SHORT REPORT ON MANAGEMENT OF HYDROMORPHOLOGICAL PROCESSES AND GOOD PRACTICES IN THE FIELD IN THE ALPINE CONTEXT

Developed according to the general appreciation received during the last meeting about the oral presentation of Italy, including the main inputs of the discussion, as well as some inputs emerging from the workshop held after the meeting.

WHAT - a document addressing the main issues in management of hydromorphological processes and the related good practices

WHY - in order to highlight the main aspects to be considered, as well to share the experiences and the main results, encouraging the diffusion of the good practices

FOR WHOM (TARGET) - for policy makers and experts dealing with sediment management and hydro-morphologic processes

HOW - a short and easy document including real cases and interventions already implemented by Alpine Countries

WHEN - during the process of implementation and revision of the management plans according to the EU 2000/60 and 2007/60 Directives

Summary

INTRODUCTION

With the 2000/60/EC Water Framework Directive (WFD), the European Commission introduces an innovative approach to the management of water resources, integrating protection and sustainable use of water bodies with the ultimate goal of achieving the good ecological status of all water bodies within 2015 or successive cycles thereafter, if special requirements for exemptions are met. The "good ecological status" of the water bodies is the result of the interplay of the three main components of aquatic ecosystems: biology, chemistry, hydromorphology, each of them represented through relevant "quality elements", described through metrics/indicators.

It is indeed acknowledged that good geomorphological processes sustain the shaping of habitats and the hydrodynamic conditions of a stream; therefore, they promote good ecological processes.

The evaluation of morphological conditions of a stream and its degree of alteration is therefore crucial in order to define strategies for morphological recovery and/or river restoration actions.

The interventions carried out over the centuries in the areas adjacent to watercourses, for urban or agricultural purposes, water abstraction, hydropower and the construction of flood defences have substantially altered the morphology of rivers. As a result, the characteristics of sediment dynamics have also been modified, leading to a lack or excess of sediment, channel incision or aggradation and in turn to a possible increase in flood risk and/or the alteration of the ecology of the river.

The goal imposed by the WFD is therefore to restore or preserve river dynamics and ecology, while ensuring standards of flood protection.

Under such a perspective, this document collects the experiences of different countries of the Alpine Convention in terms of hydromorphological assessment and management of rivers in the alpine environment, in order to support a sound and efficient programme of measures of ecological protection and safeguard from flooding required by European directives.

As described in the second Report on the State of the Alps on "Water and water management issues" (PSAC, 2009), in the Alpine context, a significant experience in establishing coupled flood and ecological measures has been already developed. Wherever this is possible, flood protection measures are coupled with the re-establishment of lateral (e.g. connectivity with the floodplain) and longitudinal continuity of water bodies and habitat improvement.

As sediments are an integral part of aquatic ecosystems and human activities interfere with sediment quantity or quality, an appropriate assessment of sediment dynamics and consequent sediment management strategies have to be accounted for inside the Management plans envisaged by many European Directives (WFD, Habitats Directive, Marine Strategy Framework Directive). If we are to manage sediment for environmental objectives (e.g. for maintaining habitats) and/or for socio-economic needs (e.g. dredging for maintaining navigation), this should be undertaken with a full awareness of impacts on a sediment sensitive system.

A coherent conceptual model at river basin scale is required for considering sediment dynamics, occurring at different spatial and time scales.

Effective sediment management requires a holistic approach taking into account system understanding both in terms of quality and quantity, the integrated management of water and sediment, upstream-downstream relationships, and supra-regional and transboundary collaboration.

Sediment processes at catchment scale are complex because of the essentially episodic nature of sediment transfer, storage times within the system etc. Sediment transport in rivers is mainly dependent on river discharge, which can vary considerably.

The quantitative and the qualitative aspects of sediment management are closely interrelated, as sediment and contaminants undergo the same transport processes, but, in addition, chemical processes may alter contaminants, and make them more or less bioavailable.
Sediment plays a crucial role in goods and services provided by freshwater and marine ecosystems. Ecosystem goods and services are affected when sediment quantity and quality characteristics change. Examples are the nutrient cycling, habitat substrate, resource, energy dissipation in the hydrological cycle, soil formation in inundation areas and delta regions, beach nourishment, recreation, and so on. The need for changes in sediment management can be expected due to the risks posed by climate change. Changes due to seasonal changes in precipitation and extreme events may induce changes in erosion, of discharge patterns and sedimentation patterns, altering sediment production and distribution over time and space. In addition, changing physical and chemical conditions may mean that sediment-bound contaminants will behave differently in the future.
Human activities impacting on hydromorphology will take place anyway. As an example, dredging is necessary to maintain and develop ports and harbours, navigable waterways, reservoirs for drinking water or energy production, etc. Both dredging and dredged material disposal may affect the environment. The overall management goal of any project should be to achieve a sustainable solution, where use is being made of the sediment for natural and/or human uses. Working with nature means to manage the dredged sediments within the system, or to use them in order to protect or at least not to impair natural resources. All associated risks and benefits of a project should be weighed and balanced, be it nature, economy, or society.

The report is divided into three main parts. Chapter 1 recalls the challenge in the implementation of the EU Flood and WF Directives and presents possible common solutions, such as green measures and green infrastructures. Chapter 2 focuses on the main aspects to be addressed for sustainable management of the hydromorphological processes starting from a sound knowledge of the river system, while chapter 3 illustrates examples of good practices in sediment management related to different countries of the Alpine Convention.

The aim of the report is to offer to the Parties of the Alpine Convention a short and easy document, including real cases and interventions already implemented by alpine Countries, in order to consider management of hydromorphological processes during the process of implementation and revision of the management plans according to the EU 2000/60 and 2007/60 Directives.

1 THE EU DIRECTIVES 2000/60/EC AND 2007/60/EC COMBINED IMPLEMENTATION[1]

As the Blueprint to Safeguard Europe's Water Resources (EC, 2012) highlights, “the current EU legal framework on water is extensive, flexible and essentially fit to address the challenges faced by the aquatic environment. However, there is a need for better implementation and increased integration of water policy objectives into other policy areas, such as [...] the integrated disaster management”.
The EU Water Framework Directive (Directive 2000/60/EC - WFD) provides an innovative approach to the sustainable management of water resources ensuring the good status of water bodies. From the same point of view, the 2007/60/EC Flood Directive (FD) constitutes a framework for flood risk management (prevention, protection and mitigation).
Although, at first sight, the purposes of the FD and the WFD can be seen as conflicting (natural conditions of the water bodies versus flood risk protection/safety, Figure 1). A coordinated implementation of the two Directives has been required (e.g. FD art. 9; EU Technical Report - 2014 – 078), eliciting a new approach aimed at optimizing the mutual synergies and minimise conflicts between them.

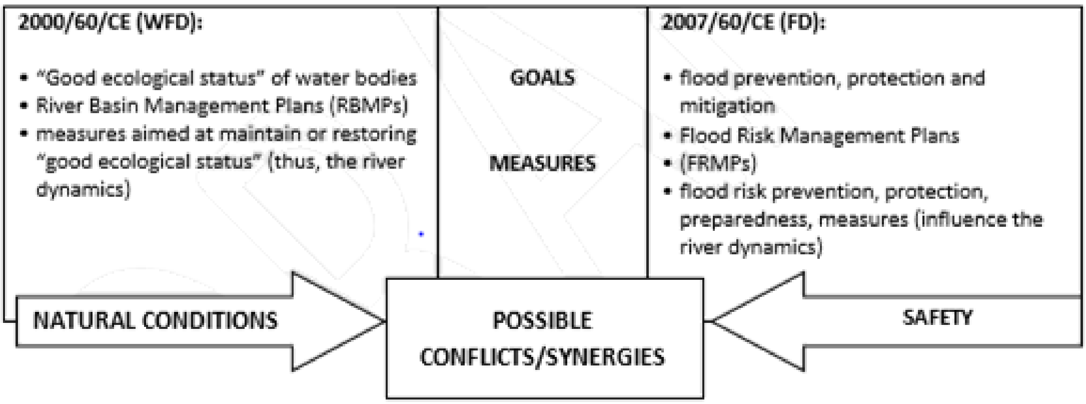

Figure 1- WFD vs. FD (Source: modified from Bussettini and Bianco, 2013[2])

Flood protection measures are not explicitly quoted within the WFD; a reference to them is made indirectly, as the WFD requires to identify, assess and control all major anthropogenic pressures on the water environment.
Moreover, many other reasons suggest the opportunity to coordinate the application of the two Directives. Among them: in many Member States the legal and planning instruments overlap; for the assessment and management they both use the same “reference area”, the river basin; measures taken under one Directive may have an influence on those of the other, the coordination raises the efficiency on the implementation of measures and on the use of resources.
Figure 2 shows how the three different aspects of sustainability overlap between the two Directives, the environmental aspect is the main one (EC, 2014).

[1] Mainly based on EC (2014) Technical Report
[2] “https://www.unibz.it/it/sciencetechnology/events/Documents/l_bussettini_2013_11_22.pdf” Martina Bussettini and Andrea Bianco, Workshop “La direttiva europea «Alluvioni»: verso una nuova gestione del rischio idraulico in ambito montano”, November 21-22th, 2013, Bolzano, Italy (viewed on 25 May 2016)

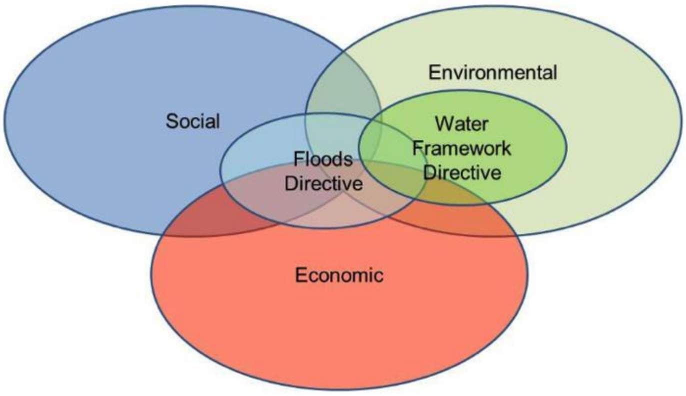

Figure 2 - Aspects of sustainability addressed by the FD and WFD and they overlapping areas (EC, 2014)

The coordinate application between the two directives has been explicitly stated by FD art 9 that oblige Member States to take appropriate steps "focusing on opportunities for improving efficiency, information exchange and for achieving common synergies and benefits having regard to the environmental objectives laid down in Article 4 of Directive 2000/60/EC". In particular:

- Flood hazard and risk maps should be developed using WFD River basin management plans (RBMPs) data;
- Flood risk management plans (FRMPs) should be carried out in coordination with and may be integrated into reviews of RBMPs;
- Coordinated stakeholder active involvement;
- Development of win-win measures: the coordination on the development FRMPs and RBMPs measures increases the opportunities for synergies to be recognized, cross referencing of objectives, and to ensure the realization of mutual benefits.

The complete description of the state of the art on the combined implementation of the FD and WFD in the Alps is reported on the "Flood Directive (2007/60/CE) and Water Framework Directive (2000/60/CE) in the Alpine context".

1.1 Possible measures to be implemented: from grey to the green measures

Several pressures affect the hydrological regime of rivers, magnitude of flow and timing, both increasing the frequency and magnitude of flood peaks and reducing the availability of water to streams during the prevailing low flow (base flow). It is the case of changes in land cover, soil structure and compacting, loss of floodplains and wetlands, and stormwater runoff from urban areas that cause loss of water retention combined with accelerated runoff.

Traditional flood management measures consist on physical interventions, construction or the use of engineering services to make buildings and infrastructure able to withstanding extreme events. These structural measures, or "grey" measures, are designed to reduce the risk related to a flood event, then to reduce the probability of occurrence of potentially dangerous events.

Main grey measures that can be used to manage floods are:

- dams and reservoirs
- embankments
- detention and retention basins
- bypass and diversion channels

- channelization.

During the last decades, structural measures were extensively used as management options for flood events. Although they continue to play a fundamental role in protecting people and things against flooding, more attention is now paid to the ecological impact that these infrastructures cause on the environment. Grey measures may in fact cause unplanned hydrological, morphological and environmental impacts.

Grey measures are being progressively substituted by a new type of environmental friendly, green measures due to their environmental impact that the contrasts with the goals of the WFD. These measures aim to improve the natural dynamics of the hydrological balance improving water retention, water storage, infiltration during the floods but also increasing the base flow during the dry season. Nevertheless, there are many cases where we still need grey measures (e.g. flood protection in large cities).

1.2 The "Green Infrastructure" concept

Green infrastructure is a relatively new overall approach on the environmental management aimed at conserving and restoring landscape's nature and biodiversity. Moreover, green infrastructures are a modern approach to protect public health, safety, and quality of life. From the water management point of view, Green infrastructure incorporates both the natural environment and engineered systems to provide the good ecological status of the water and ecosystem (values and functions) and the safeguard of things and population. This approach provides a wide array of benefits to people and wildlife. An illustration of the Green Infrastructure concept has been shown in Figure 3.

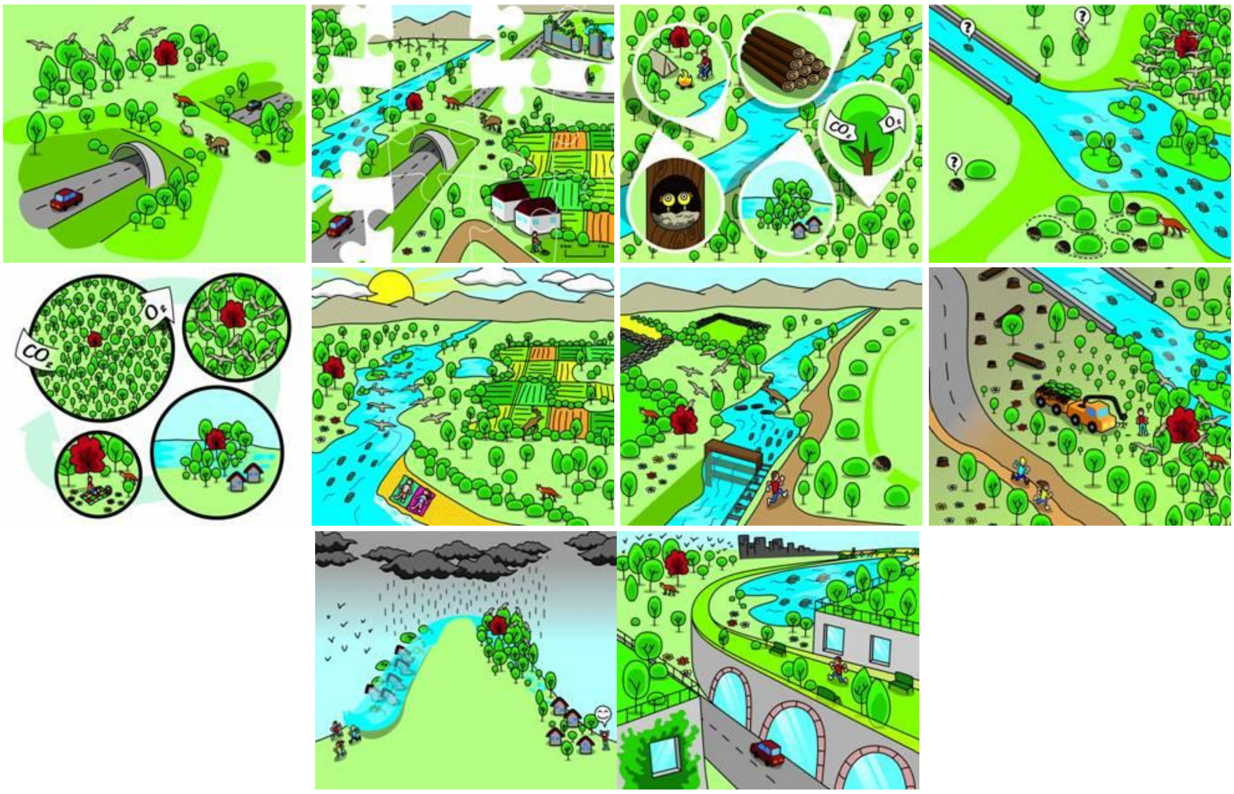

Figure 3 - Illustrations of the Green Infrastructure concept (Source: European Commission, Environment, Nature & Biodiversity. http://ec.europa.eu/environment/nature/ecosystems/illustrations.htm viewed on 25 May 2016)

A comprehensive definition and an extensive analysis of the green infrastructure concept, examples of its application and of its integration into policy sectors are given in EEA Technical report No 18/2011 "Green infrastructure and territorial cohesion - The concept of green infrastructure and its integration into policies using monitoring systems" (EEA, 2011). In the report it is also highlighted how the joint goal to preserve/recover the environment, foreseen by the WFD, can become functional to achieve those of the FD.

There are many measures that provide a significant contribution to both FD and WFD objectives guaranteeing the reduction of flood risk and multiple benefits for water quality, nature and biodiversity. River and floodplain restoration, whereby natural processes are restored, is one of these. Rivers, streams, wetlands, floodplains, and forests have an important role on flood protection, and should be viewed as essential and effective components of our water infrastructure.

Thus designing a Green Infrastructure, with reference to the two directives, means an increase in water efficiency choosing Natural Water Retention Measures to improve water retention, water storage, infiltration rather than building costly new water infrastructures. Nevertheless, we have to accept that dealing with extreme events, green measures have its limitations and usually complements with grey measures are necessary.

Natural Water Retention Measures (NWRMs) can be classified in:

- those aimed to safeguard and enhance the water storage potential of ecosystems and aquifers, by restoring natural features and characteristics of water courses and restoring ecosystems.
- those that use nature to regulate the flow and transport of water so as to smooth peaks and moderate extreme events.

Figure 4 shows how the natural flood management strategies can be classified with reference to the place where they origin, either near the source of a flood or downstream, and by how the management strategy may be distributed on the watershed (EC, 2014).

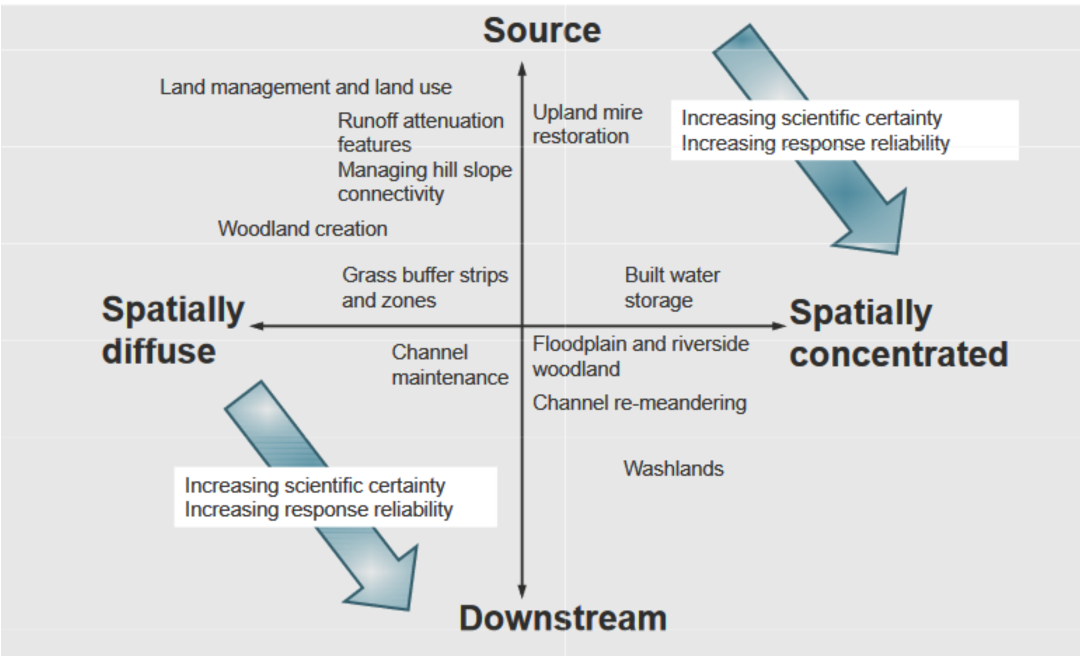

Figure 4 - Classification of natural flood management strategies. (Source: POST, 2011 in EC, 2014)

2 THE MAIN ASPECTS TO BE ADDRESSED: flow, sediment transport and habitat modelling in a river system

Rivers and their watersheds are unique, complex, dynamic systems where a wide range of hydrologic and geomorphologic processes occurs. The continuous interactions among water, sediments and vegetation within a river system are fundamental to create and maintain habitats and so to sustain communities and healthy ecological processes.

The dynamic interactions among geomorphology, hydrology, local hydraulic condition, sediment production and transport in a river system, are analysed and evaluated through hydromorphological assessment.

Adequate assessment of stream hydromorphology requires the consideration of many aspects such as the flow regime and its modifications, the sediment transport, the river morphology, the lateral channel mobility, and the river continuity (WFD).

In particular, water flows from the catchment to the rivers and can mobilize sediments and organic material. The same material then moves downstream shaping the riverbed. Sediment regime is essential to the instream and riparian ecology, which is influenced by the continuous system changes. Sediment-related processes regulate channel morphology, bed conditions, community structure and water quality: disruption to these processes leads to potential habitat degradation. Therefore, an understanding of hydromorphological alteration in river ecosystems is central to planning effective ways to protect and restore river systems.

Alterations on morphological processes and loss of biotopes have been recognized among the major pressures affecting water bodies located in Alpine areas (AWC, 2011).

2.1 Review on eco-hydromorphological methods

Acceptable assessment of stream and river hydromorphology requires the consideration of the flow regime and its modifications, of the sediment transport, of the river morphology, of the lateral channel mobility, and of the river continuity. A large variety of ecological and hydromorphological assessment methods (for a total of 139 methods, European and non-European, have been identified) have been developed over the last decades to characterize the hydromorphological conditions of streams and rivers and to classify their status, they differ, in general, in terms of targets, spatial scales, and approaches used.

Five broad categories of hydromorphological assessment methods can been distinguished (Rinaldi et al, 2013). They differ either on the aim of the assessment (e.g. physical habitat, morphological or hydrological alterations, etc.) or the spatial context (e.g. channel vs. riparian zones) to which they are applied:

1. Physical habitat assessment, i.e. methods aiming to identify, survey and assess physical habitats;
2. Riparian habitat assessment, i.e. methods aiming to identify, survey and assess riparian habitats;

3. Morphological assessment, i.e. methods performing a geomorphological evaluation at broader spatial scales rather than a physical habitat assessment, incorporating morphological characteristics or human pressures;
4. Hydrological regime alteration assessment, i.e. specific methods for the assessment of hydrological regime alteration;
5. Longitudinal fish continuity assessment, i.e. specific methods for the assessment of the longitudinal continuity for fish communities.

In Figure 5 the spatial context and scale of each category is schematically reported as well as the overlaps among them.

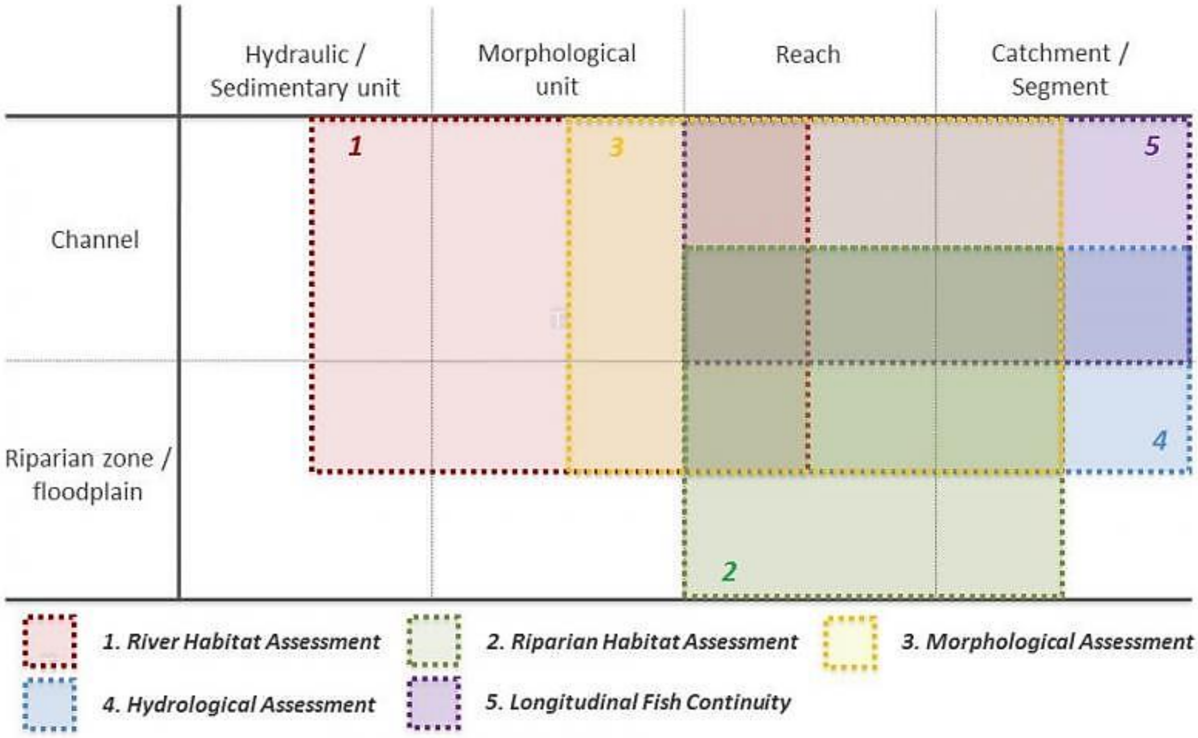

Figure 5 - Spatial context, spatial scales and overlap between assessment method categories (Rinaldi et al, 2013)

In the following paragraphs, selected examples of relevant approaches to hydromorphological assessment and process management are illustrated.

2.1.1 The EU FP7 REFORM project

The EU FP7 REFORM project (REstoring rivers FOR effective catchment Management) is the first European project highlighting the fundamental role of fluvial hydromorphology in supporting river processes and restoration actions for a sustainable catchment management.

REFORM provides a framework for improving the success of hydromorphological restoration measures to reach, in a cost-effective manner, target ecological status or potential of rivers. Such a framework encompasses different methodological approaches and tools[3], supporting each stage of River Basin Management planning and implementation, in a pressure-state response approach, with a particular emphasis on the design of programmes of sustainable WFD restoration and mitigation measures for the upcoming 2nd round of RMBP.

River management implies a sound knowledge of river processes at the different relevant spatial and temporal scales: therefore, a process-based multiscale hydromorphological framework (Gurnell et al., 2014, 2016), including a series of hydromorphological tools (Rinaldi et al., 2016a), constituting the assessment phase of such a framework, has been developed in order to characterize and assess river hydromorphology. Such tools derive from an extension of those developed in Italy in the context of the IDRAIM framework (Rinaldi et al., 2015; 2016; see par. below) and are: the Morphological Quality Index (MQI), the Morphological Quality Index for monitoring (MQIm), and the Geomorphic Units survey and classification System (GUS). The MQI is aimed at an assessment, classification and monitoring of the current morphological state; the MQIm aims at monitoring the tendency of morphological conditions (enhancement or deterioration); the GUS provides a characterization, classification and monitoring of geomorphic units (Rinaldi et al. 2015a, b, c).

2.1.2 Classification of the hydro-morphologic status of rivers: the IDRAIM methodology

IDRAIM is a comprehensive methodological framework for hydromorphological assessment, analysis and monitoring developed in Italy by ISPRA through a multidisciplinary research group (hydrologists, fluvial geomorphologists, forest scientists, engineers). It supports the management of river processes by integrating the objectives of ecological quality and flood risk mitigation envisaged by both WFD and by the Flood Directive 2007/60/CE. The framework, structured in four phases (Figure 6), provides specific consideration of the temporal context, in terms of reconstructing the trajectory of past channel evolution as a basis for interpreting present river conditions and future trends.

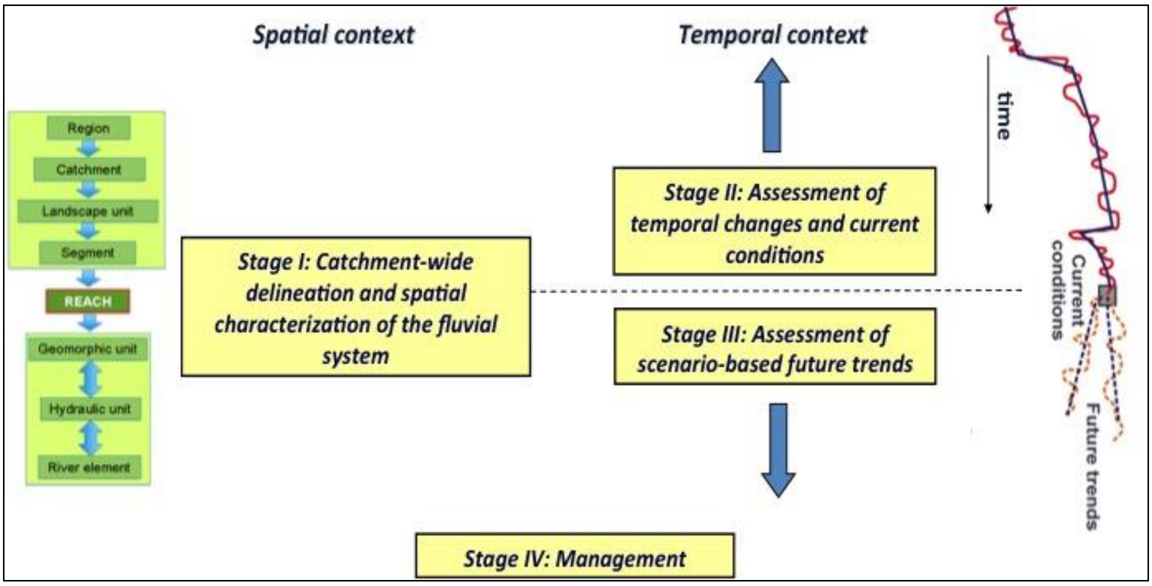

Figure 6 - IDRAIM methodological framework (Rinaldi, 2014)

[3] http://www.reformrivers.eu/results/deliverables

A series of specific tools have been developed for the assessment of river conditions, in terms of morphological quality (MQI; MQIm; GUS) and channel dynamics (the Morphological Dynamics Index – MDI; the Event Dynamics Classification –EDC; the morphological river dynamics corridors -MDC, EDCo).
The monitoring of morphological parameters and indicators, as well as the assessment of future scenarios of channel evolution, provide additional knowledge for the identification, planning and prioritization of actions for enhancing morphological quality and/or risk mitigation.
The Morphological Quality Index (MQI; Rinaldi et al 2013; 2016) is envisaged in Italian legislation both for hydromorphological assessment and for the identification of heavily modified water bodies (D.M. 260/2010; D.M. 156/2013. It was designed to comply with WFD requirements, but its use can be extended to other applications in river management. The evaluation of stream morphological quality is preceded by a phase of river segmentation, consisting of an initial division of the network into river reaches with homogeneous morphological characteristics. The evaluation procedure consists of a set of 28 indicators, which were defined to assess longitudinal and lateral continuity, channel pattern, cross section configuration, bed structure and substrate, and vegetation in the riparian corridor. These characteristics are analysed in terms of geomorphological functionality, artificiality, and channel adjustments. The method is aimed to an overall and comprehensive evaluation of river conditions, therefore promoting understanding of pressure – response that can support identification of possible management actions. In fact, the same type of pressure may result in different responses for different rivers. For this reason, the artificiality indicators identify the potential elements of alteration, whereas the functionality and channel adjustments indicators assess the geomorphic responses (effects) to these disturbances, including off-site impacts and adjustments that occurred in the past. This synergic use of the different components of the assessment and their mutual feedbacks promotes a sound understanding of the river conditions and causes of alteration, which can be used to select appropriate management actions.
Application of the method on hundreds of river reaches covering a wide range of physical conditions and human pressures of Italian streams enabled the testing of the overall methodology and its extension to European and international scale.

2.1.3 The Hydromorphological Evaluation Tool (HYMET)

The Hydromorphological Evaluation Tool (Klösch and Habersack, 2016) offers a possibility for assessing the hydromorphological condition without the need for defining a reference condition. A hierarchical assessment procedure (through multiplication of indicator values, Figure 7) ensures the consideration of sediment connectivity and transfer as the precondition for (re-)establishing morphodynamic processes. By budgeting the sediment transfer through the river network (based on data and/or expert knowledge), the reach’s trajectory (temporal change of hydromorphological condition) is traced back to upstream alterations of sediment supply and transfer. At reach scale, the impact of artificial constraints is analysed. The HYMET helps to identify the appropriate scale for effective restoration of river reaches (e.g., remobilisation of retained sediment in tributaries, removal of channel constraints at reach scale).

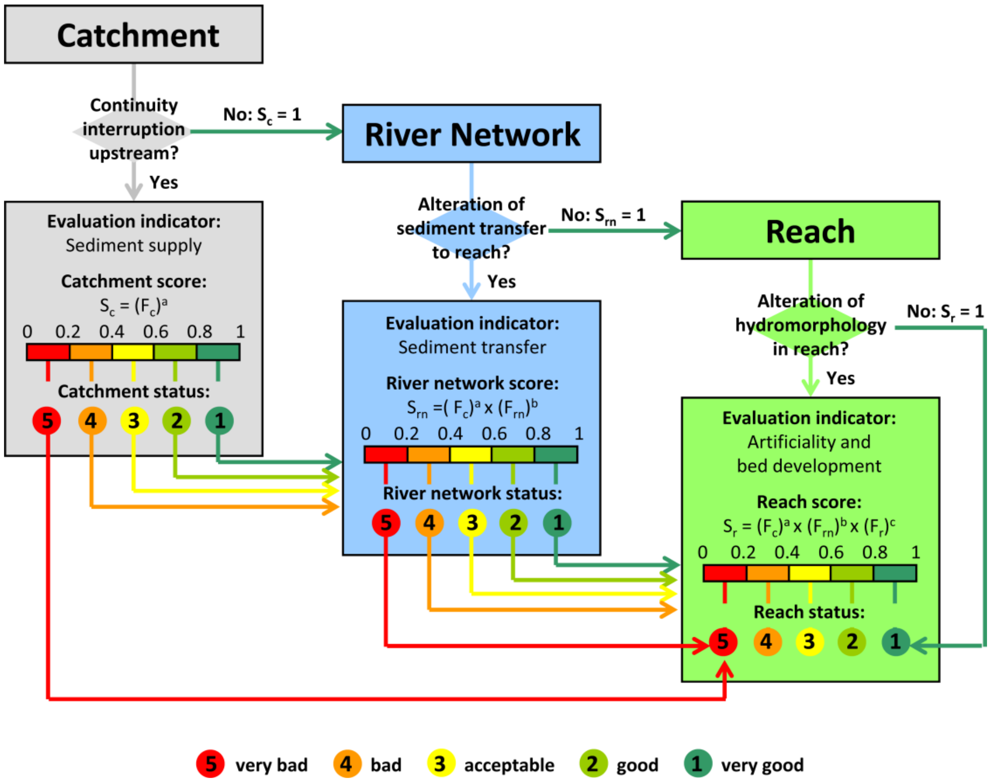

Figure 7 - Concept of the Hydromorphological Evaluation Tool. Fc = catchment factor, Frn = river network factor, Fr = reach factor; a, b and c: exponents for adjusting marking thresholds (Klösch and Habersack, 2016)

2.1.4 The MESOHABSIM methodology for habitat evaluation and modelling

The Mesoscale Habitat Model (MesoHABSIM) was presented in literature by Prof. Piotr Parasiewicz (Parasiewicz, 2001, 2007). Vezza et al. (2014b) proposed an adaptation of the habitat modelling framework for mountainous streams, considering three main steps: (1) the habitat description, (2) the biological model definition, and (3) the development of habitat-flow rating curves and (4) the analysis of habitat time series. The flow chart presented in Figure 8 outlines inputs and outputs of the MesoHABSIM model and the sequence of the main steps of the methodology.

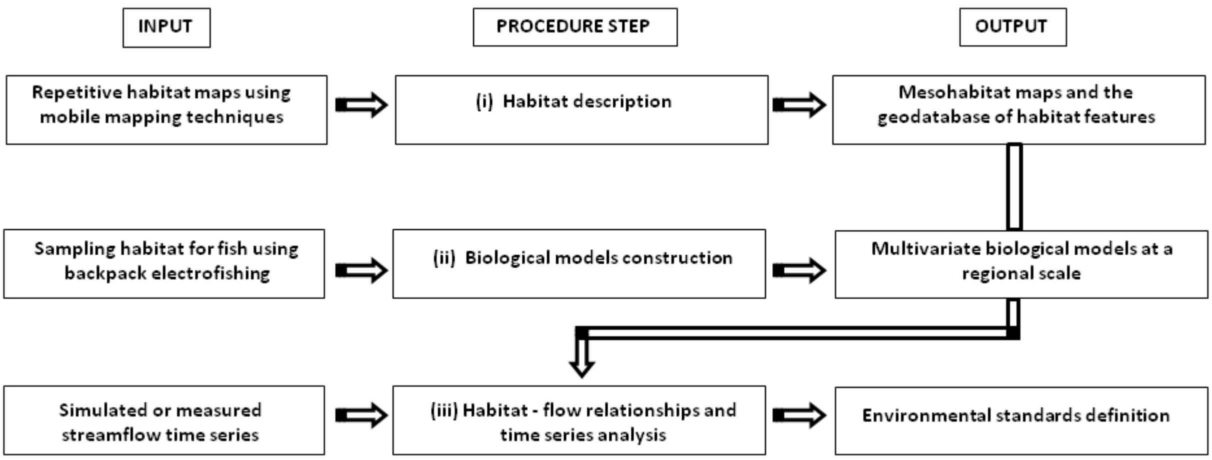

Figure 8 - Implementation steps of the MesoHABSIM methodology for the definition of environmental standards in rivers (Parasiewicz, 2007; Vezza et al., 2014b

Habitat description

The habitat description is based on two main processes: the representative site selection and the habitat survey. For both processes we use the Geomorphic Units survey and classification System (GUS, Rinaldi et al., 2015) approach, to identify, characterise and analyse the assemblage of geomorphic units within a given representative reach (e.g., pool, riffle, glide, rapid, cascade). Detailed information on habitat characteristics are generally collected walking downstream, delineating the morphological units polygons in a GIS environment and recording the mesohabitat-scale features (e.g., unit area and type, cover, mesohabitat longitudinal connectivity, water surface gradient) and coming back upstream, collecting depth, velocity, and substrate information (see, Vezza et al., 2014b, for details). Because of the regular changes due to flow in the habitat of rivers, the survey should be repeated in the same reach for three to five times, referring to key bioperiods for the considered fish community, e.g., rearing and growth stage or migration and spawning period.

Biological models construction

The biological indicators proposed for mountainous streams are based on a target fish community, due to the consistent ecological response of fish to hydro-morphological alterations (Poff and Zimmerman, 2010). Habitat suitability models are built at the mesohabitat scale using data from river reaches characterized by both natural hydro-morphological conditions and reference fish community composition. Machine learing techniques (e.g., Random Forests, RF) currently represent an appropriate method for the habitat evaluation to identify the habitat attributes affecting species distribution (see e.g., Vezza et al., 2014a). Two binary habitat suitability models are created with RF as follows: a suitable habitat model indicating the potential for fish presence (to distinguish between absence and presence of the fish) and an optimal habitat model for high abundance of fish (to distinguish between fish presence and abundance).

Habitat rating curves

The digital mesohabitat maps built during the habitat surveys and the mesohabitat suitability criteria are the basis for the development of habitat–flow rating curves for each surveyed river reach. The area of mesohabitat with suitable (or optimal) conditions is summarized for every reach by weighting suitable habitat area by 25% and the optimal habitat area by 75%, and it is plotted against the wetted area at the highest measured flow (Parasiewicz, 2007). The habitat values are interpolated using a mathematical spline function for the target species and life stages to represent the habitat-rating curve.

Habitat time series analysis

The flow time series, measured or simulated for the surveyed river reach, can be transformed in habitat time series using the habitat rating curve (Milhous et al., 1990). The obtained habitat time series is then statistically analyzed using the uniform continuous under thresholds (UCUTs, Parasiewicz, 2008) methodology to establish the habitat stressor thresholds and calculate habitat integrity indices (Vezza et al., 2015). This analysis is based on the assumption that habitat is a limiting factor, and events occurring rarely in nature create stress to aquatic fauna and shape the community. The habitat integrity index (IH, proposed by Vezza et al., 2015), reported in ISPRA Manual 132/2016 (Rinaldi et al., 2016) and in the e-flows guidance of the European Commission (European Commission, 2015), is currently considered a valuable tool for ecological assessment and monitoring in Alpine streams and rivers, which need consistent and robust ecological indicators. Small hydropower is increasingly developed in the Alps and the availability of effective tools, such as the MesoHABSIM methodology and the habitat integrity index - IH, can be of paramount importance for habitat evaluation and e-flow assessment. The abovementioned tools are critically needed to support decision-making, implement European Directives, such as the Water Framework Directive and the Habitat Directive, and to cope with the present lack of ecological indicators sensible to hydro-morphological alterations.

2.2 *The role of the sediment*

Sediment is an essential, integral and dynamic part of our river playing an important role in maintaining fluvial environments such as channel systems, floodplains, wetlands and estuaries. Natural Systems usually tend towards an equilibrium between erosion and deposition. Where human activities interfere with sediment quantity or quality, sediment management becomes necessary.

Sediment transport processes and sediment continuity play a multi-fold role. Intense natural sediment dynamics has a beneficial effect on ecological processes, but, at the same time, it promotes intensive sediment transport, often in conjunction with large woody debris, that may strongly amplify flood hazards.

Therefore, a sound understanding of the changing equilibrium between sediment supply and a river's sediment transport capability is essential for the success of overall integrated water resource management.

Alterations in sediments transport, as the corresponding impacts on morphological processes, has been recognized as one of the major pressures affecting EU water bodies (EEA, 2012) and those located in Alpine areas (AWC, 2011).

2.2.1 State-of-the-art in the monitoring of sediment transport in mountain basins

Monitoring sediment transport is crucial for a rationale and effective planning of river management activities. In particular, bedload transport is tightly linked to the morphological evolution of river channels at different temporal scales, and debris flow processes are of the utmost relevance as natural hazard within the Alps. The EU Alpine Space project "SEDALP" (2012-2015, www.sedalp.eu,) among other results (see later) – has allowed to broaden the quantitative knowledge on sediment fluxes in the Alpine channel networks (Figure 9). Moreover, the SEDALP led to the formulation of the first protocols for the local guide agencies and for other technical stakeholders through the complex task of selecting the most suitable monitoring technique for the different sediment transport processes.

The main objective of SedAlp was to develop tools and strategies for an integrated sediment management. However, the knowledge about sediment transport processes is nowadays still limited, and thus data were - and still are - very needed. Across the Alps, several different monitoring methods for sediment transport are currently in use, and the first SedAlp Milestone "Protocol for data collection method in sediment transport" (www.sedalp.eu/download/dwd/reports/milestone.pdf) aimed to ensure the comparability of the collected monitoring data. Three standard protocols for bedload transport, debris flow and wood transport monitoring were developed. These protocols are intended to describe the used monitoring technics and data processing methods. Furthermore, the protocols work also as guidelines to assist in choosing the appropriate monitoring method for supporting prospective monitoring efforts.

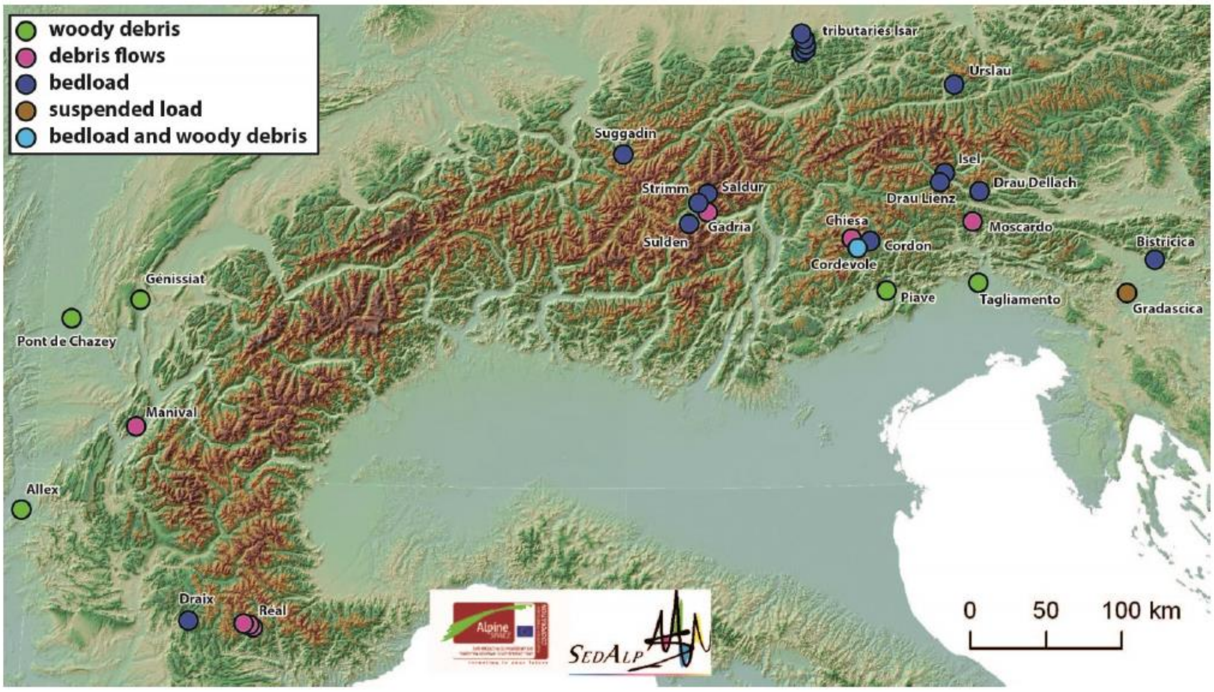

Figure 9 - Map of the monitored sites within SEDALP (WP5 – Sediment transport monitoring)

The protocol stresses the importance of deriving reliable and accurate debris-flow hydrographs, mean flow velocities, peak discharges and volumes relying on the most comprehensive approaches found in literature. Some suggestions on the acquisition parameters for the main devices applied to debris-flow monitoring are provided, in order to meet the need of standardization in data collecting and analysis for a better investigation and comprehension of these phenomena (Figure 10).
The protocol on bedload transport monitoring gives an overview about the different methods available, with a focus on those deployed within SedAlp. A suitability table provides information on whether or not a certain method is adequate to measure a given sediment-related variable (Figure 11). The protocol also provides harmonized field forms, which enable for the first time standardized monitoring activities across the Alpine region. Furthermore, the protocol assists in choosing the appropriate monitoring method and provide support in the definition of the requirements for a bedload monitoring station to be installed in a mountain river.

Remarkably, the results of SEDALP WP5 (Aigner et al., 2015) demonstrated once more why available bedload transport equations and related numerical models cannot be used without a proper calibration against field data, as highly erroneous bedload fluxes are very likely to be predicted when applied especially at low to moderate flow stages. In fact, as most mountain rivers are in supply-limited conditions, it is not the transport capacity to control the actual bedload rates, but it is the supply of available sediments to have the dominant role under non-extreme flow conditions (Comiti and Mao, 2012). Therefore, the results pointed out that bedload transport must be monitored – at least during a short period, and using direct and/or indirect methods – in order to obtain meaningful estimates for practical applications (e.g. design of river restoration interventions and/or of river control structures).

Monitoring method / Parameter of Interest	Ultrasonic sensor	Radar sensor	Laser sensor	Geo-phone	Fibre optic sensor	Wire sensor	Pendulum	Micro-phone	Doppler speed-ometers	Video-camera
Debris-flow occurrence	•••	•••	•••	•••	•••	•••	•••	•••	-	•••
Peak flow depth	•••	•••	••	-	-	•	-	-	-	•
Debris flow "hydrograph"	•••	•••	•••	••	••	-	-	-	-	-
Ground vibration	-	-	-	•••	-	-	-	-	-	-
Mean flow velocity, peak discharge and volume	•••	•••	••	•••	••	-	-	••	-	•
Surface velocity	-	-	-	-	-	-	-	-	•••	••

Figure 10 - Suitability table for debris flow monitoring (Cavalli et al., 2013)

Parameter of Interest / Monitoring method	Basket sampler (cross section wise)	Basket sampler (repeated)	Bunte traps (for wadable streams)	Slot Trap	Monitored Retention Basin	Geo-phones	Acoustic pipe sensor	Tracers	Terrest-rial Laser scanning	Aerial imagery	Scour chains
Specific bedload rate *[kg $m^{-1}s^{-1}$]*	●●●	●●●	●●●	●●●	●●	●	●	-	-	-	-
Bedload rate *[kg s^{-1}]*	●●●	-	●●●	●	●●	●	●	●	-	-	●
Total bedload volume *[kg, t]*	●●●	-	●●●	●	●●●	●	●	●	-	-	●
Spatial variability of bedload discharge	●●	-	●●●	-	●	●●●	●	●●	-	-	-
Temporal variability of bedload discharge	●	●●●	●	●●	●●	●●●	●●●	-	-	-	-
Initiation of motion *[m; m^3s^{-1}]*	●	●●	●●	●●●	●●	●●●	●●●	●●●	-	-	-
Transport path/ velocity *[m; m s^{-1}]*	-	-	-	-	-	-	-	●●●	-	-	-
Variation of sediment storage *[m, m^3]*	-	-	-	-		-	-	-	●●	●●	●●

Figure 11 - Suitability table for bedload monitoring (Aigner et al., 2013)

3 GOOD PRACTICES FOR SEDIMENT MANAGEMENT

Sediment transport is an issue relevant to the three main objectives of water resources management: water protection, water use and flood protection. Alteration of sediment dynamics in a river system causes significant changes to river functions and forms (e.g. longitudinal and lateral continuity, etc.) leading to negative impacts on river ecosystems (river bed changes and river bed break through, affected groundwater levels, losses of gravel bars), on water related uses (mainly hydropower production and irrigation) and on flood risk (Figure 12).

Figure 12 - Sediment surplus or deficit effects (Source: Schwaiger K., 2012[4])

Sediment transport is an emerging issue on the national and international level, but is not explicitly addressed in EU water legislation what results in a lack of attention and funding. In the Alpine context siltation of reservoirs and rivers is a serious and increasing problem, which was underestimated in the past. Climate change will affect sediment transport but there is no clear evidence with respect to the effects, since possible increased mobilisation in higher altitudes might be altered by flow regimes.

Tackling these challenges there is a broad range of measures in place, but there is no "one-size-fits-all‟ approach. Main objectives of sediment management should be to:

- restore a dynamic sediment balance
- stop river degradation
- improve ecological status
- improve flood management

In December 2011, the Platform "Water Management in the Alps" of the Alpine Convention organised a workshop on sediment transport in Vienna[5] to exchange knowledge, developments and concrete experiences about quantitative sediment management. The workshop concluded with a clear need for action in terms of policy framework, e.g. to use existing opportunities (e.g. 2nd River Basin Management Plans) and to close existing knowledge gaps in relation to reservoir siltation (e.g.

[4] "Results of the Alpine Convention Workshop on Sediment Transport, Vienna, December 2011 ", Karl Schwaiger, 4th International Conference "Water in the Alps" 2012, Munich, Germany.

[5] http://www.alpconv.org/en/organization/groups/WGWater/workshopsediment/default.html

conditions and effects of reservoir flushing), monitoring and modelling of sediment transport as well as effects of climate change.
In the following paragraphs, examples of good practices in sediment management are illustrated.

3.1 Sediment management in reservoirs[6]

Reservoirs interfere with sediment transport continuity causing important impacts in river ecosystem upstream and downstream. Moreover, the progressive siltation of reservoirs reduces their storage volume affecting both their usable life and their capacity to reduce flow peak during floods.

In Europe, nearly 1% of the storage volume is silted every year[6]; nevertheless, the aspect has been underestimated in the past. In recent years the problem has been growing more evident as the need for water storage seems to increase, and climate change effects are likely to intensify the situation in the coming decades.

Approaches for solution are already in place, both for existing or new reservoirs, but require case specific approaches tailored to the situation and innovative approaches in particular for new dams. For measures to overcome siltation problems, e.g. flushing, some experiences and good practice do exist. But there is not really a standardized state of the art and a need to close the knowledge gap about the ecological impacts (critical concentrations downstream), the mid- to long-term consequences and the sustainability of remediation.

In the following paragraphs, examples of good practices in sediment management in reservoirs are illustrated.

3.1.1 Sedimentary state diagnosis downstream of dams administratively classified as «list 2»[7]

The new French regulations regarding ecological continuity (Article L.214-17 of the code of the environment and its Circular of application of January 18th, 2013) oblige the administrators of transverse structures (weirs, dams) inside rivers classified in List 2, to guarantee the circulation of fishes and in particular "to insure the sufficient sediment transport for the circulation of migratory fishes" (L.214-17 IT, I, 2°). The law asks to assure on the average/long term: a surface; a thickness; a gravel size distribution, a layout (weak armoring); a frequency of movement of the alluvial substratum (allowing the survival of the aquatic communities species inside the considered reach).

This was agreed in order to guarantee the survival of aquatic communities (fishes, invertebrates, vegetation), whose habitats are subordinate in the alluvial substratum. The protection or the restoration of the functionality of the entire geomorphological reach is not required.

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[6] Summary Paper for the International Workshop on Sediment Transport, 16 Dec 2011, Vienna http://www.alpconv.org/en/organization/groups/WGWater/workshopsediment/Documents/SummaryPaperSedimentWorkshop%20.pdf

[7] "Sedimentary state diagnosis downstream of dams administratively classified as « list 2 »", Malavoi Jean-René, Loire Rémi, El Kadi Abderrezzak Kamal, I.S.Rivers - 2e Conférence Internationale, 22 - 26 june 2015, Lyon, FRANCE

EDF - Division Production Ingénierie Hydraulique developed a method, based on the overall evaluation of the 5 descriptive parameters of the unrefined alluvial substratum specified the Circular, in order to assess if the sedimentary state of a stream reach downstream of transverse structures is compatible with the life of the aquatic biocenosis "targets" present on this reach. The method also allows estimating if the potentially impacted reach presents a “sufficient state” from the point of view of alluvial habitats.

Proposed approach for the diagnosis of sedimentary state

The method proposed is based on the principle of the relative comparison of a “reference” reach situated upstream of the dam to a “potentially impacted” reach situated downstream of the dam. Two approaches are proposed:

A global “reach” approach, where all or part of a reference reach and of the reach potentially impacted is described.

A local “site” approach, at least one "representative” site by homogeneous reach, both upstream (in the reference reach) and downstream (in the potentially impacted reach) is described.

The method consists of two phases: the first phase is a synthesis of the existing data and “global" diagnosis of hydrosedimentary functioning (comparison of bathymetries, search for indications of bed incision, etc.), while the second phase consists of the “sufficient sedimentary state” diagnosis. Phase 2 also consists of two parts: the search for a reference reach and the application of the description protocols.

The identification of a reference reach is necessary in order to assess the magnitude of the change in the sedimentary state potentially generated by the dam in the considered reach. Once the reference reach has been identified, “the difference” in the sedimentary state of the reach under investigation can be calculated. The reference reach can be on the same stream (generally upstream) or on a geomorphological similar one nearby. The description protocol to apply is different in the two cases.

The choice of the reaches to be studied and to be compared is very important and must be done in a very rigorous way in order to prevent mistakes in the consecutive evaluations. Figure 13 shows an example of the difference between the geomorphological behaviour of the stretches directly upstream and downstream the “Plan du lac” dam.

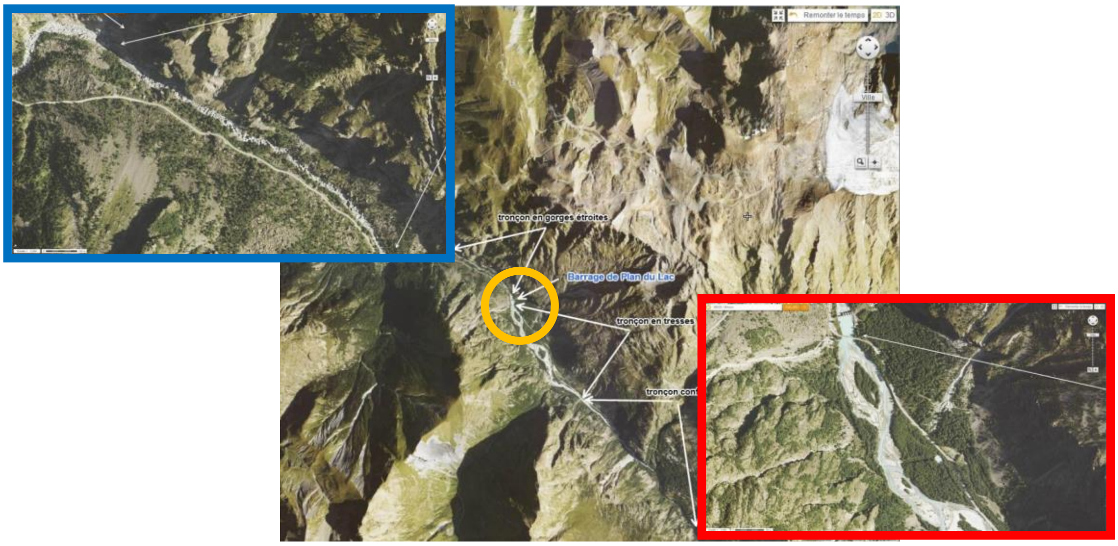


Figure 13 - Choice of the reference reach, difference between the geomorphological behaviour of the stretches directly upstream (box with blue outline) and downstream (box with red outline) the Plan du lac dam (in the orange circle)

The "sedimentary status" of the stretch and of the reference reach is then estimated using a global reach approach. Once the length of the stretch to be described has been identified and the transects are properly positioned (prepositioning of transects on map and use GPS or Topofil on field to avoid operator bias), the monitoring phase can start. The aspects monitored are the characteristics of the morphodynamic unit, the vegetation of the alluvial bars and other parameters along 15 to 20 cross sections of the riverbed (Figure 14).

Figure 14 - Identification of the wetted bed and of the bankfull bed of a river stretch

In particular the bankfull width and height, the wetted width at the observed discharge, the morphodynamic unit type (pool, riffle, etc.) are measured for each transect: one measure every 1/10 of the wetted width, even outside of the wetted area (gravel bars). For every measurement point, the water depth, the granulometric patch in a 0.5 m radius (EVHA method) and the coarse sediments thickness are observed, and the benthic clogging class is evaluated (protocol Irstea Archambaud). At the riffles transect the Wolman particle size sampling is used. Once collected, data can be processed and the "sedimentary status" obtained.

In the following figures (**Figure 15**a, b, c, and Figure 16) some results on the application of the evaluation procedure to the stretches directly upstream and downstream the "Plan du lac" dam are reported.

Nom de la Classe granulométrique	Classe de taille (diamètre en mm)	Code utilisé
Dalles (dont dalles d'argile)	>1024	D
Rochers	>1024	R
Blocs	256 - 1024	B
Pierres Grossières	128 - 256	PG
Pierres Fines	64 - 128	PF
Cailloux Grossiers	32 - 64	CG
Cailloux Fins	16 - 32	CF
Graviers Grossiers	8 -16	GG
Gravier fins	2 - 8	GF
Sables	0,625 - 2	S
Limons	0,0039 - 0,0625	L
Argiles	< 0,0039	A

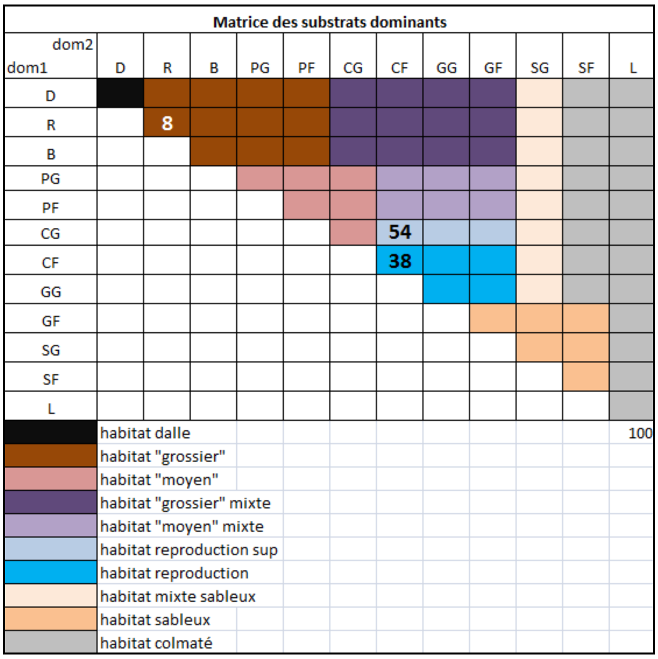
a) b)

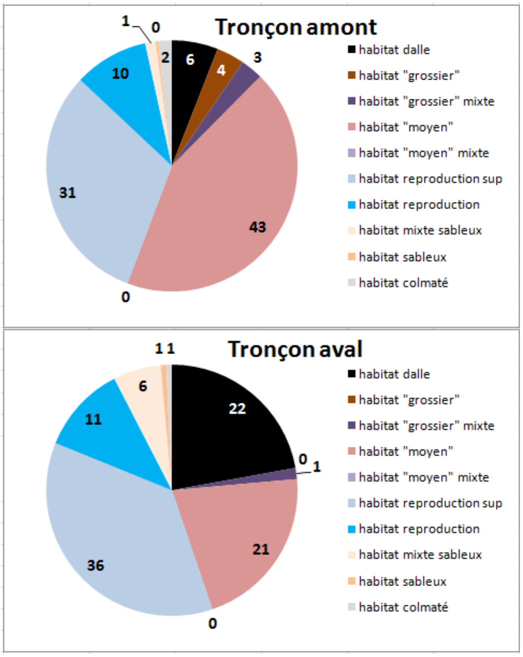
numéro T	5
Lpb	30
Lmou	30
Hpb RD	1.5
Hpb RG	99
Faciès	PLL

esp pt	3		granulo				
distance	n° de point	profondeur	+gros	dom1	dom2	épais	colma
-1	1	5	PF	PF	CG	1	2
	2	6	PG	PF	CG	1	2
	3	25	PG	PF	CG	1	2
	4	20	D	D	D	X	2
	5	28	D	D	D	X	2
	6	38	PG	PG	PF	0	2
	7	23	PG	PG	PF	0	2
	8	6	D	D	D	X	2
	9	5	D	D	D	X	2
1	10	15	D	D	D	X	2
	11						
	12						

c)

Figure 15 - Granulometry (a), EVHA method classes (b) and granulometric classes identified in the reach (c)





a) b)

Figure 16 - Evaluation of the dominant substrates (a), that corresponds to the alluvial habitats and the classification of the identified habitats (upstream reach, above, downstream reach, below) (b)

3.1.2 Sediment management during dam removal[8]

In the US a significant number of dams have been built since the XIX century. In 2013 it has been estimated the presence of over 87.000 major dams and millions of small (Figure 17), and nearly 1200 dams have been removed. The majority of dam removals occurred during the past two decades due to river restoration and fish passage, dam safety (reduce or eliminate liability), sedimentation and dam age or economic factors. In nearly all dam removal cases, the original purpose of the dam was no longer being served or the present function of the dam could be met through other means.

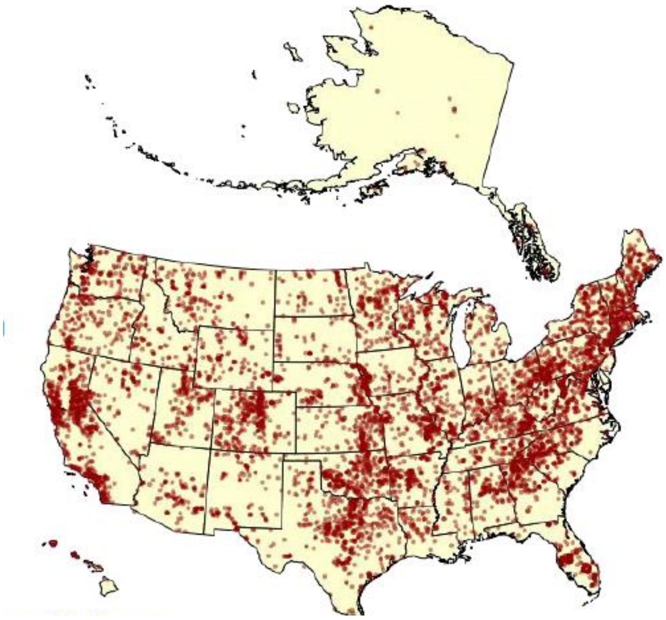


Figure 17 - Major dams in US (NID, 2013)

Dam removal challenges

The decision to remove a dam is an iterative process that involves establishing and evaluating alternatives in a collaborative framework with several entities.

There are many challenges in order to implement dam decommissioning projects:

- policy decision on implementation:
  - loss or replacement of project benefits;
  - cultural or historical significance;
- funding;
- technical capacity such as:
  - structural integrity of dam during removal;
  - diversion and care of stream during removal;
  - reservoir sedimentation and downstream impacts to water quality, ecosystem, and river channel;
  - Uncertainties.

Sediment management in the reservoir is an important and controlling part of many dam removal decisions. Sediment dynamic impacts can be very large and occur, depending on the local conditions, in the reservoir and in the river channel, both upstream and downstream of the reservoir (Figure 18).

[8] "Sediment management during dam removal", Tim Randle, Jennifer Bountry, I.S.Rivers - 2e Conférence Internationale, 22 - 26 june 2015, Lyon, FRANCE

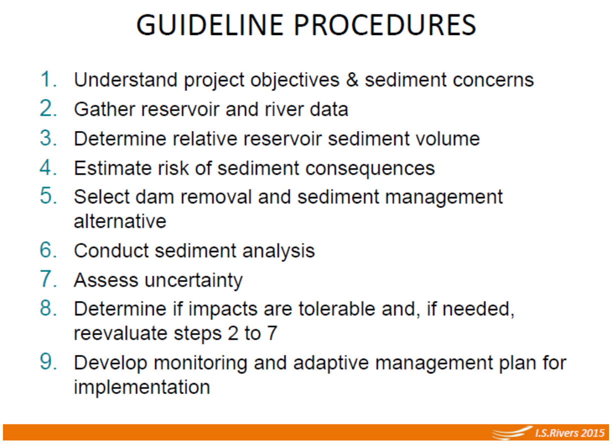
Figure 18 - Possible impacts of the sediment in a river

U.S. Subcommittee on Sedimentation: Dam Removal Analysis Guidelines for Sediment

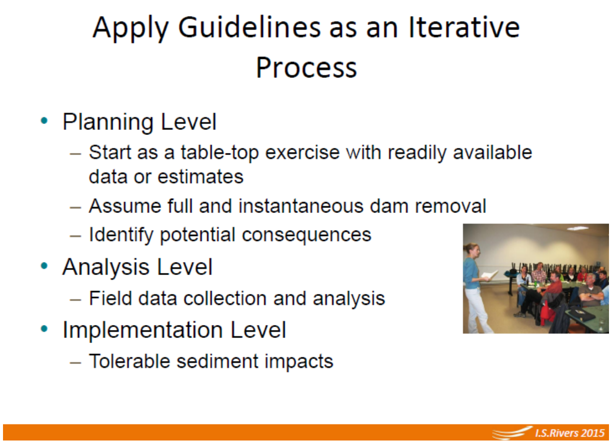
The existing manuals did not provide a framework or a guideline to the users to determine the level of analysis necessary or the certainty obtainable with analysis tools. Because of that and for the significance of the sedimentation issues, the Subcommittee on Sedimentation (U.S. Secretary of the Interior, Assistant Secretary on Water Information, Advisory Committee on Water Information) founded a workgroup of national experts and prepared different guidelines for dam removal sediment analysis.

The objective of the guidelines is to provide a procedure to link the risk associated with potential impacts from the reservoir sedimentation to the level of data collection, analysis, modeling, and sediment management alternatives. The risk is defined as the product of the probability of impact and the consequence of impact. The greater the risk, the greater the recommended level of data collection, analysis, and modeling. The guidelines are intended to be a planning-level document.

The sediment analysis guidelines are a nine steps (Figure 19, left) procedure to apply iteratively at planning, analysis and implementation level (Figure 19, right).



a)



b)

Figure 19 - The nine steps procedure of the Dam Removal Analysis Guidelines for Sediment (a) and the application levels (b)

The technical information needed are those related with the removal of the structure, with the sediment management, and with the impact mitigation. The frequent communication among technical staff, construction teams, and stakeholders is important throughout the project.
The level of sediment investigations should be of course proportional to the risk of sediment related impacts. These fundamentally depend on:

- reservoir sediment mass;
- size gradation, quality (contaminants), and spatial distribution;
- extent and rate of reservoir sediment erosion;
- tolerance and adaptability of sensitive species;
- sensitivity of critical infrastructure to sediment blockage at water intakes;
- water quality for specific users and flood protection.

The risk related to the sediment is given by the product of the probability of sediment impacts and their magnitude. The greater is the greater is the level of investigation requested by the method (Figure 20).

Probability of fine or coarse sediment impact	Consequence of Sediment Impact		
	Low	**Medium**	**High**
Small	Low	Low	Medium
Medium	Low	Medium	High
Large	Medium	High	High +

Figure 20 - Estimates of the risk of sediment consequences and level of investigation requested

The level of the investigation increases with the risk related to the sediment impacts (Figure 21); if the risk is negligible only a simple computation could be undertaken while if the risk is high the modelling detail, both computational and laboratory, must be higher.

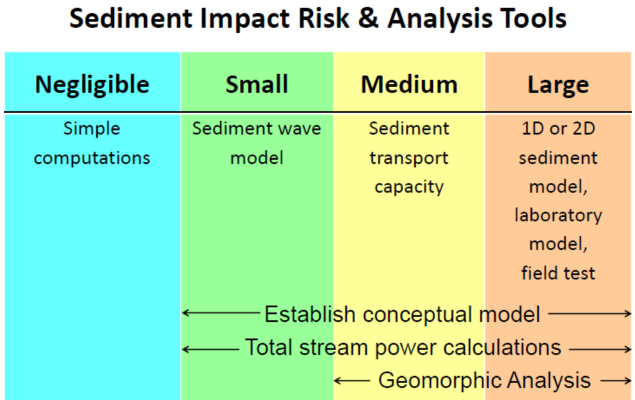


Figure 21 - Sediment Impact Risk & Analysis tool

If the impacts to resources are tolerable for the decision makers and stakeholders it is then possible to proceed to the decommissioning, otherwise different solutions must be examined. During the decommissioning an adaptive monitoring and management plan must be developed and implemented. The plan has to be able to set the parameters to monitor and their monitoring time step, to correct predictions on the sediment impacts on the base of the monitoring results. Moreover, on the base of the monitoring results, it has to be able to suggest different actions to take to guarantee tolerable impacts.

3.2 *River sediment transport and management*

Natural sediment transport phenomena along rivers can be exacerbated by hydraulic infrastructures like dams, bridges, banks etc. With the reduced transport of sediments, which are trapped in dams, due to the effect of banks or bridges constrains, the dynamic balance is disturbed, causing increased erosion of the riverbed with corresponding impacts on morphological processes, loss of biodiversity, and effects on levels of the groundwater table (PSAC, 2009). Moreover, also artificial floods downstream of the reservoirs can activate the sediment regime and impact the morphological dynamics.
Actions aimed to restore processes downstream, such as sediment mobilization or bypasses can be set in place, dependently on river sensitivity (e.g. the capacity to self-sustain restoration processes) and socio-economic constraints.

In the following paragraph, an example of good practices in sediment transport and management is illustrated.

3.2.1 The sediment management plan in the Po river basin

The incision phenomena in Po river basin

The hydrographic network of the Po river basin has undergone considerable changes during the 20th century (elevation of river bed, width variations of transversal sections, morphologic changes) mainly due to strong human pressures: sediment withdrawal from river beds, dams and canalizations building, urbanization of many torrent, rive-sides and floodplains (Figure 22).

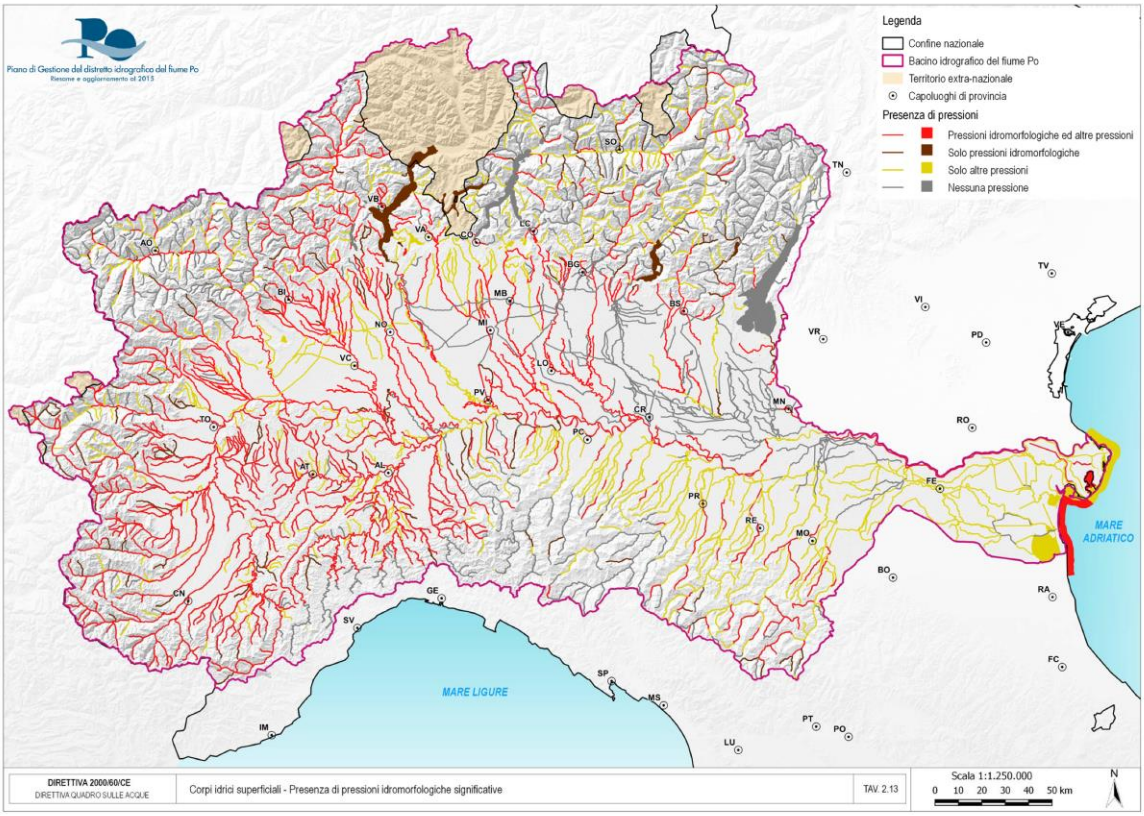


Figure 22 - Hydromorphological pressures and other pressures on surface waters in Po river basin: both hydromorphological and other pressures in red, only hydromorphological pressures in brown, other pressures in yellow and no pressures in grey

The most frequently occurring processes along the river network are a generalized deepening of the riverbeds, the consequent shrinkage of the riverbed and the transformation of complex riverbeds forms in simplified single-branch forms, with the deactivation, especially in low flows conditions, of numerous side-branches. As a consequence, many water courses nowadays present a strong morphological instability (Figure 23). Some phenomena of instability of bridges foundations and of hydraulic defence works can be highlighted in this sense, as well as the inactivity of several water-intake-structures due to the decrease of the water levels (at equal flow rates) and the need of renovation of many navigation locks and port basins.

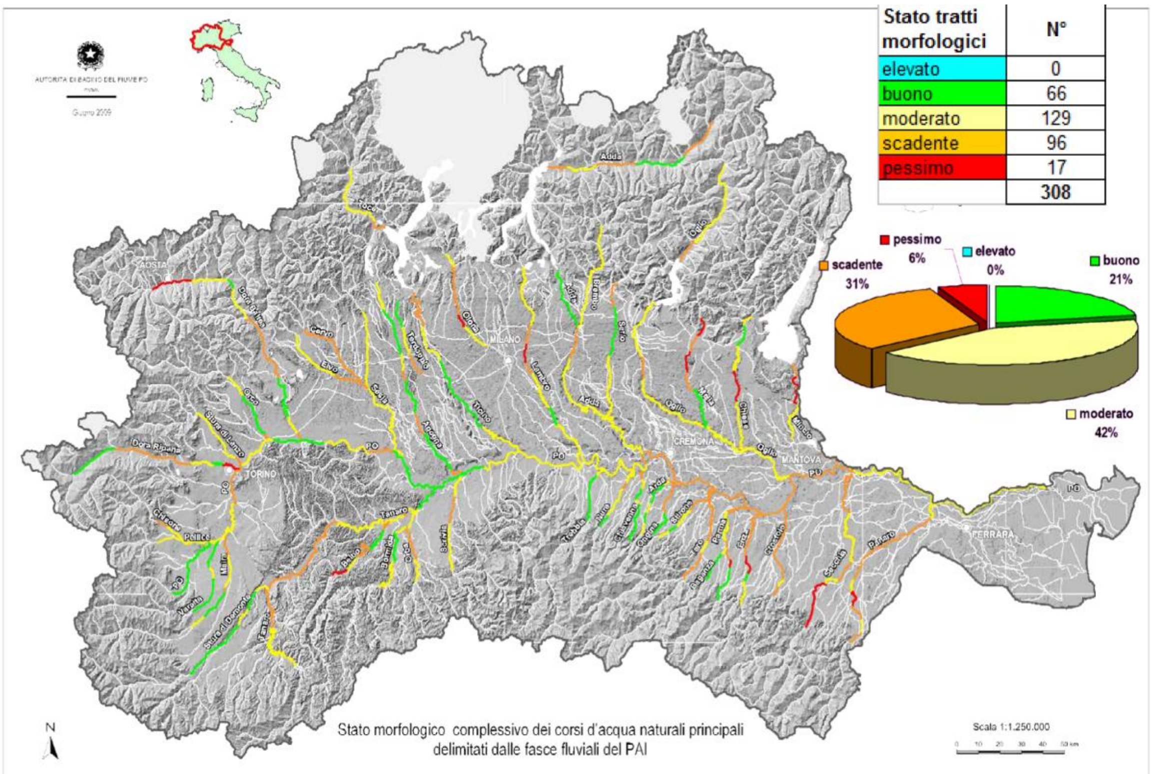


Figure 23 – River morphology assessment

The general program for sediment management of River Po

The managing Po river authority has outlined the general principles and rules that have to be followed for the correct sediment management into the riverbeds. In particular, the authority has defined the meaning of the term "good condition of functionality of the riverbed" in close relationship with the main features of the watercourse as defined on the basis of morphologic, hydraulic and environmental criteria. The need of preparing the "General program for sediment management" was also highlighted. The program is a tool to improve knowledge, management and planning of the interventions in order to regulate the activities of maintenance and restoration of riverbeds, and the eventual withdrawal of lithoidal materials, hydro-morphologic and sediment-transport monitoring activities.

The general program of sediment management focuses on the following objectives:

- Preserve the natural processes where they are still present and active;
- Reduce the effects and the influence on the natural system generated by the works in the riverbed. The aim is to reactivate the river dynamics towards less defined channels and a more natural dynamic equilibrium and to improve the ecological value;

- Improve the hydraulic safety conditions by decreasing as much as possible the hydrodynamic stress on the embankments while guaranteeing of the ongoing uses (intake-structures for water withdrawals, harbours, docks, navigation).

Following these objectives, the program identifies the following strategic priorities of action:

- Protection of all the hydro-morphological shapes and processes and fluvial processes, as well as surveillance and operating monitoring;
- Restoration of the natural erosion process, bed load transport, and sediment deposition by removing or refurbishing the ineffective and useless structures and works in the riverbed;
- Restoration of the natural morphological shapes thanks to the re-opening and re-functioning of side branches (Figure 24).

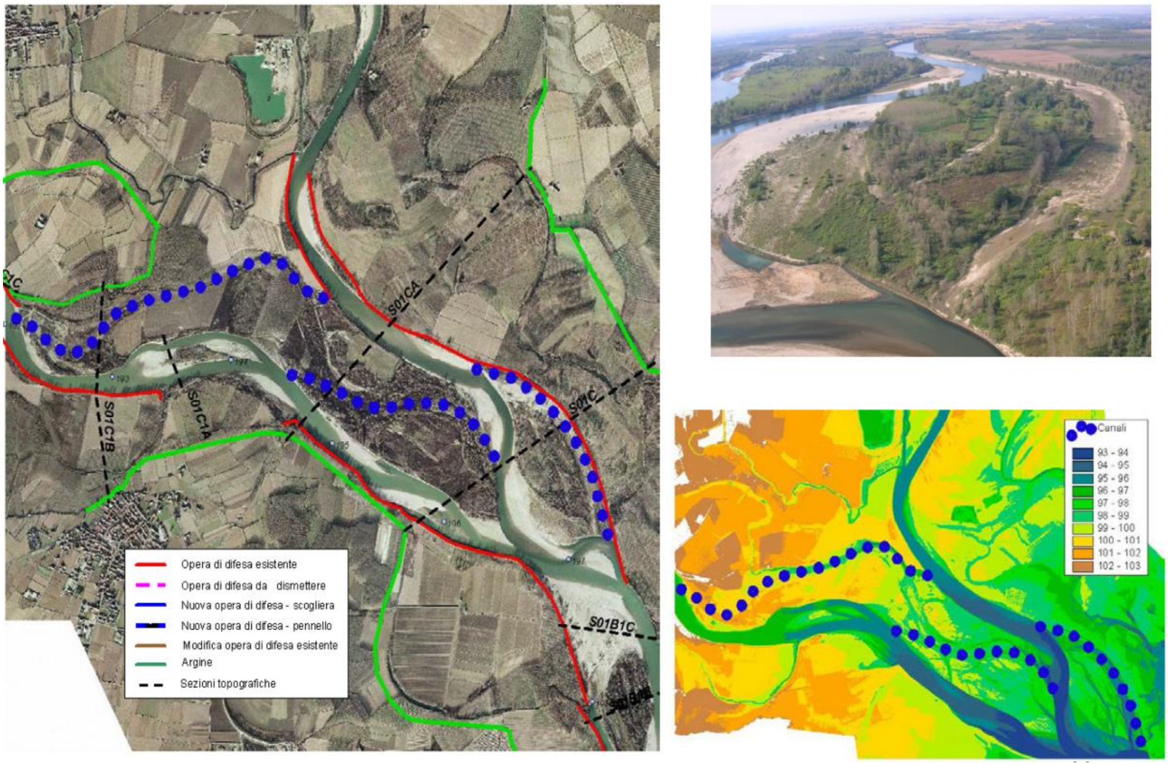


Figure 24 – Example of morphologic restoration of the riverbed and sediment management at the Sesia River confluence

The program classifies interventions in two distinct categories: exceptional/start-up works and ordinary works.

The exceptional works are to be regarded as the program start-up, being useful to remove the most significant external pressures and to stimulate the natural recovery processes of the river which then could evolve naturally without further human interventions unless corrective ones. The exceptional works have a structural nature.

The ordinary works are substantially active management interventions intended to remedy those situations completely compromised as a result of ineffective or wrong structural interventions.

The implementation of the general program of sediment management belongs to the competent Regions appointed by the Institutional Committee of the managing authority to draw up intervention programs on the basis of preliminary projects.

3.3 Examples of integrated management of sediment transport

Since the last decades, Alpine countries have been developing many pilot projects on the restoration of Alpine rivers (PSAC, 2009). The results of these projects show that restoration is a win-win strategy to improve river ecosystems quality, and then fulfil the WFD requests, while ensuring the flood protection asked by the FD.

Major water management issues have been recognized in the alpine area during the 3rd international Conference on "Water in the Alps – Striking the balance" held in Venice in 2010 (AWC, 2011):

- mitigation of hydro-morphological impacts due to flood protection infrastructures and hydropower plants,
- restoration of river continuity;
- improvement of lateral connectivity of rivers;
- provision of an ecological sound amounts of residual water; reduction of the negative effects of hydro- peaking.

Effective sediment management requires a holistic approach taking into account all the physical, social and economic factors related to the issue. Because of the links between water and sediment dynamics, sediment management and water management are strongly interconnected. Therefore, great attention should be put in the understanding of the system, in the use of integrated management of soil, water and sediments and in the consideration of the upstream-downstream interrelationships. The involvement of the stakeholders should be also included.

Examples of measures aimed to restore river basins, achieving both WFD, and FD and sediment management objectives are mentioned on the Second Report on the State of the Alps: Water and water management issues (PSAC, 2009):

- reconstruction of the longitudinal and the lateral connectivity and continuity of the rivers;
- restoration of the hydromorphological processes by removing bank protection and allowing the widening of the river bed and improving sediment transport;
- reduction of the water of the river withdrawn (eco-logically oriented minimum water flow) and also mitigation of hydro-peaking effects,
- improvement of the habitats in the river and in the inundation area with techniques such as bio-engineering in connection with maintenance work,
- restitution of more space to the river system.

Currently, structural deficits, streambed properties and connectivity issues are among the main remaining challenges in aquatic restoration, especially in streams (Geist[9]).

Due to the complexity of the problem, many procedures have been identified in order to favour the success of these "win-win" restoration initiatives. A seven step and evidence-based process was proposed by Geist (2015) recognizing that restoration needs to become more systematic, evidence-based and locally prioritized. The procedure consists of:

Step 1: Decisions on conservation objectives

Step 2: Determination of status quo

Step 3: Identification of bottlenecks and problems

Step 4: Setting priorities and making decisions on conservation action

Step 5: Conservation action

[9] "How to make aquatic ecosystem restoration a success", Prof. Dr. Jürgen Geist, Workshop on the "Dialogue between the Water Framework Directive and the Flood Directive", 17th -18th September 2015, Munich

Step 6: Evaluation and adaptive management
Step 7: Exchange and publication of results

In the following paragraphs, examples of good practices in integrated management of sediment transport are illustrated.

3.3.1 A flood event starts a river restoration project: Lindenbach, Germany[10]

Torrent Lindenbach has a watershed area of about 20 km² and flows from west to east at the northern side of the Ammergauer Alps (Figure 25). Its tributary waters are situated at the northern hillsides of Mount "Hörnle" with mean slopes of 20%.
Because of former regulations, River Lindenbach has been straightened and narrowed and has several drop structures and smaller check dams of heights up to 3 m. Its bed slope is of about 2 % in this region, but becomes much lower downstream when it flows in to the Murnauer Moos (flat moor region south of Lake Staffelsee). On 02/07/2009 a torrential rainfall of 92 mm in 3 hours caused a flood of about 57 m³/s, greater than a 100 - year flood. Due to debris and wood log jams, several check dams, bank protection works and bridges were destroyed.

Figure 25 - Topographic map of Murnauer Moos and territorial framework of the river Lindenbach

The river restoration project

The restoration project was set up by the WWA Weilheim, the water management agency (responsible for the river maintenance). Considering that River Lindenbach is a priority habitat for fish and the effect of/on the existing protection works during the flood, the Authorities decided to adopt an alternative approach for the reconstruction aimed at river renaturalization. In order to guarantee both flood protection and restore river continuity and migration opportunities for fish and aquatic fauna, matching 2000/60/EC and 2007/60/EC Directives goals, about 16 check dams have been replaced by ramps resulting in about 1 km of ramps over 17 km of river (Figure 26 and Figure 27). The project was funded by the government with a total amount of 850'000 €.

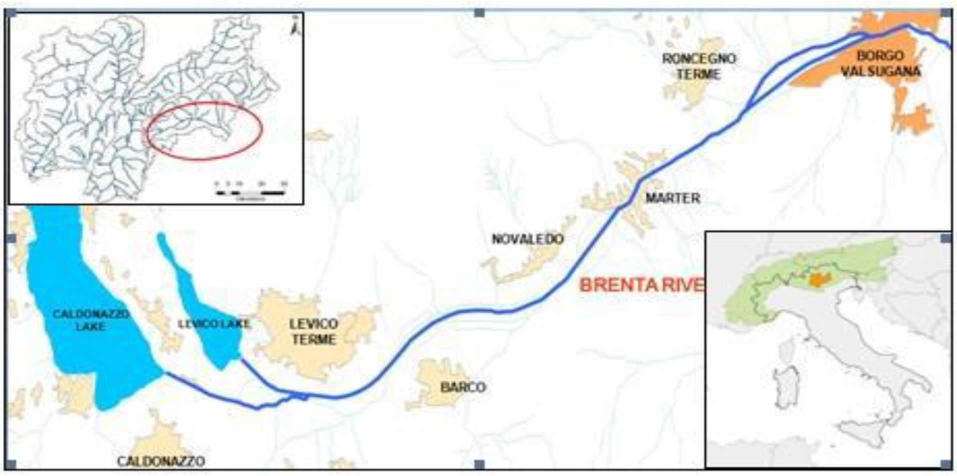
10 http://www.alpconv.org/en/organization/groups/WGWater/Documents/FD_WFD.pdf from page 40

Figure 26 - Wood log jam destroyed a bridge; also several check dams were damaged

Figure 27 - During and after the reconstruction (ramp with a height of 1,6 m and a length of 70 m)

3.3.2 Planning restoration by ensuring also river security: the case of River Brenta in Trentino[11], Italy

Brenta River originates from the Lakes Levico and Caldonazzo (Trentino, Italy) and flows to the Adriatic Sea, just south of the Venetian Lagoon, flowing across the Valsugana valley up to the town of Borgo Valsugana (Figure 28).



[11] http://www.alpconv.org/en/organization/groups/WGWater/Documents/FD_WFD.pdf from page 35

Figure 28 - Territorial framework of the river Brenta from Lake Caldonazzo to the town of Borgo Valsugana, stream network with Trentino in the red circle and topographic map of Italy with Trentino highlighted in orange and the Alps in green (from left to right).

The river is 20 km long and has a straight behaviour with almost uniform morphological features: constant depth, regular channel, sporadic, scattered and narrow riparian areas Figure 29 - left). The watershed, with an extension of about 212 km^2 just downstream Borgo Valsugana, is mainly place of semi-permanent agriculture activities. From an ecological point of view, Brenta is a low-value river: water quality is poor or bad due to the lack of biodiversity. Moreover, the basin is subjected to floods, during a catastrophic event that occurred in 1966 Borgo Valsugana town and part of the agricultural areas upstream were completely awash.

From a project to safeguard Borgo Valsugana to a plan to restore river Brenta

Since the basin, and in particular Borgo Valsugana, is subjected to flooding events, an attempt to develop a project to safeguard the area was carried out from 2001 to 2008. The project would have included a long river stretch, from Caldonazzo to Borgo Valsugana, and the interventions would have been extensive (i.e. creation of three detention basins and thalweg reshaping, or creation of a detention basin and construction of a hydraulic bypass).

In 2008, recognizing that the implementation of the identified measures would not have been neither easily nor economical feasible, the eight Public Authorities involved decided to implement a plan to restore and protect Brenta watershed from Lake Caldonazzo to Borgo Valsugana.

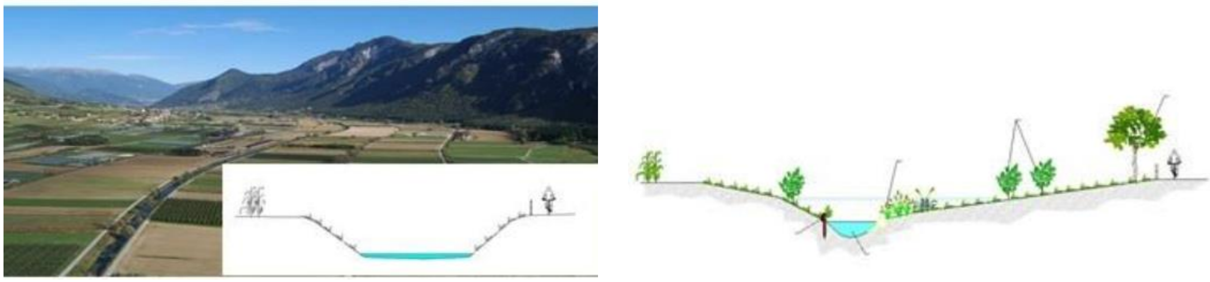
The identified solution consists in maintaining the retention capacity of the upstream basin, creating ecological connections to existing protected areas, recover the lateral areas for flooding, and improve the water quality and leisure opportunities. In particular, the identified solutions are:

- the provisional retention capacity of Lake Caldonazzo will be increased of 5 million m^3 while not damaging local touristic activities;
- the banks will be used to create retention basins in agricultural and infrastructure areas (close to the gas pipeline and the water treatment plant);
- a braided bed will substitute the rectified channel significantly changing the morphological conditions of the river (Figure 29 a, b);
- and the Brenta channel capacity will be increased in Borgo Valsugana using by barriers and reshaping existing bridges if needed.

The restoration program is right now undergoing the Strategic Environmental Assessment procedure.

Matching 2000/60/EC and 2007/60/EC Directives

The objectives of 2007/60/EC are consistent with those of 2000/60/EC: the protection – as well as the recovery - of the water ecosystems and connected watersheds, the achievement of a good status of water quality and the mitigation of flood effects, and at the same time reducing the risks of flooding. A major message came up in the planning phase: people must learn to coexist with floods and must recognize and accept that certain areas may be periodically inundated. Flood safety does not mean total avoidance or the elimination of the risk, but it is rather the set of actions that can reduce risks with sustainable and suitable social and economic costs. For this reason, a joint collaboration with the local civil protection has been established both to manage emergency situations and to teach people how to cope with hydraulic risk.



a) b)

Figure 29 - River Brenta and a scheme of its course (a) and a scheme of a restored section of the river (b)

3.3.3 Undertaking ecological restoration and flood protection on a very dynamic river: the Giffre, France[12]

River Giffre is located in Haute – Savoie, in an East - West oriented valley and springs from the Ruan and Prazon glaciers. Giffre, that is the main right - bank tributary of river Arve, is 45 km long and its watershed is about 475 km² (Figure 30).

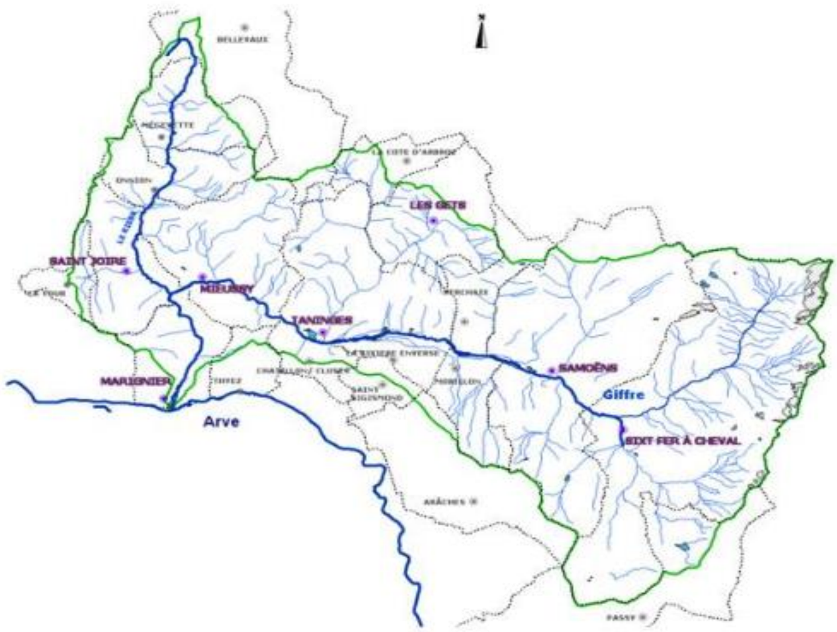


Figure 30 - Localization of the river

The Giffre experiences torrential floods that are directly related to its geological and alpine environment and also to its climate. The Giffre has an average longitudinal slope of 0.6%, that raises up to 3.5% in the Mieussy gorges and over 8% between the confluence of the Nant d'Ant and the Giffrenant dam. Sediment supply is extremely high in some areas, particularly that from very steep tributaries. About 450’000 m^3 of sediment lay in Giffre main channel. Today, about 20% of the total river length is embanked, with sometimes very little space left to the river flow. Most of the embankments had already been built at the end of the 1980s. It has been estimated that between 1912 and 2000, approximately 1.87 Mm^3 of gravels have been extracted from the riverbed. This has

[12] http://www.alpconv.org/en/organization/groups/WGWater/Documents/FD_WFD.pdf from page 43

had a very significant impact of the longitudinal profile of the river as it has been incised on average by over 1.3 m with some reaches incised by over 3.5 m (along the Marignier reach). Although not being the main cause, dams used to sustain hydroelectricity production have worsened the incision of the riverbed.

Giving space back to the river: an ambitious river restoration and flood protection project

The project has set up with the main aim to restore the erodible corridor on several reaches, thereby limiting the incision of the river, while restoring flooding areas. The restoration of two reaches has already been completed and a study is being launched to refine the work for the other reaches.

In one of the restored reaches, the active width of the river bed reduced by over 50% between 1934 and 2004 and the channel incised by over 2. 5 m. The project mainly consisted in removing vegetation from gravel bars, removing lateral riverbank protections, recreating side channels, taking back gravels from areas that had aggraded and reinjecting in areas where channels had incised. Flood defenses, where existing, are set back. The return time periods considered for the hydraulic modelling are 10, 30, 50, 100, 300 and 1000 years. The overall project is expected to last for 7 years with a total cost estimated to be 42 million euros. Some views of River Giffre during and after the works are reported on Figure 31 a and b, and Figure 32 a and b.

a) b)

Figure 31 - Examples of river incision (a) and examples of works carried out on the opposite riverbank to remobilise aggraded material (b)

Figure 32 - Views of Giffre looking downstream of the restored reach

3.3.4 Providing the degraded Austrian Mur River with sediment via restoration actions

The Mur River has its origin in the Alps at an altitude of 1900 m above sea level (Figure 33b); along the Austrian-Slovenian border it drains a catchment area of 9767 km^2 at a mean discharge of 148 m^{3}s^{-1}.

The Mur once was a braided river there, composed of multiple threads which covered a floodplain width of up to 1 km. After flooding, sedimentation and sudden river course changes repeatedly damaged settlements and infrastructure, the Mur River was systematically narrowed and straightened in the late 19th century. However, new problems arose in the late 20th century, when the river regulation together with sediment retention behind hydropower plants caused the river bed to incise, which degraded the ecological status, lowered the groundwater table (affecting water supply and agriculture) and destabilized riverbank protection structures. Moreover, in some places the small thickness of the gravel layer threatened to fully erode in near future, and to cause a breakthrough of the river into the underlying, finer-grained sediment of the Tertiary, eventually resulting in a sudden lowering of the bed levels. Hence, there was an urgent need for counteractions, as after a breakthrough ecologically oriented methods would no longer be an option for restoring the bed levels.

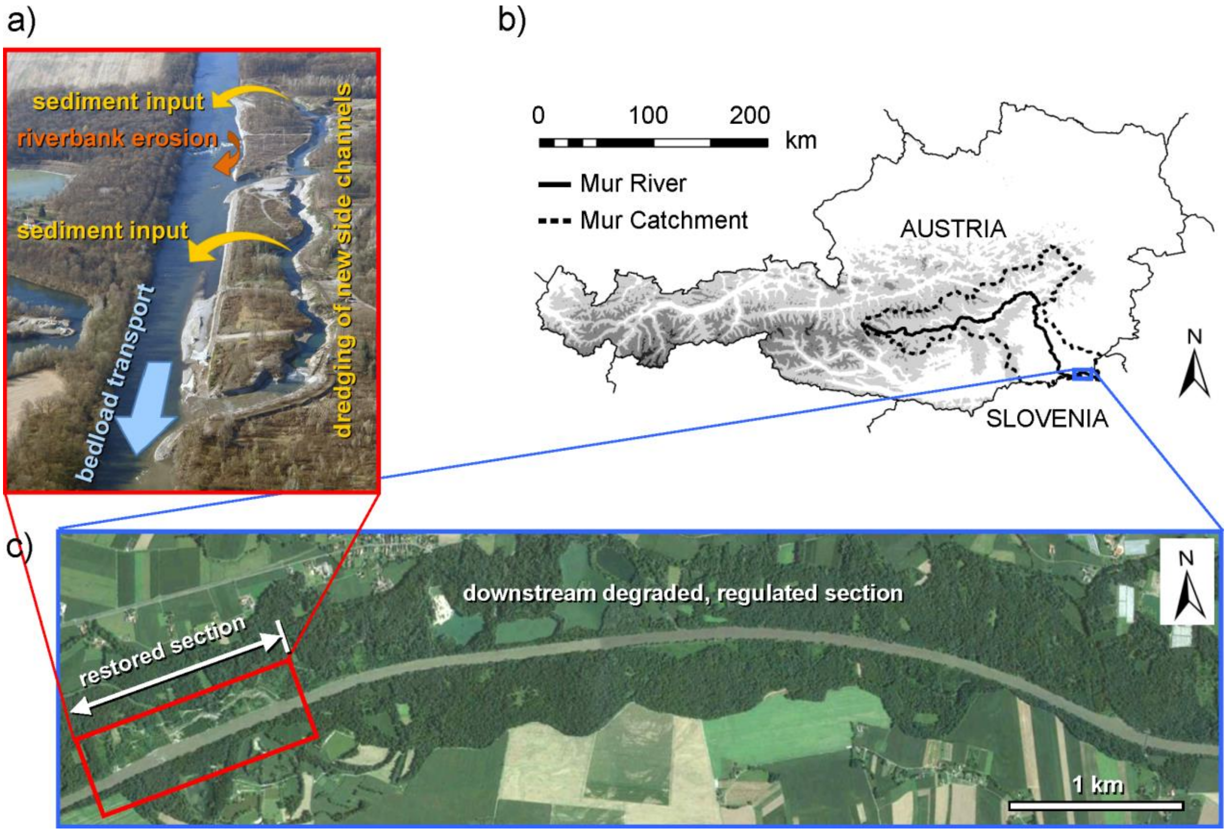


Figure 33 - a) Restoration actions implemented in a reach 1 km in length, b) the Mur River's catchment of the section where the presented measures were implemented, c) Aerial view (source: google earth) of the restored site and of part of the downstream regulated site suffering degradation.

In 2001, a comprehensive management concept was established for the Mur River, which suggested a series of measures for the border section to mitigate channel incision until solutions are found for re-establishing sediment transfer from upstream. The proposed pilot measure was implemented in 2006 and 2007 and consisted of the excavation of a new side channel (Figure 34a) and the removal of bank protection in a river section 1 km in length. As an immediate sediment supply for the downstream regulated section (Figure 33c), the excavated sediment was inserted into the main channel to be transported downstream (Figure 34b).

a) b)

c) d)

Figure 34 - a) Immediate sediment supply into the main channel from side channel excavation, b) Opening of the side channel, c) Restored and eroding gravelly banks of the main channel, d) Dynamic morphology of the side channel (Suppan, 2015)

An intense monitoring program was started after measure completion. Artificial stones equipped with active radio transmitters documented the transport velocity of the supplied gravel and allowed estimating the residence time of the supplied gravel within the degraded section. Photogrammetric surveys of the restored, gravelly riverbanks (Figure 34c) showed repeated bank retreat, which supplies the downstream section with bedload for longer term. The self-dynamic widening of the riverbed decreased the hydraulic load exerted on the riverbed in the restored section. Repeated bed surveys exhibited an increase of the bed levels in the restored section and in the downstream, regulated section, thus proving the achievement of the desired bed stabilization. Basket sampler measurements were conducted to assess the bedload transport in the Mur River.

The natural banks in the main channel as well as the established hydromorphologic features in the side-channel (Figure 34d) increase the habitat availability for an improved ecological condition.

The monitoring results (observed bank erosion rates, gravel transport velocities and bed level changes, etc.) now allow reviewing and adapting the strategies defined in the Basic Water Management Concept, aiming for increased effectiveness of restoration actions.

Figure 35 - Development phase of about ten years

4 CONCLUSIONS

The increasing demand by citizens and environmental organisations for healthier and cleaner rivers and lakes, groundwater and coastal beaches, has been highlighted for a considerable time. This demand was one of the main reasons to have the Commission set water protection at the center of its environmental agenda, starting with the issuing of the he "Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for the Community action in the field of water policy" or, in short, the EU Water Framework Directive (or even shorter the WFD).

As mentioned in this report and required by Art. 9 of the FD, the combined implementation of the WFD with the Flood Directive (Dir. 2007/60/CE or FD) should be the praxis for any intervention in order to implement win-win measures beneficial to both directives.

The objectives of both directives, i.e. water protection for WFD and flood risk mitigation for FD are indeed closely intertwined.

In order to allow socio-economic developments, interventions have been carried out over the centuries in floodplains and mountainous areas, accompanied by the construction of flood defences. Those interventions have significantly altered river morphology and hydrology and, in turn, river ecology has also been caused by the substantially altered morphology of rivers. Where flood defence schemes are already in place and no better environmental alternatives can be found to mitigate the flood risk (e.g. “room for the river”), mitigation measures might be implemented in order to enhance ecological quality (e.g. fish ladders; creation of bank roughness to elicit more habitat diversity, etc.) which do not lower the level of flood protection. Where new flood defence schemes are to be planned, win-win solutions should be preferred to avoid water body deterioration below the good status. The unfeasibility of such a solution should anyway be proved by the application of WFD art. 4.7 test.

Sediments dynamics influence everyday life population living close to the rivers, and vice versa, the rivers are affected by human activities developed in the floodplain. Hydromorphological processes occur at different spatial and temporal scales across the catchment, and their management needs a sound knowledge of all the aspects that characterise them, together with a conceptual framework allowing the contextualization of observations.

Based on this concept, this report describes the situation in regard to the management of hydro-morphological processes and gives an overview of the best practices that can be implemented in this field. In addition, a series of case studies related to different countries of the Alpine Convention are given to prove the efficiency of a process based sediments management, which can be carried out through several different options, compatibly with the specific characteristics of a catchment in terms of pressures and hydromorphological processes (i.e. Restoring lateral/longitudinal connectivity and continuity of rivers, improvement of the natural riverine habitats, etc.).

The German case study of Lindbach restoration shows a sound way to sediment management. On 02/07/2009 a terrible flood event occurred that destroyed several check dams, bank protection works and bridges. In this case, the river restoration project focused on restoring natural processes which could guarantee at the same time a sound ecosystem protection and a proper flood protection.

A second case study concerned the river Brenta, in North-Italy, which in 1966 underwent a destructive flood in Borgo Valsugana. The situation has been solved in this case giving more space to the river and so the possibility to inundate the floodplain. Simultaneously, through the help of the civil protection department, population was trained on a resilient behaviour to flood, to get awareness and preparedness to cope with flood events.

The third was the river Giffre one. The Giffre is a French river, often subject to floods, and for this endowed of lateral embankments. For the Giffre river also the solution was the “Room for the River” one. An ambitious river restoration project was carried out implying the removal of part of the lateral riverbank protections, for a project of about 7 years and 42 million euros.

The last case study regards the Mur river, in Austria. A pilot project was implemented in order to re-establish the sediment dynamics and mitigate the channel incision. The project consisted on the removal of bank protection and the excavation of a side channel from which dredge the sediments to feed the riverbed. The proposed solution allowed to achieve the desired bed stabilization and the improvement of the ecological conditions of the river.

Experience has shown that a very important part of the management process is the consultation phases to discuss and promote such projects. People are often scared by sediment management projects in alpine rivers while in fact, the socio-economic benefits of such projects are often greater than the “do-nothing” or “carry on as usual practices”, both in terms of flood management and achieving WFD goals.

In conclusion, human activities affect hydromorphological processes and sediments management is often a necessary practice. Any project related to flood protection or anyway impacting hydromorphological processes should have the goal of being beneficial to both FD and WFD objectives. In order to do so, the hydromorphological impacts related to any given project scenarios should be evaluated. A sound knowledge of river hydromorphological processes at the different scales (hydrological regime, sediment dynamics, sediment connectivity, sediment budget, evolutionary trajectory, etc.), supported by a consistent monitoring activity, and a conceptual framework to contextualise the specific observation are therefore needed (Rinaldi, 2016).

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