are rarely followed up after the project and even when data has been completed this is not always effectively analysed to answer original objective questions. May be 500 restoration projects but general small and fish habitat related projects.
- Belgium – Few projects are monitored and generally related to fish migration issues. Most monitored as small scale although trying to introduce new initiatives

- England and Wales – 30-35% of project may have some monitoring but often this only related to one indicator or is a simple assessment such as some photos.
- Scotland – similar to the England but now centred a lot on fisheries monitoring.
- Israel – No monitoring
- Germany – the main problem here seemed to be getting hold of past data for comparisons. There are no standards.
- Australia – not much monitoring instead tends to be theoretical discussion of aims
- US – lots of monitoring but tends to be for river status and is not generally linked to restoration sites or monitoring that takes account of pre- and post changes in conditions.
- Spain – starting to develop some methods and indicators and approaches for monitoring restoration projects but only few projects as yet completed. Tends to focus on water quality and macro-invertebrate assessment (and invasive plants in Catalonia). There is no national framework with each region developing their own protocol. In Catalonia a monitoring assessment tool will be developed within the next few months.
- Finland – Much restoration completed but hardly any has been monitored
- Switzerland - projects with monitoring are increasing. Beside ecological indicators stakeholder participation is also appraised.

This discussion highlighted that who completes the monitoring varies considerably from one country to another.

In many countries consultants tend to complete monitoring. In Denmark there was a follow through from the group charged with instigating the project which resulted in consultants or environmental agencies completing any pre and post project monitoring.

In China, Portugal, Italy, and USA government agencies were far more likely to instigate protocols and complete the assessments with the first 2 countries focusing on water quality; in the case of Portugal, however, there was also a growing trend towards local stakeholder groups becoming interested in being involved in monitoring their local projects.

Monitoring that has been completed has tended to fall into 3 key categories:

- Funders are beginning to ask for information to ensure that they projects are accountable.
- Most are, in theory meant to be for river management purposes but conversely this often does not include an adaptive management approach.

- Especially in the European Union there is a tendency to concentrate of monitoring water framework directive parameters. This often means that indicators such as fish species, water quality, macro-invertebrates and hydromorphology are high on the list, but these do not necessarily link to the specific project objectives.

In nearly all European countries the current trend was to consider water framework directive monitoring rather than projects that specifically focused on restoration project and the effectiveness of project techniques. The sophistication of the approaches varied considerably between member states. In addition China's main focus was nearly always water quality focused and although there was a good national set of information about point source pollution, these data are not publically available. The approach in the USA was very different and focused on demonstrating the benefit of restoration projects in a bid to secure more future funding for further projects. Monitoring and appraisal is therefore, much more project focused than other countries.

In most countries, however, there was a consensus that social-economic assessment of projects was relatively poor and that appropriate measurable indicators are often missing. However, Switzerland and Catalonia (Spain) developed a standard monitoring procedure which includes social-economic indicators. The need to understand the importance of monitoring projects in terms of socio-economic effectiveness should not be underestimated and indeed a pre-project assessment in China stopped one urban development. Switzerland appears to be the most advance in terms of recognising the value of these indicators and tried to include some monitoring of this type in most of its projects.

2A. WHAT ARE THE GAPS AND WHAT DO WE REQUIRE TO ADDRESS GAPS?

Data sharing was one of the main gaps identified.

The need for consultants for be trained effectively in why they are monitoring and more importantly to ensure that the results are not only well analysed but that the results are compatible across that board so that the evidence base can be improved.

There is a need to some guidelines for all completing monitoring to help ensure that river restoration monitoring is directly linked to the initial project objectives and vice versa. The figures shown are part of this project were seen to be a useful first step towards such guidance.

There is a need to have a before and after approach to ensure that there is baseline data to measure against. Currently this is not always done which means that scientific uncertainty remains high in many projects.

One of the key issues in many countries is that species data is charge for and the collectors of that data are very protective which makes future analysis of data difficult.

Most participants felt that there was little baseline monitoring and that there was a need for more informed objectives which would then feed into help answering some of the missing questions.

It was suggested that a lot of monitoring is associated with evaluating the water course and these indicators are for status of watercourse. The emphasis of this monitoring in Europe has become very water framework directive focused. Elsewhere, there is no focal point or protocol for monitoring and no centralise reporting requirements. Some countries including Australia tried to have mandatory requirements but failed because no incentive.

Social monitoring was identified as a very large gap even though it was recognised as very important and needs to included in the decision making process to identify who benefits from the project that is restored.

Key problems and gaps included:

- Better understanding needed between social and physical process.
- Need to measure the process e.g social communication between groups and also measuring sediment transport as an example.
- Need to restore resilience but not sure how to measure this. Need criteria for how to measure this would be useful. E.g. Biodiversity - how quickly it restores after disturbance and in social aspects we might measure happiness overtime in different groups.
- A general view was that economics drove monitoring. This was demonstrated from the Denmark example, where the centre of river restoration was closed because no more funding..
- In all cases data sets tend to be incomplete and disparate demonstrating more clearly the need for an international set of data that could be interrogated on a set of parameters that asked questions about restoration objective, technique(s) used and type of river.
- Information about success criteria would also be useful at both a national and international level.
- Reference systems are often not included in the assessment procedures

2B. OBJECTIVE SETTING AND RELATIONSHIP WITH MONITORING INCLUDING SELECTION OF INDICATORS

Overwhelming view that there must be more synergy between objectives and the way that projects are monitored and this level and type of monitoring will need to vary between project types.

3. FORMULATION OF A NEW PROJECT 'EVALUATING/MONITORING IN EUROPEAN RIVERS'

Limited time was available to answer this question however the following key points were highlighted:

- Strong need for guidance to managers that help them to factor in monitoring at the beginning of a project – need to recognise that monitoring needs to be appropriate for size, cost and risk. Also need to understand rationale for monitoring.
- Some joined up thinking in terms of different levels of project appraisal is essential to look at impacts of restoration so we can be in a position to provide recommendations how to address this.
- Cost is a major problem – this needs to be addressed and key decisions made about how to integrate costs of monitoring early into project planning.
- River restoration monitoring and appraisal needs to be embedded in WFD assessments (when related to European countries) but it also needs to address the specific restoration project answers – to this end a database that brings this information together that helps to answer restoration success for failure questions is essential.
- Considering appropriate reference systems is a major task in monitoring programs. Without a reference the assessment analysis is vague.

4. NEXT STEPS

This workshop has built on previous workshop outputs some of which can found at: http://www.therrc.co.uk/rrc_workshops.php and http://www.iwmf.eawag.ch/2007/downloads.

All highlighted the need for more pragmatic guidance on river restoration monitoring and appraisal for practitioners and river managers in Europe. To this end the River Restoration Centre is committed to pulling together pragmatic information which should act as to deliver such guidance. In addition however, there needs to be a European-wide guidance for practitioners and river managers alike.

The Rhone-Thur project in Switzerland (www.rivermanagement.ch) provides 2 handbooks (project evaluation/decision making) which will be used by practitioners in future. These tools will help to increase project quality and ensure project planning.

The workshop highlighted the importance of common strategies and the value of knowledge exchange amongst countries and projects. An international working group could help to harmonize evaluation practices/stakeholder involvement and related knowledge. More exchange of experiences between international projects would help to improve restoration knowledge and project quality.

ECOHYDROLOGY: ENVIRONMENTAL FLOW AND HYDROPOWER IMPACTS

Coordinators: Maiolini B.[1], Jormola J.[2]

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Open workshop with invited panelists:
Robinson C.(Eawag/ETHZ - Switzerland)
Binder W. (Bayerisches Landesamt für Umwelt – Germany)

1. SUMMARY

Construction of dams and disruption of the natural flow has been recognized worldwide as a major impact on the ecological health of rivers and thus on the availability of the ecosystem benefits that they produce for the environment of for human needs and welfare. The workshop discussed the impacts of hydro power and damming of watercourses and possibilities to prevent and mitigate the adverse development of connectivity and hydrological regime for river organisms.

2. QUESTION PRESENTED IN THE DISCUSSION

1. Fishpass types and their different advantages
2. Intermittent hydropower production: hydropeaking as a physical barrier
3. Flash floods as a tool for river restoration
4. Sustaining fish migration or healthy self sustaining fish polulations

3. IMPACTS OF ALTERED FLOW CONDITIONS

Minimum flow in hydropower permits is generally fish-based programmed. Other ecosystem benefits are generally little considered. Reasons for this are both scientific and social:

- Using high level consumers as indicators provides better evidence of restored ecosystem health. This is true if we consider the diversity and the structure of the fish community and not the sole presence/absence of selected species (generally chosen among salmonids).

- The angler associations are the most active stakeholders in requiring river restotation projects. The more general public is still not sufficiently aware of the importance of the ecosystem benefits and goods that river restoration can increase.

4. FISH PASSES AND MITIGATION OF HABITAT LOSS

Longitudinal connectivity is severely reduced in most European rivers. The major problem is generally considered to be a restriction to up and downstream migration of fish. It is important to note that hydropower not only has caused migration problems, but has also changed the quality of streamwater habitat through damming of long river sections. Thus in many rivers former rapids have been changed to more lentic habitats. This has declined the spawning and rearing habitats of many streamwater orientated fish like salmonids.

To attenuate migration problems, fish pass facilities have been and are built to by pass weirs and dams. When constructing fish passes, it may also be possible to mitigate for some extent the loss of valuable streamwater habitats. When feasable, nature-like bypasses, which can be ecological corridors also for inverteberates and slow swimming fish species, appear to have multi-purpose functions compared to technical fish ladders. In fact they not only favour up and downstream migration but also represent an interesting habitat *per sè*.There is evidence that fish corridors act as a refuge and even spawning and nursery areas for different species of fish. This is particularly important in heavily modified river reaches that offer low quality (or lack) spawning areas.

5. CHANGES OF FLOW AND HYDROPEAKING

Hydropower production has changed the hydrograph of many European rivers of different order to a severe exstent. At a large resolution scale this resulted in rivers with higher winter discharge and lower summer discharge. The tendency to a linear annual hydrograph is increasing in recent years. The absence of large floods resulted in loss of habitats, clogging of the hyporrheic zone, thus reducing exchanges of organisms and organic matter between surface and ground waters. Experimental releases of water to mimick annual floods have been conducted in Switzerland on the river Spool and proved to be efficient in restoring habitat loss and vertical connectivity, and related biodiversity by redistribution of sediments.

Hydropower production, viewed at a smaller resolution scale, highlights the undesiderd effects of intermittent releases downstream of power plants (hydropeaking). These frequent and sudden changes regard not only discharge but also alteration of the physical (temperature, suspended sediments) and chemical properties of water. This is viewed as a major problem and should be considered in restoration projects in river systems affected by hydropeaking, as this may severely reduce the possibilities of reaching the environmental goals established for river restoration projects. Alteration of flow and temperature regimes may negatively superimpose on the advantages prospected by river restoration initiatives. Basic and applied research is needed to meet the demand of a good ecological condition for rivers and the strategic importance of hydropower production as a renewable and gas free energy source.

6. MIGRATION AT THE BASIN SCALE

At the watershed level there are differences within European basins: systems such as the Rhine need longitudinal integrity along the channel to the sea for catadrome and anadrome fish species (salmon and eel), while others as the Danube have not such species (with the exception of the sturgeon) and so connection to the sea is not so compelling. For this it is recomended to develop Master Plans for the migration of fish species to priorize the measures. Such a Master Plan is in preparation by the International Commission for the Protection of the Rhine for the Rhine system.

7. MAIN OUTCOMES OF THE WORKSHOP

When hydroper is promoted, the adverse impacts for river ecosystems should be mitigated and compensated as as a basic requirement of powerplant permits. Fishpasses should be built in connection with all new powerplants, combining the construction of habitats in the bypasses when possible. Fishpasses should also be required for heavily modified rivers. Flow regimes should be adjusted in accordance with restoration goals for sediment transport and conditions for organisms. Connectivity programs at the watershed level should be promoted in Europe, to priorize international restoration measures.

WORKSHOP PARTICIPANTS: About 25

RECREATIONAL USE OF WATERCOURSES: HOW TO CHARACTERIZE IT IN ORDER TO SUPPORT PARTICIPATORY DECISION PROCESSES?

Coordinators: Gusmaroli G.[1], Melucci A.[1]

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1. INTRODUCTION

1.1 Background

The river represents an element of attraction in terms of recreational value. Many kinds of outdoor activities are carried out along the river and its surroundings: hiking, kayaking, fishing, biking, horse-riding, boating, ecc… Many tourist operators and citizens are more and more eager to experience nature and this interest is on the agenda of watercourses administrators and managers.

The recreational use of rivers can be definitely considered a specific form of tourism, and in such terms it can determine the economical development of the community living along the river, but also an important way to bring people back to the river thus contributing to form a new environmental culture. Furthermore, just a few researches have been carried out in order to provide a set of indexes and indicators to measure the recreational value of a watercourse. Together with this, many participatory processes within decision making protocols concerning rivers (agenda XXI, SEA, Contrat de Rivière,…) are involving large groups of recreational users that provide important contributions in terms of knowledge, proposals, interests and expectations.

In spite of this, the discussion on value of recreational use of watercourses and its position within decision making processes is still open. Several cases of conflict concerning rivers are still open between different objectives in which recreational uses are key issues. According to this, the question is: is recreational use of watercourses an opportunity or a threat for river restoration?

An example of this dispute is common within protected areas, in which Conservation is the main goal but often tourism is also an important issue as an instrument for economical development: usually the result is the conflict. Again, where tourist powered boat transport is a strong interest, several impacts to river ecological integrity are generated.

So, what can be done where recreational uses of rivers are consolidated – or growing? Is it possible to find a quantitative measurement protocol for recreational use of water, in order to compare it with other objectives within participatory decision processes? If yes… in which way?

1.2 Aims

The following list summarize the aims of the WS:

- identification of a shared position on the role of recreational value of watercourses in relation to ecological status improvement and other objectives concerning rivers;
- analysis of the main attributes of the recreational value of watercourses for classification;
- discussion about possible solutions to integrate recreational value of watercourses within governance policies of river basins.

1.3 Program

Previously of the workshop a preparatory survey has been requested to WS participants. The survey has been carried out with a questionnaire with open questions concerning synergies and antagonisms among recreational uses of watercourses and other objectives. The document has been submitted by 8 participants. The results are reported in the following part of this document.

The WS has been developed through two phases: the former has been an introductory presentation done by experts (invited speakers) concerning a general description of typology and experiences of recreational uses of watercourses (Maurizio Bacci) and assessment issues in DM processes (Andrea Nardini), the latter has been a plenary discussion on the topic.

2. MOST INTERESTING OUTCOMES EMERGED FROM THE WORKSHOP

2.1 Outcomes of the preparatory survey

The survey outcomes represent a general overview of the main synergies and antagonisms noticed by WS participants among recreational uses of rivers and other objectives. The results are not exhaustive but they highlight some recurrent element of contact to be considered within IWRM (integrated Water Resources Managment) actions, in particular when dealing with recreational values. In short we can recognize that:

- good ecological status of rivers is attractive for recreation, but recreation itself can contribute to its worsening (in relation with typology, intensity, occurrence,...) → need of river restoration strategies together with education, organization and regulation in recreational uses;
- economical uses of rivers can heavily reduce recreation potential, but for instance environmental flow requirements (and regulations) or water retention reservoirs can meet both conservation/production/safety and recreation targets → a comparative cost-benefit analysis should take into account recreational values pro&con (that could be an economical use too);
- traditional flooding risk reduction strategies (river banks, settlement removal, artificializations, water flow management,...) impact river environment and recreational value → more nature oriented techniques and strategies can improve river attractiveness and accessibility;
- navigation can cause severe impact to river in relation with transports typology, size and intensity → integrated infrastructures and activities can accomplish both recreational and commercial targets.

Table 1 – Preparatory survey outcomes.

RIVER RECREATIONAL USE vs…

… ECOLOGICAL STATUS IMPROVEMENT	
synergies	antagonisms
Water quality and bathing requirements	*Surface run-off / sewage from touristic facilities*
Biodiversity (flora and fauna)	*Disturbance effect on biota from recreational activities*
More space for the river and for people	*River restoration/conservation costs*
Landscape	*Ecological loading capacity overcoming*
Educational and awareness value of experience	*Restrictive conservation rules much penalizing "soft fruition"*
	Incompatible behaviors of users
	Water protection policies not including recreational uses
	Blind environmentalism
	Disturbance of reference site (WFD) open to recreational use
	Impacting infrastructures
	Developing and prevailing of impacting type of fruition

RIVER RECREATIONAL USE vs…

… ECONOMICAL USE OF WATER (hydropower, irrigation, drinking water, industrial water)	
synergies	antagonisms
Environmental flow requirements	*Extended and consistent extraction/stock of water*
Multi tasking reservoirs	*Interruptions by weirs*
Participated water management	*Strong economical interests ("recreational water" cost)*
Drawing and release control by recreational users	*Water quality decrement*
Recreational use as guarantee of river care	*Priority in water uses in case of drought*
Recreational uses within artificial water-bodies	
Recreational use is an economical use itself	
Lower flow stretches for wide accessibility	

RIVER RECREATIONAL USE vs…

… FLOODING RISK REDUCTION	
synergies	antagonisms
More space for the river and for recreation	*Hydraulic works impact attractiveness and accessibility*
Multi tasking water retention areas	*Channelization of rivers*
Water levels and works surveillance by recreational users	*Flattening of hydrologic regime*
Accessibility increase because of safety	*Accessibility decrease because of restricted areas*
Recreational infrastructures nearby hydraulic protections	
Water slide and/or fish passages on weirs	
Cultural improvement (flooding risk cohabitation)	

RIVER RECREATIONAL USE vs…

… OTHER (navigation)	
synergies	antagonisms
Integrated infrastructures	*High impact infrastructure*
	Sediment management

2.2 Outcomes of the workshop discussion

Recreational uses of water course are both a tool for River Restoration in term of education potential and a threat for ecosystems in term of pressure. Within this dualism, WS outcomes have been classified and here presented as statements emerged with an instant report methodology during the plenary debate.

FRUITION as TOOL

1. Recreational uses of watercourses (in a broad definition comprehending environmental education, sport, tourism) are relevant with a cultural process that lay at the basis of River Restoration principles → bring back people to exciting river means to grow an environmental attachment, consciousness and motivation.
2. Not every river is in a good ecological status → through addressed recreational uses it is possible to aware affection and interest in River Restoration processes.
3. Recreational value of rivers should be integrated within basin scale management and governance issues → the stakeholder of recreational uses ask to be involved in Decision Making Processes, in order to share their specific experience of the river and to get more integrated governance practices.
4. A few practitioners and technicians are experienced with nature and common design approach are far away to work with nature → training through experience as a learning step to educate specialists.
5. Not all recreational users have environment sound behaviours → need to grow environmental knowledge among "river users" and educate a broad part of them to good practices (a clean river is not a river with no vegetation at all...).
6. Recreational uses should be an instrument to teach how to discern real beauty of nature → a river in good ecological status is not a handmade garden...
7. Recreational use need to pass through sensitive experience (also for adults.. is never too late) → all senses should be involved in experiencing rivers, in order to deep merge with nature.

FRUITION as PRESSURE

8. River accessibility design should be contest based → within urbanized areas there is a need for safe, easy and artificial fruition, but within wild (more natural) areas the tourism demand concern emotions, that is less comfort and more adventure.
9. Zoning, seasoning and timing → accessibility should be regulated in order to preserve undamaged sites and respect specific ecological patterns.
10. From soft transport to soft mobility → even environmental sound transport infrastructures could be more impacting than soft mobility strategies
11. Recreational infrastructure not to be a mitigation of high impact artificializations → a riparian forest is better than a linear bank with a bike track...

12. No recreational use at all costs → too much pressure (even for recreational uses) could severely damage river habitats
13. No recreational use just to move problems downstream → environmental accessibility is very popular and raise consensus, but is not automatically the answer to environmental matters.

3. PROPOSALS

The participant at WS "Recreational use of watercourses: how to characterize it in order to support participatory decision processes?" have discussed and agreed the following proposals:

1. Enhancing Recreational Uses of Watercourses is not River Restoration at all. River restoration strategies are multi-disciplinary and multi-objectives processes in which River Basin Authority needs to develop a unitary vision in which Recreational Uses of Watercourse plays a double-face role: the former as important tool to enhance life quality and a cultural change in citizens, technicians and administrators, the latter as critical pressure on ecosystem if not well planned and ruled.
2. Recreational Uses of Watercourse should be fostered as training tool for children and adults through which experience nature and gain deep understanding and feeling of ecological patterns. The more emotional and "wet" is the experience, the more it will raise a demand for river care and an effective inspiration for river governance, management and design.
3. Recreational uses of watercourses need to be managed through aiming users to appropriate behaviors, organizing the environment with low impact reversible infrastructures and zoning core habitats, ruling the accessibility in term of seasoning and timing.
4. Designer should take into consideration the paradigm to keep down recreational infrastructures within pristine or wild environments, focusing more on damaged river in which a soft and safe form of fruition could raise a River Restoration approach.
5. In the name of Recreational Uses of Watercourses, no artificalization or other traditional engineering action should be carried out. Recreational Uses are not to be used as a mask or a mitigation results for river damaging scheme.

The previous statements are far to be comprehensive, and the group has been conscious of the need to go deeper into detail of Recreational Uses of Watercourses in relation with opportunities and threats coming from any "living the river" activity. The shared auspice is that an applied research could be developed in a short time, in order to better study this specific topic and to provide a guideline tool for all people involved in Recreational Uses of Watercourses.

WORKSHOP STATISTICS:

The following tables and figures summarize some relevant statistic concerning WS audience, in term of typology and country provenience.

Table 2 – WS participants by number.

organizers	2
invited speakers	2
invited guests	5
participants	8

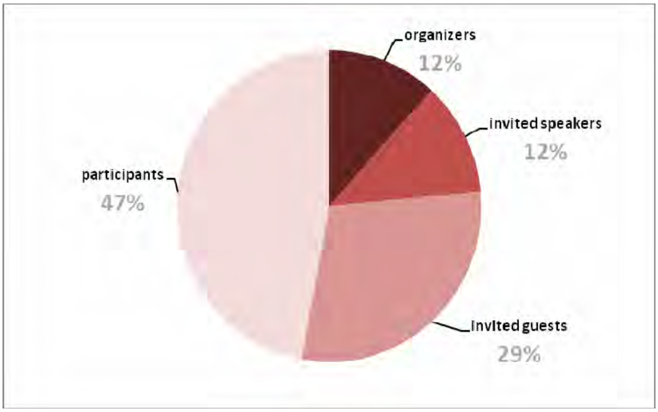

Figure 1 – WS participants by percentage.

Table 3 – WS participants by country.

Italy	11
Austria	2
Colombia	1
France	1
Germany	1
Poland	1

INTEGRATING SCIENCE WITH PRACTICE: A TOOLKIT OF GOOD PRACTICE ADVICE AND A DATABASE OF RIVER RESTORATION PROJECTS

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1. INTRODUCTION

River restoration has been described as both a science and an art. It is a process whereby we utilise the science and research and the practical understanding from previous experience. It requires integration of the range of disciplines (engineering, hydrology, geomorphology, ecology, biology, landscape, water quality…, both scientific and applied. It is complex.

With more hopes being placed on river restoration as a tool, or mitigation measure to undo past damage to natural riverine systems, it is no longer sufficient to state “it is complex”. We need to demonstrate the complex links and back up the general assumption that river restoration is a ‘good thing’ with scientific analysis and applied success.

The Water Framework Directive requires assessments of cost effectiveness of mitigation measures, based on levels of confidence in the ability of the measure to off-set the pressures. Funders of stand alone river restoration projects need similar justification for investment. As a river restoration community, we need to access this information and be able to use it to allay fears and old prejudices, and to promote new ways of river management.

The workshop aims at:

- defining how we as a “river restoration community” can build science and practice to inform and justify the large sums of money required to restore our rivers;
- setting up a common European database methodology and format for gathering river restoration project data.

2. SCIENTIFIC EVIDENCE FOR RIVER RESTORATION

Under the Water Framework Directive (WFD), the UK has to ensure that all current and future flood defence schemes do not affect the ecological or hydromorphological habitat quality of a river, estuarine or coastal system. Where water bodies are designated as Heavily Modified due to flood risk or land drainage pressures, measures to mitigate these to achieve Good Ecological Potential are required. In addition, to comply with WFD, operating authorities will have to assess their current and proposed flood defence or land drainage schemes and maintenance activities to determine if they reduce habitat quality and if so, what mitigation measures are required to attain 'Good Ecological Potential'.

River restoration appears in papers in many countries and there are many good practice manuals that give guidance on river design and mitigation measures, but the degree to which its application or implementation has been monitored and evaluated (Workshop 7) and scientifically appraised remains low. A recent study in the UK to produce a compendium of information relating to river restoration mitigation measures (related to Land Drainage and Flood Risk Management) has provided interim results. This suggests that there is a 'reasonable' body of evidence, in most cases enough to support many of the applicable techniques or measures that river restoration proposes. Much of this is not simply a question of does the restoration measure work, but also questioning the converse "what does the science tell us is the impact of river degradation?".

There is also assumed to be a large body of information in written reports from non-academics, together with expert judgement, that has yet to be compiled. Is there a 'simple' way to access this information, and the expertise that is available?

This UK based study looked at European papers and targeted members of the river restoration community, but do we as a group agree and was valuable information missed.

In Europe, how do different countries currently, and plan in the future, to justify expenditure on river restoration?

3. DIGITAL GOOD PRACTICE MANUAL

The solution to the problems resulting from an absence of a single source of advice for river, estuarine and coastal engineers is the development of a good practice manual. The basis for this Manual is a decision making tool that allows users to access information on methods/techniques that are commonly applied to restore/enhance/mitigate waterbodies. This information is comprised of the latest 'good practice' and contains a critical evaluation of the science (as discussed just previously), the expert opinion (especially where the science base is poor) and the applicability of the method to different rivers and different climates. This manual will be readily and widely available through a web site and incorporate a simple tool that leads managers to the most suitable, feasible and acceptable options. The manual will be usable as an environmental audit system for flood risk management and land drainage schemes.

The project will produce the following:

- **Phase 1.** A review of the scientific evidence base for all mitigation activities undertaken on rivers, estuarine and coastal water bodies. This can be used with a high level assessment tool (or checklist) for existing flood risk management and land drainage systems. The tool will allow a quick identification of where there is scope to reduce the impacts of a scheme on habitat quality or whether a system already represents good environmental practice. The executive summary for this output is provided below.
- **Phase 2.** A more detailed assessment tool for new schemes to determine whether proposals represent good environmental practice and where mitigation options would significantly reduce the impacts of a proposal. This tool will be complimented by a series of detailed guidance sheets on each mitigation option and will include information on cost effectiveness and ecological benefits.
- **Phase 3.** A web-based searchable digital guidance manual to hold the advice outlined above.

3.1 Project timetable

The first stage of the project; the production of a review of the evidence for mitigation activities is complete. The remaining phases of the project will be complete by Spring 2009.

3.2 Project funding and governance

The project is jointly funded by the Environment Agency, SNIFFER and the Scottish Government. For further details of the work, please contact David Corbelli (Environment Agency, Hydromorphology Team; david.corbelli@environment-agency.gov.uk) or Jacqui Cotton (Flood Risk Science Team; jacqui.cotton@environment-agency.gov.uk)

4. DIGITAL GOOD PRACTICE MANUAL: PHASE 1 REPORT (REVIEW OF TECHNIQUES). EXECUTIVE SUMMARY

The main component of Phase 1 has been assimilation of an evidence base (Review of Techniques) that has now been compiled for rivers, lakes, transitional waters and coasts. This is based on an extensive literature review (including Internet Searches) and telephone or face-to-face interviews with a select list of practitioners from the UK and Europe. The report includes a synthesis of the information collected, including a description of the studies and an initial Screening Checklist. It also illustrates pan-European initiatives for tackling Flood Risk Management (FRM) and Land Drainage (LD) issues.

There is considerable information relating to rivers, much less so for transitional waters and coasts and very little for lakes. For Phase 1 many hundreds of papers have been obtained and reviewed from readily accessible sources. There is much previous experience to draw upon and the literature can be split into existing user manuals, grey (or unpublished) literature and published scientific papers. Over the last 20 years considerable progress has been made in mitigating the impacts of FRM activities (as a result of legislation, including the implementation of the EU EIA Directive in 1988). The European Centre for River Restoration (ERRC) and in particular the UK River Restoration Centre (RRC) have acted as catalysts since about 1990 in promoting the art and science of river restoration. This contrasts markedly with FRM activities over the previous 50 years which generally gave scant attention to environmental constraints and opportunities, although there is now much optimism in Europe with the Floods Directive and the development of Flood Management Plans to include exploration of alternatives such as enhancing storage in floodplains, re-creation of wetlands and the removal of hard engineering structures on some rivers.

The judgment as to whether there has been a scientifically proven ecological benefit (or otherwise) as a result of a measure/ technique is regarded here as a function of the publications in the scientific literature. This is distinct from the 'basis for use' of an individual measure/ technique described in the checklists which is a mix of user manuals and grey literature (reflecting more localised experiences) as well as the scientific literature. It is also recognised that much data/information held by operational staff has never been published (indeed many experts do not have the incentive to publish their experiences and monitoring results). Interviews and questionnaires carried out for Phase 1 indicate that the depth and breadth of scientific monitoring and publications remains low in comparison to the large number of projects completed.

Scientific information can be (cautiously) imported from other countries such as the USA. However the numbers of papers remains very low (to non-existent) for many measures/ techniques. For many physical environments there will not be any directly applicable information. The lack of monitoring is a key issue that has been flagged up by practitioners for more than two decades and still remains a weakness (there is rarely any baseline data. Mitigation measures/ techniques are most likely to be successful when properly visioned, designed and implemented at a site. For the majority of projects in Europe and the UK there has been very little or no monitoring. A project also needs to have a minimum combination of geomorphological, ecological and engineering expertise (and in urban areas a contaminated land expert and landscape architect) to be successful. It is also important to consider the opportunities and challenges presented by mitigation measures/ techniques and to arrive at a balanced view which inevitably will be site specific.

The Report includes the following key sections:-

- Chapter 1 – introducing the project and report.
- Chapters 2 and 3 – describing the methods by which the science evidence base was compiled the UK and European contexts for the development of a manual.
- Chapter 4 – explaining how the checklists have been developed.
- Chapter 5 – a practical chapter for operational staff containing details of the main mitigation measures/ techniques, where they have been applied, the order of their costs and potential effect on FRM/LD.
- Chapter 6 – presenting some conclusions of this interim report.

5. RIVER RESTORATION PROJECTS - A DATABASE OF SUCCESSES AND FAILURES

Linked to the need for good science is the need for reliable, accessible and plentiful information on completed river restoration projects. We need to learn from what *we* have done to apply it in the future. Better still, we need to learn from what *everyone* has done.

In some countries this information is being collated within various databases or inventories, in others it is simply sourced by individuals or organisations for a single study. The ECRR has recently begun to populate a web based database of river restoration projects. The UK RRC has a similar inventory of 1500 projects and the Danish NERI has over 1000 projects from across the different counties. In the US, a recent synthesis of river restoration science (NRRSS) collated over 30000 projects involving river enhancement and rehabilitation. Also the NOAA collected information on about 350 river restoration and fisheries projects, but often, many of them were missing a number of data (i.e. where the projects were carried out, their goals, the monitoring, etc.). Such resources are key to help to deliver WFD targets.

The group felt that the development of a European database on river restoration initiatives and projects would be a valuable tool to facilitate information sharing and good practice to a range of potential end users (policy makers, academics & practitioners)

It was agreed that there was scope to use a simple ECRR database to better use information collected at country and basin level in various other project datasets. The model being developed in England & Wales was a good approach and could serve as the starting point for developing a European equivalent..

The group also agreed to circulate a draft of the key data fields that could be included, identify the key questions that people would need to be answered by such a database, and refine the two into a draft database format. This would link in with other initiatives in the US, UK, Denmark, Germany, Austria and be open to other with datasets that could be shared to better inform the wider river restoration community.

A representative of the EU LIFE programme provided and overview of the LIFE programme and funding mechanisms: the LIFE+ "Information and Communication" seems to be the most suitable for the development of a projects that could include the following issues:

1. Toolkit of good practice advice
2. Database of river restoration projects
3. E-learning programme at European basin scale to increase the knowledge
4. A series of seminars and meetings

It is important that the proposal also focuses on the information sharing, on the stakeholder participation and that could be able to facilitate sharing of good practice.

6. ACTIONS

The ECRR, David Corbelli, Martin Janes, will explore the potential funding opportunities to develop the Toolkit of good practice advice and Database of river restoration projects.

The EU LIFE+ (information and communication component) seems to be the most suitable instrument to proceed with the activity, but this must be clarified.

For this reason, a series of seminars and meetings may be organized to discuss how to go on, who will be involved, what will be the scheduling and the deadlines for submitting the proposal.

WORKSHOP PARTICIPANTS: About 20

4th ECRR Conference on River Restoration
Italy, Venice S. Servolo Island
16-21 June 2008

REFERENCE RIVER ECOSYSTEMS: HISTORICAL STATES, BEST ECOLOGICAL POTENTIAL AND MANAGEMENT CHALLENGES

Coordinators: Kondolf M.[1], Zolezzi G.[2]

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Open workshop with invited speakers:

Introduction/Overview	
Matt Kondolf *UC Berkeley (USA)*	Setting Restoration Goals – What Role Reference River Ecosystems?
Hervé Piégay *Université de Lyon (F)*	Reference River Corridors: Pristine or Artifacts of Land-Use Change?
Angela Gurnell *King's College (UK)*	

1. GENERAL PRESENTATION

Reference conditions for surface water bodies are a central element in the implementation of the Water Framework Directive, WFD (EU 2000/60). It is therefore crucial to identify and learn from reference river reaches that resemble the functioning and historical states of natural river bodies prior to extensive regulation of their hydro- and morpho-dynamics.

This workshop focussed on goal-setting and the concept of reference reaches in river restoration. We consideried the case of regulated rivers, in which it is largely impossible to restore fluvial processes, and the reference ecosystems of the Tagliamento River (Italy) and the Eygues River (France), the latter having developed its riparian forest since the late 19th century. These sites offer excellent opportunities to investigate relatively unconstrained biotic and abiotic processes at basin-scale scales observable in very few sites in Europe, illuminating functional roles of riverine attributes important for conservation, and also highlighting the importance of understanding historical land-use changes in creating such ‘natural’ habitats.

A lively discussion ensured, centred around how these systems should be managed and studied in the future, to preserve their functions both for societal needs and to preserve biodiversity and ecosystem services, and taking their special ecological character into account.

2. WORKSHOP OUTCOMES

2.1 Background - Reference conditions according to EU Directives

The EU Water Framework Directive (EU 200/60) indicates that "for each surface water body type, type-specific hydromorphological, physicochemical and biological conditions shall be established representing the values of the hydromorphological, physicochemical and biological quality elements for that surface water body type at high ecological status". Reference conditions are therefore those that represent such high ecological status of a given water body type, a concept that is also put in close relation to its maximum ecological potential. Reference conditions are type-specific, and they shall be evaluated differently depending on the considered water body type. The Directive also broadly indicate the approaches that can be followed to assess these reference conditions. Namely "reference conditions may be either spatially based or based on modelling, or may be derived using a combination of these methods, or based on expert judgements when the previous two methods cannot be used". Finally in the Directive it is encouraged that Member States develop a reference network for each surface water body type. Such "networks should contain a sufficient number of sites of high status to provide a sufficient level of confidence about the values for the reference conditions".

2.2 Critique of the concept of "Reference System".

To illustrate some key issues within the reference conditions concept as used in the WFD, the workshop started with illustrative examples taken from a specific water body type: highly dynamic, piedmont river reaches dominated by a braided morphology. The Tagliamento River (NE Italy) and the Eygues River (SE France) illustrate different perspectives and contrasting considerations about such river reaches as reference systems.

The braided piedmont reach of the Tagliamento River has been subject to extensive interdisciplinary research in the last decade, since it retains sufficient physical, chemical and biological process dynamics and morphological integrity to serve as reference system. Although no entirely natural river systems exist within mainland Europe, systems like the Tagliamento River can be considered to form an important Alpine to Mediterranean braided reference system. It has also been argued that the Tagliamento cannot be considered a reference system since, in Europe at least, human pressure is everywhere, has been occurring at different dates since a long time both upstream and in the reach. The Eygues River makes for a thought-provoking example because its riparian forest has been designated as a site of ecological interest under the Natura 2000 program and reference ecosystem because of its "near-natural" conditions with high ecological status, i.e. with maximum richness of ecosystem functions. However, the riparian forest did not exist in the 19th century, but resulted from subsequent reductions in upstream sediment supply and agricultural use of riparian areas. The newly established riparian forest can be considered an example of an anthropogenic landscape, which in some cases can even be more biodiverse than natural landscapes.

Thus, historical conditions are not always associated with least anthropic impacts, and at least in Europe, some rivers are more ecologically diverse today than a century ago. This relates to another critical issue: the need to account for geographical differences when defining reference systems, due to the much different history of anthropic impacts in among the different continents.

Another issue with using historical states to determine reference conditions is potential effects of long-term changes in climate, which implies that even with reference sites reformed according to their historical state, their functions today might not be comparable. Drawing an analogy from forest ecology, foresters don't know the pre-historic extent of forest in Europe. Similar uncertainty can be recognized in our understanding of pre-human-disturbance river states.

Regionally-specific aspects (often neglected) might include a history of heavy ungulate grazing in Mediterranean areas, which is concentrated in riparian zones in summer because these are the only available green spaces at that time of the year.

2.3 Operational experiences

The discussion has offered the opportunity to briefly present other experiences related to the operational definition of reference conditions in various countries. Three main examples have been proposed, from the Netherlands, Australia and Germany.

The branch of the Rhine in the Netherlands is known to be degrading yearly. Several interventions have been taken to limit the process, like groyne construction for navigation. At present managers and stakeholders are concerned about excessive degradation of the riverbed which is reaching the bedrock in some sections. In seeking to understand cause–effect relationships, there is no reference river system for the Rhine. Thus, the former river has been reconstructed through focussed investigations. Cores of the riverbed provided information on sedimentation rates and former vegetation communities. Mathematical models have exploited these data to understand possible past scenarios of system dynamics. In this case the historical study of the site in question has proven to be valuable as much as reference rivers can be in cases when they are available.

The methods for selecting reference rivers in New South Wales (AU) use river style typologies to categorize reference sites based on present behaviour. There are problems using historical evidence as reference since everything has changed, including the climate; using historical states would imply dealing with a moving target in management, which is not desirable. The main criteria are therefore based on the natural rate of change regardless whether the reaches were disturbed in the past or not. The criteria are built looking at responsive indicators, not at all possible aspects of the system.

Discussion is ongoing in Germany. Due to the limitations of the present approaches, a way to follow can be to look into the future rather than into the past, by considering how reference reaches will develop to get a "potential natural state". This idea has shown promise when applied to small streams.

2.4 Dynamic perspective on reference systems: guiding image

All systems are somewhere on a trajectory, not necessarily under equilibrium conditions. Trajectories can be defined in terms of parameters such as riparian vegetation cover, active corridor width, level and trends of aggradation/incision. Functions and processes may be maximized at a given time in the trajectory of the river adjustment. Assessing the position of a given river reach along its trajectory can be a more useful concept than focussing on historical states as a reference. Historical states are by nature dynamically linked with the river trajectory, while the term "reference" might imply "fixed". A terminology shift from "reference systems" to "reference trajectories" may help to reflect the dynamism of fluvial systems by explicitly including the temporal element.

Finally the concept of "guiding images" has been proposed concerning goal setting in restoration projects. A guiding image – an attempt to create a vision for restoration – is a useful concept because it draws on history but at the same time it is not aiming for a perfect replica. The Tagliamento River and other similar ones (very few in Europe) are interesting because of the diversity of processes within them. In Europe, sites retaining processes, linkages, and dynamic complexity are valuable and worthy of monitoring and research to understand mechanisms of interaction among water, sediments, vegetation, animals and the airscape – a knowledge that is far from fully established and that can guide innovative restoration programs in other heavily modified river reaches.

3. CONCLUSION AND OPENED OPPORTUNITIES FOR FUTURE COLLABORATIONS

The following synthetic conclusions have been drawn from the workshop.

- Historical states are best used to to understand the system trajectory rather than a reference *per se*.
- A useful framework for setting goals is maximising the functions in a given trajectory to achieve societally-desired outputs such as biodiversity, species conservation, and risk management.
- River reaches retaining processes, linkages and dynamic complexity are worthy of study to support the definition of guiding images that, as a broader vision for restoration, is a useful concept in goal setting for restoration projects.

The workshop highlighted the need for a pan-European network of reference sites, and highlighted the scientific value of such reference systems, with many processes acting on them, whether natural or not.. These sites can be selected reaches based on the continuity of study or completeness of understanding. A network of long-term ecological sites is already present in the USA. A similar need was expressed repeatedly at the European Science Foundation (ESF) Exploratory Workshop titled "*Linkages and feedbacks in highly dynamic, alpine, fluvial systems*" held on the Tagliamento River two weeks after the ECRR Conference. Workshop convenors were Angela Gurnell, Klement Tockner and Marco Tubino. Other participants from ECRR included Hervé Piégay, Bruno Maiolini, Massimo Rinaldi, Dov Corenblit, Bartolomej Wyzga.

WORKSHOP PARTICIPANTS: There were nearly 50-60 participants in the room, of whom at least a dozen actively contributed to the discussions.

CONCLUSIONS AND RECOMMENDATIONS
4th INTERNATIONAL RIVER RESTORATION CONFERENCE
VENICE, SAN SERVOLO ISLAND, 15-19 JUNE 2008

Introduction

This summary paper on conclusions & recommendations of the 4th International Conference on River Restoration aims at identifying the key issues for river restoration for the near future, as they were noted during key note presentations and workshops. Individual sections elaborate in statements on the state-of-the-art in river restoration today and the key aspects for the future, and on the interaction between the EU and river restoration. The paper concludes with an elaboration on the envisioned role of the ECRR and its activities in contributing towards preparing river restoration for the future.

The authors wish to thank all key note speakers for the insights and experiences provided, and all workshop and session chairs for their stimulating and useful summary contributions which all provided the basis of this paper.

State-of-the-art in river restoration

From the multitude of abstracts read and presentations heard, past and present features of river restoration practices can be characterized in an number of statements:

- Often the term "river restoration" does not regard ecological restoration, the terminology of river restoration is misused for other purposes;
- River restoration is more research-oriented instead than focusing on practical implementation;
- Predominantly river restoration is tackled on small-scale, focusing on the river, more rarely on (part of) the floodplain, hardly ever on the river basin. It is often uncertain whether local restoration efforts tackle the impact of relevant larger-scale regional factors on the right location;
- Clear descriptions of reference situation are used only occasionally to elaborate or define envisioned future ecological desirable conditions to be aimed for after the completion of river restoration activities;
- objective which produce targetable and measurable outcomes for river restoration are rarely defined in advance;

- Often the broad possibilities featured by river restoration meet with entrenched practices and mind-settings: commonly implementation of river restoration is dominated by the engineering approach of modifying hydro-morphological processes;
- River restoration is increasingly facing a policy gap: growing organizational complexity, tighter procedures and control enforced by government authorities and funding agencies oppose the need for diversified risk protection strategies;
- During the latest decades new policy drivers have emerged, which link river restoration to risk management, flood safety, renewable energy etc.
- river restoration implementation strategies are increasingly providing an explanation of the factors affecting the development of selected species instead of an interpretation whether predefined, integrated ecological objectives are being achieved. In fact, descriptions of local changes prevail, commonly supported by statistical analysis “before” and “after” intervention;

River restoration ready for the future

The presentations and discussions of the conference participants, however, also demonstrated that as a result of the increased number of implemented river restoration projects during the last 10-15 years, learning from practice has increased. There is a progressively growing awareness and knowledge among stakeholders of the need to use new approaches. More and more national policies become available and/or are under implementation, while there is more attention for regional differences within Europe. Last but not least, there is an increased awareness and understanding of opportunities and benefits related with river restoration among the various stakeholders. More specifically, a number of more specific observations on the future of river restoration have been formulated:

- River restoration should target at restoring complete ecosystems and ecosystem processes in which, as in undisturbed conditions, dynamism is a key feature, expressed as the self-sustaining capacity of river and stream ecosystems and their capacity to respond to imposed external environmental changes. In this, hydro-morphological processes remain a key factor in steering ecosystem processes and ecosystem quality;
- Uncertainty is inherent in ecosystem processes, guided by changing environmental conditions and human activities. On the one hand the capability to predict the effects of interventions needs to be improved, but on the other hand the understanding and level of acceptance of uncertainty in restored ecosystem processes needs to be improved as well;
- A pre-inventory, preferably quantitative, definition of ecological success criteria is necessary to assess the success level of river restoration;

- In defining ecological success criteria, historic standards may be largely inappropriate due to the need to take external changes into account (climate change, human population growth, land use changes, economic developments, etc.). Therefore, rivers must be designed for the future with reference to the past, with the understanding that only selected services can be realistically restored;
- River restoration should aim at tackling or contributing to solving regional impacting factors, from the river to the basin via the floodplain. Key targets are the restoration of lateral and longitudinal connectivity, both aquatic and terrestrial;
- River restoration must be based on scientific processes and predictions to anticipate outcomes and guide design. Meanwhile, research should shift more towards supporting practical implementation;
- With increasing scale, river restoration should be based on multidisciplinary, adaptive management approaches and the acceptance of non-stationarity. With increased scale, public involvement in planning, monitoring and appraisal, social processes and interactions between stakeholders are increasingly important. Engaging the range of stakeholders and most specifically the 'public' in decision-making processes is the major challenge. A better analysis of the possible conflicts and synergies between ecological and social functions of river restoration projects allows a better understanding of the needs of nature and its possible use by people;
- In planning and assessment, river restoration should use approaches including multi-criteria analysis, cost-benefit analysis, economic evaluation. This requires also the elaboration of pre-interference restoration assessment plans, as well as adequate (long-term) multi-level monitoring, including monitoring of restored processes and separating the effects of natural variability from those if the intervention Monitoring could vary from in-depth scientific monitoring at a few selected sites, to expert opinion and small scale local stakeholder monitoring.

River restoration and the EU

The embedding of river restoration into an appropriate policy context is crucial for decision-making processes and implementation practices to reach defined results. In western Europe, the Water Framework Directive (WFD) has been an effective driver although slow to make its effect felt. In other regions (e.g. Eastern Europe, Latin America) policy exists but government is weak or failing to enforce such policies; here the roles of academic institutions and civil society to act as an 'honest broker' to support policy implementation are critical. In most cases there is a gap between policy development and practice, in which the learning processes linking the two are lacking.

Commonly agreement exists, both within EU authorities and ECRR delegates, that on the one hand river restoration practices are being supportive to the implementation of various EU Directives, while on the other hand the implementation obligations under the EU Directives often are a driving force for the implementation of river restoration projects. The sustainable maintenance of biodiversity is especially the objective of the combined implementation of the WFD and the Bird & Habitat Directives (BHD), especially in Natura-2000 sites. Implementation of the WFD deals strongly with the reduction of nutrients, micro pollutants, reduction of heavily modified waterbodies and improvement of the ecological quality of the riverbed, while river restoration is based on an integrated ecosystem development approach. This difference creates evident good opportunities, but also some threats with respect to an effective joined implementation of both river restoration measures and the EU directives.

Although there is a common understanding that river restoration is more than an instrument to implement EU Directives obligations, river restoration practices can contribute to the creation of habitats (Habitat, Bird Directives, Natura 2000), reduction of flooding (Flood Directive) abatement of pollution. The EU and related national implementation programmes can therefore be targeted to finance river restoration, especially when river restoration targets are formulated in line with programmes on flood defence, water quality improvement, the Common Agricultural Programme, ecological networks, fisheries, renewable energy etc. The ECRR in this respect could assist EU member states in implementing EU Directives using river restoration where it is the most cost-effective instrument to obtain good ecological quality.

However, some questions remain, mainly dealing with river restoration in relation to river basin management, variability in ecological and physio-chemical targets, the protection of wetlands in relation to water quality and quantity status, the position of saturated and unsaturated groundwater zones, and the contribution of restored sites to the environmental cost recovery. It is also unclear how river restoration can be best included formally into the programs of measures under EU directives. While EU directives have a strong legislative basis, there is some flexibility in the implementation of river restoration measures.

The ECRR

The European Centre for River Restoration is an excellent platform providing both scientists, project managers and decision-takers with the opportunity for a regular refocusing of actual practices and forecasting of future human developments and their impact on river restoration.

The network function of the ECRR translates into several proposed strategic fields of activities for the ECRR:

- Policy support: The ECRR should be the supportive link between the EU and the professionals who have to apply the WFD and related directives. The ECRR should collect questions and problems from the different member states of the EU and should reflect on these in reports to the EU, proving the achievements of the EU Directives goals in the light of socio-economic benefits they can provide to the society (economic evaluation as a pillar to prove the goodness of river restoration). Aspects as climate change, renewable energy, fisheries, sustainable fisheries, (minimum) ecological flows, changed land use should be taken in account as well. ECRR should spread information on good experiences with river restoration (projects) as a possible solution to these problems, including the communication of common policy vision at international and national platforms like the EU, UN, FAO, the 5th World Water Forum etc.
.- Cooperation: the ECRR has a key role in providing support to strengthening the national and international networks. One way to do so is by expanding the number of official cooperation agreements with trans-national and national organizations. The ECRR should aim for more and stronger cooperation with NGOs, to assure better project implementation through commitment of local communities, municipalities and stakeholders, like farmer organisations, water boards, power companies etc. towards river, wetland and floodplain restoration.
- Information: Conference participants generally agreed on the need to assemble a best practices database and tool-kit on river restoration & river management techniques, based on commonly accepted guidelines as to what can be considered as best practice and expert assessment of selected projects. The database & toolkit should be structured in accordance with the different fields of application, with both scientific and non-scientific evidence included and accessible in various ways. Improved communication aims at targeting researchers, policy makers, practitioners and the public alike. Instruments available include an improved newsletter,r a distant e-learning course on techniques & best practices on river restoration, regional seminars, international conferences, publication of proceedings, etc. The ECRR intends to target EU funding to further elaborate this strategic field of activities.

- Communication: Strategic objective for the ECRR is to promote the conversion from research-oriented local river restoration activities to the elaboration and implementation of integrated larger-scale practical activities. As such, ECRR activities aim at increasing the base of knowledge and the common understanding of expectations among scientists, practitioners and decision-takers at the European level by means of publications, website conferences, all based on the recognition of the various stakeholder groups – technical disciplines, policy makers, decision makers, practitioners, funders, etc. The ECRR should emphasis the link between strategic and operational levels, by improving the base of knowledge of the decision-makers (awareness raising) and improving the understanding of scientists and practitioners on relevance and complexity at the policy level. It also provides scientists and practitioners with opportunities to exchange experiences and best practices. The ECRR serves as a representative of its mebers in international and national platforms like national governments and the EU, at international conferences, river basin commissions, the World Water Forum, etc., where the common view on river restoration can be expressed.

Bart Fokkens, Harald Leummens