Policy brief
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A fresh look on effective river restoration: Key conclusions from the REFORM project

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About REFORM

There is increasing emphasis in Europe on river restoration driven by demands of the Water Framework Directive (WFD). The assessment of the 1st River Basin Management Plans indicated that 40% of European rivers are affected by hydromorphological (HYMO) pressures caused predominantly by hydropower, navigation, agriculture, flood protection and urban development. As a consequence, the programmes of measures of EU Member States have a strong focus on restoring river hydrology and morphology. Their implementation requires substantial investment in these measures. Proper planning and prioritisation of such measures requires a better understanding of ecological response to hydromorphological pressures and restoration measures[1]. Furthermore there still remains a great need to better understand and predict the costs and benefits of future river restoration.

Against this background, REFORM (REstoring rivers FOR effective catchment Management, http://reformrivers.eu/) brought together 26 renowned research institutes and applied partners from 15 European countries to generate **tools for cost-effective restoration** of river ecosystems, and **for improved monitoring of the biological effects of physical change** by investigating natural, degradation and restoration processes in a wide range of river types across Europe.

REFORM placed emphasis from its outset on directly engaging with stakeholders at different levels in order to receive feedback on its research programme as well as the applications and tools to be ultimately delivered. Close interaction was maintained especially with water managers involved in the ECOSTAT working group of the WFD Common Implementation Strategy, who were consulted at the REFORM stakeholder workshop (Brussels, February 2013) and at an ECOSTAT workshop dedicated to hydromorphology (Oslo, October 2015). In addition, several national stakeholder events were organised (in the Netherlands, UK, Spain and Italy) to present and discuss the project results.

Project funded by the European Commission within the 7th Framework Programme (2007-2013).

Relevance to EU policy

REFORM specifically seeks to support the **River Basin Management Plans** (RBMPs) for implementation of the **WFD**. WFD implementation will benefit from a better understanding of ecological-hydromorphological linkages and processes in order to improve river basin characterisation, status assessment, monitoring and the selec-

[1]Restoration does not mean returning streams and rivers to an undisturbed high ecological status which quite often is impossible, but is used here as an umbrella term to cover the full array of mitigation, rehabilitation and restoration measures meant to reduce the impact of human alterations on river ecosystems.

tion and assessment of measures and their effectiveness.

In planning flood protection measures to implement the **Floods Directive**, restoration measures through improved retention, storage and discharge (e.g. retention in tributaries and upstream wetlands, storage in enlarged active floodplains, discharge through side channels) may play a significant role in lowering flood risks. In measure selection, it is important to consider synergies between restoration and flood protection.

In 2013, the Commission issued a Communication aiming to promote **green infrastructure** in water and adaptation policy, and called upon planners to use natural measures or a combination of engineered structures and natural solutions more proactively. River restoration is particularly relevant to green infrastructures for reducing flood risk, especially in terms of floodplain restoration measures.

REFORM's results are also relevant to the **EU Biodiversity Strategy** whose targets include restoring at least 15% of degraded ecosystems by 2020, by integrating green infrastructure into land-use planning. Restoration measures can play a significant role in the achievement of biodiversity protection objectives for specific habitats and species (according to the **Birds and Habitats Directives**).

What does this Policy Brief offer?

This Policy Brief presents **key conclusions and recommendations** of the REFORM project, which are **relevant for policy-makers** involved in river basin management planning.

The key thematic conclusions and recommendations are relevant for the following phases of river basin management planning:

RBMP phases		REFORM areas of work
✓ Characterisation	**How does my river work?**	✓ Hydromorphology framework ✓ Hydromorphological assessment methods ✓ Remote sensing for river hydromorphological investigation ✓ Role of vegetation and floodplains
✓ Status monitoring and assessment	**What's wrong?**	✓ Hydromorphological assessment methods ✓ Groundwater-river interactions ✓ Coupling hydromorphology to biotic responses
✓ Programme of Measures ✓ Individual restoration projects	**How to improve?**	✓ Planning stream and river restoration ✓ Cost-benefit analysis of restoration measures ✓ Linking e-flows to sediment dynamics ✓ Restoration measures at project level and their effects

Making REFORM results available for river basin management planning

REFORM placed strong emphasis on making its results available in various forms to support both practitioners and scientists. To this end, REFORM developed a WIKI (http://wiki.reformrivers.eu) populated throughout the course of the project with information relevant for various phases of River Basin Management Planning to meet this need (see Figure 1). The logical framework of the WIKI systematically guides practitioners through two main planning stages of river restoration: catchment planning and the project cycle.

You can find detailed information about all themes raised in this Policy Brief in the REFORM WIKI, which will remain available online after the end of REFORM.

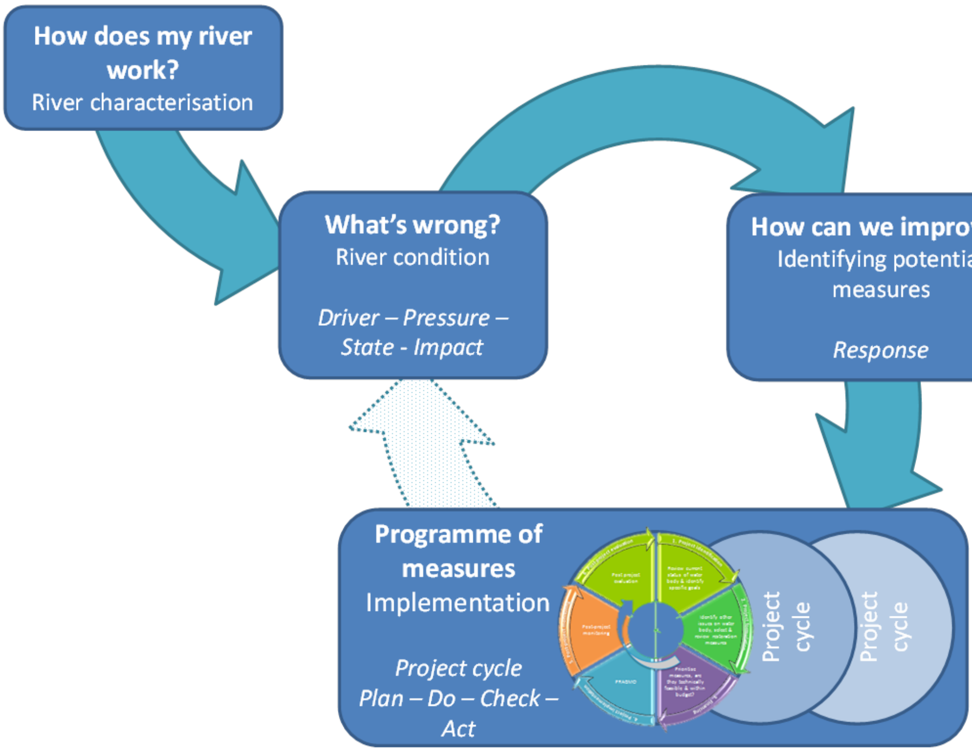

Figure 1. The online WIKI presents REFORM results in the implementation cycle of River Basin Management Plans.

REFORM hydromorphology framework

- ✓ REFORM developed an open-ended **Hydromorphology Framework** incorporating multi-scale spatial and temporal aspects, which characterize fluvial processes, into river assessment and management. It aids users in developing understanding of the morphology and dynamics of river reaches and their causes.
- ✓ Hydromorphological assessment should consider **physical processes** and appropriate **temporal and spatial aspects** beyond river restoration project boundaries and project life span.

In most EU Member States, the consideration of physical processes remains the main gap in hydromorphological assessment methods. There is a need for more comprehensive process-based hydromorphological assessments that consider the character and dynamics of river reaches and how these are affected by present and past natural and human-induced changes within the catchment as well as the reach (Belletti et al 2015).

Within REFORM, two complementary approaches have been proposed for hydromorphological assessment: an open-ended approach - the REFORM Hydromorphology Framework - and a set of more specific hydromorphological assessment procedures, which incorporates a set of clearly defined stages and steps – the REFORM Hydromorphological Assessment Methods.

To date, there has been too strong a reliance on the reach scale in assessing hydromorphology.

For sustainable solutions, it is crucial to develop understanding of the functioning of river reaches in a wider spatial context and of the ways in which river reaches have responded to changes in the past. This process-based approach provides understanding of the current and past condition of river reaches and their causes and thus crucial information for forecasting how reaches may change in the future. Hydromorphological conditions need to be placed in a catchment context (to capture the way in which natural influences and human pressures and interventions at their relevant spatial scales influence river reaches) and need to be evaluated over time (to capture impacts of past changes in influences on reaches demonstrated by reach dynamics, trajectories of temporal change, and thus their sensitivity to imposed changes). The REFORM Hydromorphology Framework (Figure 2) allows users to assemble available information, associate it with relevant spatial units and time periods, and so build a process-based understanding of the spatial and temporal influences on reach hydromorphology and dynamics. This understanding can be built into river assessment and management, including consideration of future scenarios (Gurnell et al. 2014a, Gurnell et al. 2015).

The benefits of this framework to WFD implementation include the provision of indicators of hydromorphological conditions which can be derived from commonly measured or freely available datasets, as well as the improved understanding of multi-scale process-based linkages between hydrology, the transfer of sediment, channel and floodplain morphodynamics, and ecology.

Furthermore, the delineation of WFD water body boundaries can be integrated into the REFORM framework at the segment scale. The water bodies can be further subdivided into 'reaches' using additional geomorphological criteria such as the identification of river (morphological) types.

The REFORM river reach typology is designed for assessing the hydromorphological functioning of individual river reaches and is as such highly relevant for river restoration (Rinaldi et al. 2015b). The relation with the European broad typology (ETC/ICM, 2015), which refers to the (sub)catchment setting of a river in terms of altitude, size and geology, is not straightforward, because that setting does not change in time. In contrast, REFORM river reach types may change in time because they represent the response of the river reaches to processes of flow, sediment and vegetation. Thus the European broad types may contain several reaches of different REFORM types.

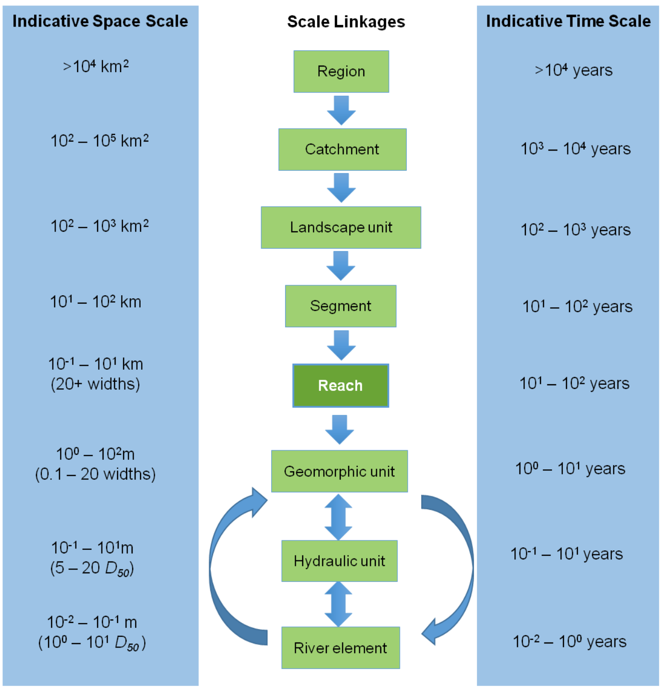

Figure 2. Hierarchy of spatial scales for the REFORM Hydromorphology Framework, including indicative spatial dimensions and timescales over which these units are likely to persist.

REFORM Hydromorphological Assessment Methods

- ✓ The **Morphological Quality Index (MQI)** is the method recommended by REFORM for assessing river conditions. The method is extremely useful for analysing and interpreting critical problems and causes of alteration.
- ✓ The use of MQI should be implemented for the **entire gradient of morphological conditions (not only for high status water bodies)**.

The hydromorphological assessment methods proposed by REFORM combine to provide a specific, comprehensive and synergic morphological assessment based on the integration of three tools, originally developed in Italy and then expanded to other European countries (Rinaldi et al. 2013; Rinaldi et al.2015a).

- The Morphological Quality Index (MQI) is a tool designed to assess the overall morphological condition of a stream reach and to classify its current morphological state (see Figure 3).
- The Morphological Quality Index for monitoring (MQIm) is a specific tool for monitoring the tendency of morphological conditions (enhancement or deterioration) in the short term.
- The Geomorphic Units survey and classification System (GUS) is used to characterise the typical assemblage of geomorphic units within the reach.

The three tools, used in concert, can provide an overall assessment of stream reaches, which helps to understand their morphological functioning and condition, and thereby guide the identification of appropriate management and restoration actions. The MQI and MQIm assessment includes those hydrological aspects having significant effects on geomorphological processes, whereas the overall changes in the hydrologic regime can be analysed separately by a specific index of hydrological alteration.

Furthermore, most of current hydromorphological methods define reference conditions in terms of precise channel morphology or a set of channel forms. However, recognising that fluvial systems are dynamic and follow a complex evolutionary trajectory with time implies that static, well-defined channel geometry is not suitable for defining reference conditions. In the case of the MQI, reference conditions are defined in terms of processes and functions that are expected for a specific morphological typology.

The Morphological Quality Index (MQI) can also be used in a multi-purpose way. The MQI does not only serve hydromorphological assessment to fulfil WFD requirements but it can also support assessments related to the implementation of the Floods and the Habitats Directives.

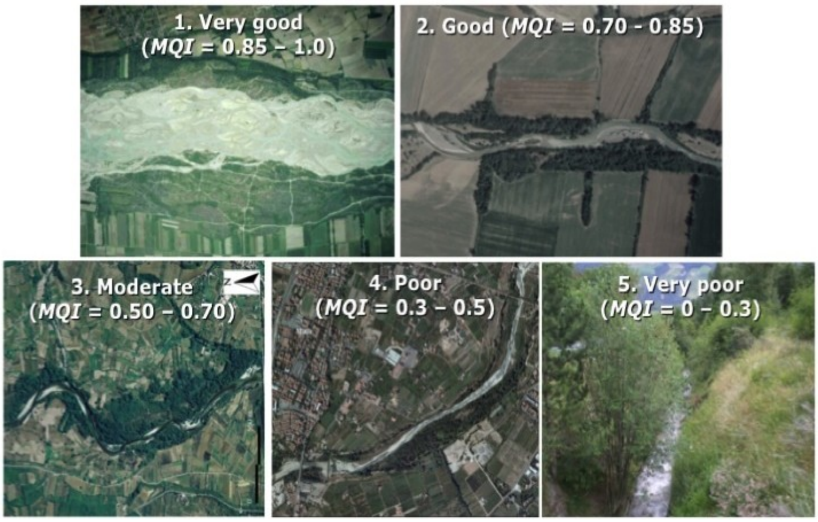

Figure 3. Examples of the five MQI classes.

Remote sensing for river hydromorphological investigation

- ✓ **Remote sensing data** has large potential to **support hydromorphological assessment and monitoring** of European rivers. Hydromorphological characterisations based on remote sensing are objective, repeatable through time and support large scale planning according to the WFD.

Over the last decade, technological progress of remote sensing techniques (among others satellite, airplane and UAV (unmanned areal vehicle)) has opened the opportunity to monitor many hydromorphological components of our river systems in a way that is unprecedented. Remote sensing technology is transforming our capacity to analyze river systems by increasing the spatial coverage of the morphological information gathered by field campaigns.

Remote sensing data are integrative and do not substitute traditional river surveys based on expert interpretations, field surveys and historical analysis. Remote sensing data will support conclusions drawn from these sources providing objective, repeatable and comparable information.

The amount of high-resolution remote sensing data on river systems will soon blur further with the coming new satellites (e.g. missions SWOT and Sentinel 3) and the growing availability of flexible acquisition tools such as drones. Remote sensing data over large areas, such as regions and entire countries, will be systematically acquired by satellites of new generation with planned re-acquisition times. Quantitative investigation on typology and diversity of river systems at large scale such as catchment and beyond regional scales will be feasible. Sequential acquisitions of the same area will soon be available opening the way to systematic historical analysis of hydromorphological processes.

Remote sensing data is already available but has been so far too scarcely exploited by water authorities in most Member States. However, it has become obvious that remote sensing data has notable potential to support the hydromorphological assessment and monitoring of European rivers as well as requirements of the WFD (e.g. water body definition, classification of ecological status, definition of heavily modified water bodies) (Bizzi et al., 2015).

Role of vegetation and floodplain ecosystems

- ✓ Existing EU Directives provide a **too limited legislative framework for riparian zones and floodplains**. Riparian and floodplain ecosystems are not subject to extensive monitoring but are crucial to river morphodynamics and ecology.
- ✓ Findings suggest that **direct measurements of hydromorphological processes and riparian vegetation** are likely to be better in assessing hydromorphological degradation than in-stream biota.
- ✓ Vegetation and plants can play a cost-effective and significant role as **physical ecosystem engineers** for river restoration.

A crucial aspect of hydromorphology that is too often neglected is the influence of vegetation on river channel form and dynamics (Gurnell 2014; O'Hare et al. 2015). Furthermore, riparian vegetation is not included as a biological quality element in WFD status assessment and riparian and floodplain ecosystems are thus not subject to extensive monitoring. Yet research conducted over the last 20 years has clearly shown that riparian vegetation has a fundamental influence on the hydromorphology of rivers and their floodplains. REFORM research has presented new scientific concepts and analyses that clearly demonstrate the importance of riparian and aquatic vegetation as a key physical control on river form and dynamics and a crucial component of river restoration (Gurnell et al. 2014b).

Moreover, the current focus on in-stream biota that is routinely monitored ignores that **many**

of the pronounced effects of degraded hydromorphology relate to the riparian zones and the wider floodplain. Riparian zones are especially important as they influence in-stream processes as well as providing a very diverse habitat for both aquatic and terrestrial organisms. Like the river channel, a healthy riparian zone reflects the dynamic processes to which it is subject to, and thus interactions between riparian vegetation and physical processes provide a complex, dynamic physical habitat mosaic across the river channel and its riparian margins. Overall, findings suggest that direct measurements of hydromorphological processes and riparian vegetation are likely to be better in assessing hydromorphological degradation than in-stream biota (Friberg et al, 2015).

REFORM scientists have developed a **conceptual model of vegetation- hydromorphological process interactions** within river corridors. These interactions drive the development and dynamics of naturally-functioning river channels and their corridors (Gurnell et al., 2014b; Gurnell et al. 2015b). This model links closely to the REFORM Hydromorphological Framework (Figure 2; Gurnell et al., 2014a) considering interactions laterally as different physical processes dominate from the river channel to the floodplain (e.g. erosion, sediment deposition, inundation), from river source to mouth, and in association with different river types (e.g. braided, meandering). The conceptual model helps recognise features indicative of natural river-floodplain function that may guide restoration and can support our understanding of how rivers may change in response to modification of hydromorphological processes. The model has been tested on several example rivers showing different levels of degradation (Baattrup-Pedersen et al., 2015).

Figure 4. Part of Vorgod å situated in Jutland, Denmark (photo: B. Moeslund).

Groundwater-river interactions

- ✓ Groundwater is the main factor **supporting e-flows** in streams during low flow conditions in dry seasons.
- ✓ Groundwater will play a crucial role in **maintaining the resilience** of the water system and aquatic environment during projected increasingly dry periods in the future and **more ecosystems will become groundwater-dependent**.
- ✓ Groundwater is the main provider of high quality water that supports groundwater-dependent ecosystems (ecosystem service).

- ✓ Successful mitigation and adaptation of groundwater-river connectivity to restore groundwater-dependent ecosystems requires **strategies for solutions at catchment scale**.

One of the recommendations at the REFORM stakeholder workshop in Brussels (26-27 February 2013) was to take further into consideration the interaction between groundwater and surface water. As response to this stakeholder demand, REFORM made a first step in combining groundwater characteristics and pressures with stresses on rivers, floodplains and wetland ecosystems (Hendriks et al., 2015).

River restoration measures may not be successful if streams run dry or water quality is poor due to decreased connectivity with the groundwater. Policy-makers and water managers should enhance their knowledge of issues related to groundwater-river interactions and ecosystems response. Groundwater is not only a key factor in supporting ecological flows, determining both the quantity and quality of surface waters, it is also a very important aspect in enhancing the resilience of water systems necessary to prepare for future climate conditions (Hendriks et al. 2015).

Secondly, close cooperation between the relevant fields of expertise (groundwater and e-flows) should be promoted (e.g. Hendriks et al. 2014). Available knowledge needs to be combined and it should be made clear how this knowledge can be applied in RBMPs and the practice of local water management.

Finally, river basin-wide strategies rather than isolated mitigation and adaptation measures should be developed because groundwater bodies extend mostly beyond the scale of individual water bodies or beyond surface catchment boundaries. For example, pressures that affect upstream infiltration and groundwater recharge (e.g. groundwater abstraction, soil compaction, intensive drainage and changes in vegetation) can have major impacts on groundwater conditions across the whole catchment. Catchment-wide measures may require land use changes and/or reduction of groundwater abstraction in upstream parts of the catchment.

Improved coupling of hydromorphology to biotic responses

- ✓ Hydromorphological impacts can take years to fully manifest themselves.
- ✓ **Fish** is the **most sensitive biological quality element** (BQE) with regard to hydromorphology.
- ✓ **Macrophytes** can be used for assessing hydromorphological degradation **in lowland rivers**, if a trait-based metric is developed e.g. plants with high overwintering capacity of their vegetative parts showed higher resistance to hydromorphological (HYMO) stress.
- ✓ Current sampling methods are not appropriate to capture HYMO impacts and they underestimate the influence of HYMO on biota. There is a need to **develop new biota sampling methods that are more sensitive to HYMO impacts**.
- ✓ **Alternative/new methods** using biota (not standardised; not intercalibrated) can be used **in investigative monitoring** already now to assess HYMO impacts. This includes sampling of habitats (e.g. the riparian) that are in particular impacted by HYMO degradation.

- ✓ Hydromorphology **should be used as a quality element in its own right in the WFD status assessment** as BQEs cannot differentiate between different degrees of HYMO degradation with sufficient precision. Hydromorphological assessment should be used to assess impact along the entire gradient, from high to bad ecological status, rather than using BQEs as indicators of HYMO degradation. The proposed REFORM hydromorphological assessment method is specifically tailored to this purpose.

Existing metrics have been evaluated for their strength to distinguish the impact of HYMO pressures on the mandatory biological quality elements (BQEs) of the WFD from other stressors (Friberg et al 2013). This showed that fish and macrophytes appear better suited to assess HYMO degradation than diatoms and macroinvertebrates.

Macroinvertebrates should be used with care with the majority of currently used metrics and sampling methods: They are good indicators for general river degradation, but most cannot indicate HYMO stress with a necessary degree of certainty. However, there was evidence that traits as macroinvertebrate metrics held some potential to indicate HYMO degradation. Some countries are using related macroinvertebrate metrics, in particular traits related to habitat preferences, for their national assessment systems (e.g. Germany) (Lorenz et al. 2004; http://www.fliessgewaesserbewertung.de/).

What are traits?

An alternative to species identity-based methods is the use of species traits. This approach has recently gathered momentum because of its spatial and temporal robustness. Traits are inherited characteristics of species that relate to their biology and the environment they live in (ecological and functional traits). Examples of traits are e.g. feeding mechanisms, longevity, body size and mobility. The advantage of traits compared with identity-based (taxonomic) species composition, when investigating stressor-response relationships, is that they can be used across areas with different species diversity, are directly related to habitats and can inform about ecosystem functioning. Traits provide a mechanistic understanding of how environmental change influences biotic communities and are therefore a step towards being able to diagnose cause and effects drivers.

Even for fish, the BQE which showed most promise, there is a significant amount of work to do before sensitive metrics to HYMO stress can be applied in water management.

Monitoring data are designed to detect change at individual sites through time and can miss some crucial hydromorphological impacts. Revision of some of the monitoring methodologies can help, however adherence to monitoring data alone will not supply knowledge and system understanding (O'Hare et al. 2015).

The overall lack of clear linkages between the currently used assessment systems (sampling, numeration, identification and metrics) based on the WFD defined BQEs and hydromorphological degradation should initiate a targeted development within the EU on innovative methods and indicators that are sensitive to changes in HYMO conditions (both degradation and restoration).

Current sampling methods are not appropriate to capture HYMO impacts and they underestimate the influence of HYMO on biota. There is a need to develop new biota sampling methods that are more sensitive to HYMO impacts, especially in the interface of rivers and lakes with their floodplain.

Water managers still face a significant challenge when diagnosing the reason for not obtaining good ecological status in a water body (Friberg 2014). BQEs with the current sampling methods can primarily inform on the impact of other stressors, in particular organic pollution and eutrophication, which are relevant in multiple stress scenarios. It appears from the analysis undertaken that e.g. eutrophication is a stronger driver of community changes. This is, however, most likely also related to the quality of the HYMO assessments, which in most of the larger data sets were fairly superficial.

Another inherent problem is that dispersal mechanisms are likely to be highly influential, especially in relation to colonisation of physical features and biotopes (Heino, 2013). In many cases, this may de-couple any direct link between local hydromorphology and biota, or at least ensure that any biotic response may lag significantly behind changes in hydromorphology. Previous detailed field studies have shown that habitats that are assessed as being similar can differ markedly with regard to biota and that suitable habitats might not be colonized or colonisation may be severely delayed due to dispersal limitations.

Planning stream and river restoration

- ✓ Restoration projects should have **well-defined quantitative success criteria** e.g. ranging from hydrological and morphological improvements to the expected beneficial impact on biota and ecosystem services.
- ✓ Application of **existing planning and management tools** such as PDCA (Plan-Do-Check-Act), DPSIR, setting SMART objectives and BACI monitoring, can substantially enhance the efficiency and effectiveness of restoration.
- ✓ Restoration planning should adopt a **synergistic approach with other resource users** to secure win-win scenarios for improving ecological quality of rivers.

Despite the rapid increase in river restoration projects, little is known about the effectiveness of these efforts and many practitioners do not follow a systematic approach for planning restoration projects. REFORM has developed a planning protocol that incorporates benchmarking and setting specific and measurable targets for restoration and mitigation measures (Cowx et al. 2013). The approach uses project management techniques, such as the PDCA cycle (Plan – Do – Check – Act, the DPSIR approach, setting SMART project objectives, BACI monitoring) to solve problems and produce a strategy for the execution of appropriate projects to meet specific environmental and social objectives.

Development sectors such as water resource management, flood protection, inland navigation and hydropower have led to the replacement of naturally occurring and functioning systems with highly modified and human-engineered systems, resulting in a number of pressures on the freshwater ecosystem. However, multiple benefits can be achieved by integrating management across these sectors and win-win approaches are now emerging in river restoration from such cross-sectoral interactions. These interactions are, however, limited at present because of both weak governance and technical capabilities. Technical barriers to integrated cross-sectoral planning are substantial, related partly to limited data and poor understanding of drivers of each sector and thus cross-sectoral threats as well as indirect effects of actions, and partly to the inadequacies of decision support tools. REFORM provides guidance and tools to assist project managers with decision making, problem solving and planning strategies to identify suitable Programme of Measures (PoM) to support future RBMP that integrate cross-sectoral interactions. These include techniques to optimise benefits between cross-sectoral river services and ecological requirements whilst considering climate change effects (Angelopoulos et al. 2015). Identification of the drivers, synergies and trade-offs allows policy-makers to better understand the hidden benefits from working with other sectors to support restoration activities and maximize outcomes.

Cost-benefit analysis of restoration measures

- ✓ **Cost data are too scarce** hampering cost-benefit analysis of restoration measures. There is a need to invest efforts in standards and protocols to gather and **incorporate cost information in a more systematic way**.
- ✓ **Cost-benefit analysis can help in prioritizing** restoration measures and plans.

A review of case studies and literature on costs and benefits of river restoration in Europe showed that cost data are quite variable and usually not available in a form appropriate for further assessments (Ayres et al. 2014). On this basis, it is also difficult to determine ecosystem benefits and services from restoration projects both individually and as a whole. Thus, investing efforts in standards and protocols to gather and incorporate cost information in a more systematic way will benefit decision-making on restoration measures.

In Europe, prioritization of restoration measures in the context of the WFD based on cost-effectiveness or cost-benefit analyses is still very limited. Cost-benefit analysis (CBA) can help in prioritizing restoration measures and plans. The challenges for river restoration with CBAs concern in particular defining the baseline scenario, identifying exogenous developments and valuing project impacts. Manuals and guidelines for the economic analysis of river restoration projects do not yet exist. Yet important guidelines on the economics of water management in general offer valuable advice (Brouwer et al. 2015).

	Priced	**Non-priced**
Direct	• Investment costs • Operation & maintenance • (Avoided) damage costs	• Public perception safety • Landscape amenities • Biodiversity conservation
Indirect	• Grit extraction • Hydropower • Commercial shipping • Business disruption	• Re-location farms, houses • Recreational benefits

Table 1. Possible effects of restoration projects including second-order indirect effects on sectors and non-priced socio-economic and environmental effects.

Linking e-flows to sediment dynamics

- ✓ E-flows are mainly set with focus on the hydrologic regime in anticipation of promoting ecological response. A broader approach to estimating e-flows is to **identify those flows required to maintain certain geomorphic processes and forms** that directly contribute to aquatic habitat and ecosystem functioning.
- ✓ This broader approach includes other types of actions beyond specifying flows alone, such as **focusing on the sediment transport regime or directly manipulating channel morphology**.

✓ **Monitoring the outcomes of e-flows including sediments is needed** because our understanding of water and sediment requirements by key aquatic biota and ecosystem functions is not precise. Often critical decisions are made with relatively weak ecological evidence.

One of the recommendations at the REFORM stakeholder workshop in Brussels (26-27 February 2013) was to contribute to the development of guidance on the definition of environmental flows. As response to this stakeholder demand, REFORM organised expert exchange on the linkage of e-flows to sediment dynamics (Garcia de Jalon et al, 2015).

Water and sediments are intrinsically interconnected in natural river systems. Fluvial communities have evolved to be adapted to this interaction, and thus their habitat requirements depend on hydromorphological dynamics.

The estimation of e-flows is not straightforward, as the quantitative links between hydromorphology and biology are not yet well known, due to the insufficient number of consistent data and to the weak response of current biological metrics to hydromorphological pressures.

The current strategy for setting e-flows is to focus on the hydrologic regime in anticipation of promoting some ecological response. In the same time, geomorphic dynamics of a river and the functioning of natural physical processes are essential to create and maintain habitats and ensure ecosystem integrity and the links between hydrology and geomorphology are generally well known. On this basis, a broader approach to estimating e-flows is to identify those flows required to maintain certain geomorphic processes and forms that directly contribute to aquatic habitat and ecosystem functioning.

Elements of this broadened approach include other types of actions beyond specifying flows alone, such as focusing on the sediment transport regime (e.g. releasing sediments downstream of dams or other obstructions), or directly manipulating channel morphology (i.e. morphological reconstruction). Any of these actions (hydromorphology-based measures) may induce morphological channel changes, therefore promoting habitat recovery and diversity.

The choice of the best option to be considered in combination with changes in the hydrologic regime (i.e. sediment transport vs. morphological reconstruction) depends on the specific context, for example the reach sensitivity and morphological potential. Selecting the appropriate measures requires setting the river reach within a wider spatial-temporal framework (see REFORM Hydromorphology Framework presented in this Policy Brief).

E-flows including sediments should be implemented and monitored within an adaptive management framework. Monitoring the outcomes of e-flows is needed because our understanding of water and sediment requirements by key aquatic biota and ecosystem functions is not precise and often critical decisions are made with relatively weak ecological evidence to support them (Garcia de Jalon et al, 2015).

Restoration measures at project level and effects on river morphology and biota

In the REFORM project, two types of analysis were carried out to reach conclusions on general principles and aspects that have to be considered when selecting restoration measures in restoration projects. First, the scientific peer-reviewed literature and unpublished databases were reviewed to summarize existing knowledge (120 projects included in the review of Kail & Angelopoulos 2014; Kail et al. 2015). Second, 20 restoration projects were investigated in more detail, including a broad range of abiotic and biotic variables (different organism groups, hydromorphology, ecosystem services) and using a standardized monitoring design, to fill some knowledge gaps (e.g. the role of restoration extent for river restoration effects in Hering et al. 2015, Kail et al. 2014).

The reviewed literature as well as the case-studies mainly covered small to medium-sized rivers in Northern, Eastern and Central Europe, reflecting the relatively long tradition in river restoration in these regions. Furthermore, common restoration techniques were planform measures like remeandering and widening as well as in-channel measures like the removal of bank fixation and addition of large wood and boulders. Regional differences have to be considered when applying these results to other river types and regions (e.g. large or Mediterranean rivers) or restoration techniques.

- ✓ Hydromorphological restoration has an **overall positive effect on biota**, but effects are highly variable and even negative. It is thus essential to **monitor and adjust restoration projects**.
- ✓ Restoration pays - it **increases ecosystem services**, especially cultural and regulating services. This should be considered in the assessment of river restoration projects.
- ✓ **River restoration benefits not only aquatic biota.** Terrestrial and semi-aquatic species benefit most (e.g. floodplain vegetation, ground beetles) and hence, should be considered in assessments.
- ✓ There is **no single "best measure"** for restoration. **Widening** of water courses to restore a more natural planform generally has a high effect (especially on macrophytes and ground beetles). **Instream measures** have the highest effect on fish and macroinvertebrates. Overall, measures should be selected taking **consideration of the targeted organism group**.
- ✓ It is important to select measures that **restore specific limiting habitats at relevant scales** and not necessarily mere habitat diversity. For instance, macroinvertebrates need substrate diversity at the microscale. Surprisingly, restoration measures which enhance mesoscale habitat conditions, and hence are visually pleasing, do not necessarily improve microscale habitat conditions, which may explain a low effect on invertebrates.
- ✓ Restoration results in a **higher number of individuals (abundance) but few new species (richness)**. For this, it is important to bear in mind the **recolonization potential**, which might be limited if source populations are missing, particularly in extensively degraded river basins.
- ✓ Restoration had **positive effects even in small restoration projects**. Effects did not increase with project size, most probably because even the largest projects investigated in REFORM were still relatively small. However, other studies indicate that exceptionally large projects indeed have higher effects.

Figure 5. River bed widening, Kleblach – Lind, Austria (photo: A. Loach)

The way forward

The interdisciplinary team of REFORM has made significant advances in clearly presenting fundamental concepts to look at hydrology, geomorphology, vegetation and aquatic biological communities in an integrated framework. The strength of REFORM also lies in the development of guidelines for measurement and conceptual frameworks to understand why restoration might succeed or fail and how restoration can be improved.

In parallel to REFORM, much work on hydromorphology and its links to biology has taken place and is ongoing in individual European countries. The challenge remains in creating a European exchange network and a platform for sharing knowledge on issues related to hydromorphology and biological reaction to hydromorphological pressures. There is also still potential to strengthen capacity building and training of experts and practitioners on hydromorphological assessment methods. We hope that the fundamental concepts and framework laid out by REFORM will provide a foundation for water managers, practitioners, scientists and trainers to take the next steps beyond REFORM towards a better approach to river restoration.

Further reading

Ayres, A. et al. (2014) Inventory of river restoration measures: effects, costs and benefits. REFORM deliverable 1.4.

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Coordinator

Tom Buijse, Deltares

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