Final Report Summary - REFORM (REstoring rivers FOR effective catchment Management)

Executive Summary:
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. Against this background, REFORM (REstoring rivers FOR effective catchment Management, http://reformrivers.eu/) has generated substantial outputs to support WFD implementation: over 30 deliverables and 60 scientific publications. For application in river management relevant results are summarised user-friendly in the REFORM wiki. Furthermore, the outcomes of REFORM has been discussed and disseminated through stakeholder workshops, an international scientific conference, a summer school, numerous presentations, newsletters, policy briefs and discussion papers. In summary the key results and conclusions are:

Hydromorphological assessment should consider physical processes and appropriate temporal and spatial aspects beyond river restoration project boundaries and project life span. For this, REFORM developed an open-ended hydromorphology framework incorporating multi-scale spatial and temporal aspects. It aids users in developing understanding of the morphology and dynamics of river reaches and
their causes. The Morphological Quality Index (MQI) is the method recommended by REFORM for assessing river condition. The method is extremely useful for analysing and interpreting critical problems and causes of alteration. 

Vegetation and plants can play a cost-effective and significant role as physical ecosystem engineers for river restoration. Riparian and floodplain ecosystems are not subject to extensive monitoring but are crucial to river morphodynamics and ecology. Direct measurements of hydromorphological processes and riparian vegetation are likely to be better in assessing hydromorphological degradation than in-stream biota. 

Current biological 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. This includes sampling of habitats (e.g. the riparian) that are in particular impacted by HYMO degradation. Hydromorphological assessment covering the entire range from high to bad should be a quality element in its own right in the WFD status assessment. 

Restoration projects should adopt a synergistic approach with other resource users to secure win-win scenarios and have well-defined quantitative success criteria e.g. ranging from hydromorphological 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. 

Cost-benefit analysis can help in prioritizing restoration measures and plans. At present, cost data are too scarce hampering cost-benefit analysis of restoration measures. There is a need to gather and incorporate cost information in a more systematic way. 

Restoration had positive effects even in small restoration projects. However, other studies indicate that exceptionally large projects indeed have higher effects. Restoration pays - it increases ecosystem services, which should be considered in the assessment of river restoration projects. River restoration benefits not only aquatic biota. Terrestrial and semi-aquatic species benefit and should be considered in assessments. It is important to select measures that restore specific limiting habitats at relevant scales. Hydromorphological restoration has an overall positive effect on biota, but effects vary. It is thus essential to monitor and adjust restoration projects.

Project Context and Objectives: 
Europe is characterized by a dense network of rivers that provide essential ecosystem services. From an ecological perspective, rivers and their floodplains form some of the most diverse ecosystems worldwide. Over time, use of rivers by humans has led to severe degradation of water quality and ecosystem functions. In the 20th century water quality in major European rivers was so poor they could no longer support higher life. Huge investment in waste water treatment followed improving water quality across the continent. However, rivers remain degraded; notably hydrology and habitats have been altered, while eutrophication, toxic substances and emerging stressors contribute to the complex of pressures affecting our rivers. Thus there is a great need to better understand and predict the costs and benefits of future river restoration.

In 2000, the EU Water Framework Directive (WFD, EC 2000) was established as the principal legal instrument to manage and restore aquatic ecosystems. It fundamentally changed water management in all EU states by using ecosystem health as the basis for decisions. “Biological Quality Elements” BQE (e.g. fish, benthic invertebrates or aquatic flora), which integrate the effects of all stressors, are now used to...
fish, benthic invertebrates or aquatic flora), which integrate the effects of all stressors, are now used to assess the status of rivers. Initial WFD implementation and monitoring showed that the majority of rivers still suffer from degradation, despite successful efforts to tackle pollution. Based on these findings, EU states have drafted River Basin Management Plans with restoration measures focusing on restoring river hydrology and morphology. 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, there is increasing emphasis in Europe on river restoration driven by demands of the Water Framework Directive (WFD). The programmes of measures of EU Member States focus, among other issues, on restoring river hydrology and morphology. Their implementation requires substantial investment in these measures, but there still remains a great need to better understand and predict the costs and benefits of future river restoration. The benefits of wastewater treatment were based on well understood system responses. In contrast, ecological response to hydromorphological restoration is complex and poorly understood for the following reasons:

- Characterisation of HYMO status focuses on pattern not processes: data collected represent small spatial scales, with relevant larger spatial scales or long term impacts neglected.
- How HYMO change affects Biological Quality Elements (BQE; fish, invertebrates, macrophytes) and ecological functioning is poorly understood and is particularly challenging for multi-pressure systems.
- Exploitation of knowledge is weak between scientists and restoration practitioners.
- Unlike water quality improvement, HYMO restoration implies a demand for either space or resources, i.e. land or water. Mutual interactions and benefits for ecosystems and their goods and services are not sufficiently understood.
- Restoration projects have failed to achieve their objectives. This alienates public opinion and limits future participation and support. Risk analysis approaches are required in which objectives are explicit and used to assess project success.

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 (Figure 3). This with the aim to support member status with drafting the 2nd and future River Basin Management Plans (RMBPs) for the implementation of the WFD. To allow full use, all results of REFORM will be made available online in the public domain of the project website.

The consortium of partners in REFORM represents a wide range of disciplines: hydrology; hydraulics; geomorphology; ecology; socio-economics; and water management. The project consortium is supported by an Advisory Board of 8 independent representatives of international and national stakeholders, including river basin managers, representatives of the economic sectors relevant to river restoration and lead scientists in river ecosystem restoration.

Aims of REFORM are (1) to provide a framework for improving the success of hydromorphological restoration measures and (2) to assess more effectively the state of rivers, floodplains and connected groundwater systems. The restoration framework addresses the relevance of dynamic processes at various spatial and temporal scales, the need for setting end-points, analysis of risks and benefits, integration with other societal demands (e.g. flood protection and water supply), and resilience to climate change.
Integration with other societal demands (e.g. flood protection and water supply), and resilience to climate change. The workplan is organized in three modules: (1) natural processes, (2) degradation, (3) restoration (Figure 2). Data from monitoring programmes and restoration projects will be pooled and linked with landscape-scale hydromorphological and physiographic data and catchment models. Targeted field and experimental studies using common protocols will fill data gaps on the role of scale in restoration success. A wide range of statistical modeling approaches will improve indicators for hydromorphological change and factors determining restoration success. All work packages are multidisciplinary and will feed into products for application in river basin management, e.g. guidelines for successful restoration and a web-based tool for exchanging experiences with river restoration measures facilitated and enhanced through consultation with stakeholders (Figure 2). In addition to its impact on the RBMPs, REFORM will provide guidance to other EU directives (groundwater, floods, energy from renewable resources, habitats) to integrate their objectives into conservation and restoration of rivers as sustainable ecosystems.

REFORM’s objectives are grouped into three categories: application, research and dissemination.

APPLICATION
• To select WFD compliant hydromorphological and biological indicators for cost-effective monitoring that characterise the consequences of physical degradation and restoration in rivers and their services.
• To evaluate and improve practical tools and guidelines for the design of cost-effective hydromorphological restoration and mitigation measures for practitioners and end-users.

RESEARCH
• To review existing data and information on hydromorphological river degradation and restoration, underlying physical and ecological processes, their interactions and ecosystem services.
• To develop a process-based, multi-scaled hydromorphological framework on European rivers and floodplains and connected groundwaters that is relevant to river ecology and suitable for hydromorphological monitoring.
• To understand how hydromorphological pressures interact with other pressures that may constrain successful restoration.
• To assess the significance of scaling effects on the effectiveness of different adaptation, mitigation and restoration measures to improve ecological status or potential of rivers, floodplains and connected groundwaters.
• To develop instruments to analyse risk and assess benefits of successful river restoration, including resilience to climate change and relations to other socio-economic activities.

DISSEMINATION
• To increase awareness and appreciation for the need, potential and benefits of river restoration through active involvement of and dissemination of project outputs to policymakers, practitioners and stakeholders.

REFORM ambition was to give strong emphasis from its outset on directly engaging with stakeholders at different levels to receive feedback on its research programme as well as the applications and tools to be ultimately delivered. Key bodies are the ECOSTAT working group of the WFD Common Implementation Strategy, the European Centre for River Restoration (http://www.ecrr.org/) and the LIFE+ project RESTORE (https://restorerivers.eu), but at the same time planning was open to take advantage of new opportunities such as national stakeholder workshops. Interaction was scheduled throughout the whole...
opportunities such as national stakeholder workshops. Interaction was scheduled throughout the whole duration of the project. The plans and initial outcomes of REFORM are to be discussed and disseminated through an EU-wide stakeholder workshop. The final outcome of REFORM to be presented through an international scientific conference, a summer school and a final EU-wide stakeholder workshop. To inform interested audience a project website to be launched to give all project results and 6-monthly newsletters, policy briefs and policy discussion papers were scheduled to present new results both from REFORM and other relevant projects.

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 selection 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).

Project Results:
The main S&T results are presented in line with the various phases of river basin management planning (RBMP). They are presented as the key conclusions and recommendations of the REFORM project, which are relevant for policy-makers involved in river basin management planning. Illustrations are given in a separate document with supporting information. References to figures refer to this supporting document.

CHARACTERISATION “HOW DOES MY RIVER WORK?”
Knowing how a river works is essential for achieving success in river restoration. It should be the first step in any restoration process, and the basis for any future river basin management plan. Important aspects are hydromorphology, the role of vegetation, and ecosystem services.

• Hydromorphological assessment
  o Hydromorphology Framework
  o Hydromorphological assessment methods
  o Use of Remote sensing
• Role of vegetation and floodplain ecosystems

STATUS MONITORING AND ASSESSMENT: “WHAT’S WRONG?”
The second stage of river basin planning is to assess what is wrong. REFORM researched methods for assessing the hydromorphology (HYMO) and biological elements. REFORM focused on linking...
assessing the hydromorphology (HYMO) and biological elements. REFORM focused on linking hydromorphology to biology, notably water plants, macro-invertebrates (aquatic insects) and fish
- Impact of hydromorphological pressures;
- Improved coupling between hydromorphology and biota;
- Groundwater – river interactions

PROGRAMMES AND MEASURES, INDIVIDUAL RESTORATION PROJECTS “HOW TO IMPROVE?”
An integrated planning framework supports the design of river restoration measures. This framework is cyclic for both entire river basins (catchments) and individual projects.
- Planning stream and river restoration
- Cost-benefit analysis of restoration measures
- Risk and uncertainties in river rehabilitation
- Linking e-flows to sediment dynamics
- Restoration measures at project level and their effects
- Fact sheets for restoration projects

Hydromorphological assessment

Effective river restoration calls for an understanding of how rivers work. A key step for this is hydromorphological characterization, looking at rivers from a perspective that discloses the relevant processes and forms. Hydromorphology is a matter of water and sediment, but also of vegetation interacting with water and sediment. This makes both geomorphological and ecological processes relevant.
- REFORM developed an open-ended Hydromorphology Framework incorporating multi-scale spatial and temporal aspects into river assessment and management. It aids users in developing understanding of the morphology and dynamics of river reaches and their causes.
- 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).
- 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.
- 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. The integrated use of different components of the assessment is limited but is recently increasing. 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). The core of hydromorphological evaluation should be represented by the morphological and hydrological components. Physical, riparian, and longitudinal fish continuity assessments should provide a further characterisation of the overall stream conditions at selected sites.
assessments should provide a further characterisation of the overall stream conditions at selected sites (Figure 10). The REFORM wiki gives a full overview of all reviewed assessment methods. 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.

REFORM Hydromorphology Framework

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 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; Figure 7).

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.

REFORM Hydromorphological Assessment Methods

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; Figure 11).

- The Morphological Quality Index (MQI) is a tool designed to assess the overall morphological condition...
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.

- 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 a 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 a 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.

Remote sensing for river hydromorphological investigation

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
Vegetation does not just depend on hydromorphology. It influences hydromorphology too and plays an active role in shaping a river. REFORM carried our research on the reciprocal relations between hydromorphology and vegetation. Understanding these relations can be a major factor in the success or failure of restoration projects.

- 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; Figure 8). 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 are 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, 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 (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).

Impact of hydromorphological pressures

European rivers have been altered by means of changing their morphology (straightening and canalisation, disconnecting channels from flood plains, occupying riparian lands, building dams, weirs, bank reinforcements, etc.) to facilitate agriculture and urbanisation, to enable energy production and...
Bank reinforcements, etc.) to facilitate agriculture and urbanisation, to enable energy production and protection against flooding (Figure 12). Also, water has been abstracted from rivers and their natural flow regime to be used as a resource for irrigation and to supply urban and industrial needs. All these human activities have damaged fluvial habitats and have had severe and significant impacts on the status of the aquatic ecosystems.

A bibliographic review identified the most significant HYMO pressures as well as relevant hydromorphological effects of the different pressure types on fluvial systems across spatial and temporal scales and in particular those that have a significant impact on aquatic biological elements. This review further provided a tool to identify gaps in present HYMO knowledge, which is needed to improve our understanding of the mechanisms that control degradation-restoration processes. To illustrate relevant gaps conceptual schemes have been developed of the interactions between HYMO pressures, the main processes affected and the resulting quantified changes on HYMO variables (Garcia de Jalon 2013; Figures 13 and 14).

The quantitative variables provide the measures of the intensity of the processes and are useful to monitor river changes and to evaluate pressure effects. Whilst the biotic communities typically respond to the status of the variables, sustainable and successful river restoration should address the processes behind which determine the variables’ state. Therefore, all pressure specific conceptual schemes developed have been incorporated into one single effect matrix and analyzed using Fuzzy Logic Cognitive Maps (FCM) to identify the most relevant HYMO pressures as well as the most affected processes and variables (Lorenz et al. 2015).

Dynamics of flowing water emerged as the most important hydromorphological process. This was not surprising, but it still underlines the necessity to rehabilitate a more natural flow regime to improve the hydromorphological status of the rivers and the related biological communities. Vegetation encroachment emerged as second most important process which seems well in line with the natural river typology developed in WP2 and the identified importance of riparian vegetation in shaping riverine landscapes. The next important processes were all related to sediments underlining the key role of bedload transport and sediment dynamics in forming fluvial habitats.

In the wiki fact sheets for 19 different pressures belonging to either water abstractions, flow regulations, River fragmentation or morphological alterations are given.

Improved coupling of hydromorphology to biotic responses

Once we know how our river works, we can assess what is wrong. This regards both hydromorphological quality and biological quality. Based on the outcomes of the REFORM project, we recommend using the hydromorphological assessment method for ecological class assessment directly, circumventing the use of biological indicators. Degradation of quality can be due to hydromorphological pressures, although it is often very difficult to single out the effects of these pressures compared to other pressures in a multi-stressor environment (Figure 15).

• 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 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
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.

- The proposed REFORM hydromorphological assessment should be 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. It should cover the entire range from high to bad ecological status, rather than using BQEs as indicators of HYMO degradation.

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.

Algae appear to be the least suitable of the biological quality elements. As a biological quality element, they primarily relate to very small scales and substrate-specific sampling. Moreover, most methods in Europe use only the algae group of diatoms, and not algae with larger growth forms such as for instance filamentous green algae.

Macroinvertebrates are slightly better as indicators of hydromorphological degradation, but they appear sensitive to multiple stressors. It is thus almost impossible to single out the effects of hydromorphological conditions on community composition. As was the case for algae, macroinvertebrates are usually sampled at a relatively small scale and often on specific substrates, making any linkages to hydromorphological degradation on larger scales spurious. Macroinvertebrates represent the only biological quality element for which specific metrics have been developed that are sensitive to hydromorphological and hydrological degradation. However, these metrics have not been intercalibrated and tend to respond in manner similar to the response of metrics sensitive to other stressors. Thus 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/).

Macrophytes show more potential. For certain river types it must be possible to develop robust metrics that will be sensitive to hydromorphological degradation. Additionally, the key role of aquatic and riparian vegetation in shaping hydromorphological processes offers an additional argument for increased focus on this biological quality element in indicator development.

Fish appears to be the most promising biological quality element. It can be used to detect hydromorphological stress, although a need remains to develop more stressor-specific metrics. So 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 (Figure 9).

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...
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. 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).

Water managers therefore 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.

In conclusion, with the current level of knowledge, it remains difficult to use biological quality elements for detecting hydromorphological degradation. Therefore REFORM recommends using the hydromorphological method directly for ecological class assessment, circumventing the use of biological indicators.

Which central HYMO processes need to be addressed? How does biota respond to HYMO degradation and restoration? The dynamics of flowing water emerged as the most important HYMO process in the HYMO pressure/impact system (Wolter et al. 2013). This underlines the necessity to reinstate a more natural flow regime to improve the HYMO status of the rivers and related biological communities. The next most important processes were related to vegetation encroachment (in line with the importance of riparian vegetation in shaping riverine landscapes) and to sediments underlining the key role of bedload transport and sediment dynamics in forming fluvial habitats.

Coarse gravels maintained by stream power and flow velocity emerged as key indicators for HYMO integrity with relevance to aquatic organisms. Species preferring or depending on coarse substrates provide specific indicators for HYMO degradation, rehabilitation and integrity (Wolter et al. 2013). A second, rather unspecific, response of biota to hydromorphology emerged from the limitation of species by stream power, i.e. by physical forces of flows. Indirectly related to that is a positive response of species to habitat diversity and habitat complexity providing shelter from high flow velocities, and resources. In addition, river zones encompass a characteristic set of HYMO processes and patterns, thus, species preferences for specific zones are of indicative value for assessing HYMO integrity and have been developed accordingly for European fish species. Highly promising results have been obtained using the Fish Region Index, whose applicability and sensitivity will be further tested and improved. Ongoing work comprises the improvement of the newly proposed indices and indicators.

Groundwater-river interactions

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...
In 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). This work which was conceived at a REFORM expert workshop on the role of groundwater for river ecosystems (Poland, September 2014) is currently being continued in the FP7 projects MARS (www.mars-project.eu/) and GlobAqua (www.globaqua-project.eu/).

- Groundwater is the main factor supporting Eflows 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.

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 Eflows) 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.

Planning stream and river restoration

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; Figure 17). 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. Using this strategy, it is important to recognise that each restoration scheme proposal should be treated on an individual basis, as no two situations are alike. The decision support tool allows proposals to be evaluated at different levels and stages and will effectively curtail a proposal at an early stage should it be impractical or unviable.

- 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.
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.

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. 2015a).

Identification of the drivers, synergies and trade-offs allows policymakers to better understand the hidden benefits from working with other sectors to support restoration activities and maximize outcomes.

Cost-benefit analysis of restoration measures

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.

- 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.

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).

Risks and Uncertainty in River Rehabilitation

Analyses of costs and benefits require the prediction of the effects of restoration measures and the quantification of societal values. Both of these estimates are uncertain. Key issues related to the
quantification of societal values. Both of these estimates are uncertain. Key issues related to the assessment, description and quantification of uncertainty are discussed and guidelines are provided for considering uncertainty and in more detail, how uncertainty can be considered in CEA/CBA and in MCDA (Reichert et al. 2015a). There are two important sources of uncertainty to consider in environmental management in general and in particular for river restoration:

- Uncertainty about scientific predictions of outcomes.
- Uncertainty about the preferences of the society elicited from inquiries or stakeholders.

This resulted in the following policy recommendations:

- Communication of uncertainty is a key element of any communication of scientific predictions.
- Clearly separating scientific predictions and societal valuations is an essential element of any decision support procedure (Reichert et al. 2015b). In particular if there are disagreements among experts about scientific predictions and of stakeholder groups about preferences.
- Uncertainty about scientific predictions can be addressed by probability distributions and scenarios, while uncertainty about societal preferences are often better addressed by sensitivity analyses of the ranking of the alternatives resulting from combining predictions of the outcomes of decision alternatives with preferences.

Linking e-flows to sediment dynamics

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).

- 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.

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
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; Figure 16).

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 re-colonization 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.

Fact sheets for river restoration

For 13 different types of river across Europe a synthesis of pressures, restoration experiences and variables suited for monitoring restoration is compiled (Verdonschot et al. 2015b). It is meant to give insight into the diversity and similarities of restoration techniques for different types of rivers in terms of present practice and promising but to date little used approaches. Each fact sheet gives information on river type name, pressure categories/pressures, measure categories/measures and monitoring scheme.

Per river type the valley- and planform, hydrology, morphology, chemistry, riparian zone are briefly described. Major pressures, problems and constraints for river restoration, common restoration practice with their problems and constraints and promising and new measures are given for each type. The river typology adopted for the factsheets differs from the river reach typology developed in REFORM and refers to the (sub)catchment setting of a river in terms of altitude, size and geology and as such links to the European broad river types (ETC/ICM, 2015. The setting of these types does not change in time. In contrast, the REFORM river reach typology is designed for assessing the hydromorphological functioning of individual river reaches. REFORM river reach types may change in time because they represent the response of the river reaches to processes of flow, sediment and vegetation. Furthermore, river (sub-)catchments of a single type according to the types presented in these factsheets may and often will contain different REFORM reach types. Thus when identifying the most appropriate restoration techniques it is even for apparently similar river types i.e. covered by the same factsheet not a ‘one size fits all’ approach, but a tailor-made approach acknowledging the governing hydrological and morphological conditions and the interaction with vegetation. The factsheets drawn by regional experts are thus meant to support decision making, and should not be used as cookbooks.

In the wiki fact sheets for over 40 different measures belonging to following categories are given.
- Water flow quantity improvement
- Sediment flow quantity improvement
- Flow dynamics improvement
- Longitudinal connectivity improvement
- River bed depth and width variation improvement
- In-channel structure and substrate improvement
- Riparian zone improvement
- Floodplains/off-channel/lateral connectivity habitats improvement

An important observation is, however, that measures are mostly taken in concert i.e. restoration projects comprise multiple measures. Next, the effectiveness of measures strongly depends on the wider setting in which they are realised. As a consequence general descriptions of measures such as given in these fact sheets are of use, but how measures actually contribute in projects to improve ecological status can vary considerably.
Final conference 'Novel Approaches to Assess and Rehabilitate Modified Rivers'

The conference is addressed as a separate topic, because it covers all aspects of the REFORM project. The much appreciated and successful scientific conference was organized to highlight the importance of the benefits of river restoration. 170 participants from 26 countries shared experiences, aspirations, challenges, analytical frameworks and new approaches to enhance the success of river restoration and to come to a better understanding of the consequences of hydro-morphological changes to the ecological status of running waters (Figure 19). The conference attracted universities and research institutes, environmental management organisations, NGOs and consulting firms in the field of river restoration. 15 keynote lectures from Europe, North America and New Zealand, 58 oral presentations in breakout sessions and 38 posters provided the ingredients and inspiration for animated conversations during the breaks.

Among others, evidence outlined by the conference speakers and participants gave fundamental insights into how rivers work, and presented a wide span of research from global to catchment and all the way down to the species level. It became evident that attention is shifting towards reflecting on the river in its full scope including the role of the riparian zone and the floodplain for ecosystem functioning. Keynote and oral presentations made a case for the need to develop more process-oriented restoration measures, and to consider hydromorphological changes and their evolution both in terms of space and time. A lot of inspiration for further work was given by presentations on the application of biotic indices for the assessment of river ecological conditions as well as by a multitude of case studies presented on the achievements by restoration and mitigation practices in Europe and beyond. The conference also provided a platform for exchanging experiences and ongoing work on the challenging issues of socioeconomic assessments related to river restoration, tools and strategies for more closely linking science to the practitioner level.

The proceedings contain the extended summaries of nearly all keynotes and oral presentations as well as several poster presentations (Angelopoulos et al 2015b). They are preceded by a description of the scope, objectives and topics of the conference, feedback from the advisory and a visual impression of conference. The contributions are grouped within the six conference topics:

- Assessment and rehabilitation of hydromorphological processes in rivers
- Discerning the impact of hydromorphological modification from other stressors
- Achievements by restoration and mitigation practices
- How to improve the (cost-)effectiveness of river rehabilitation?
- Benefits of river rehabilitation and synergies with other uses (flood protection, navigation, agriculture, hydropower)
- Linking science to practice: tools to assess river status and guide rehabilitation to optimize river basin management

Scientific publications

At the end of the project there are already more than 60 peer-reviewed scientific publications. Besides individual publications, several special issues have been prepared or are under preparation:

- In the journal Aquatic Sciences: research across boundaries, 10 papers are published in a special issue: “A multi-scale framework for supporting river assessment and management” (Gurnell et al. 2015a)
A multi-scale framework for supporting river assessment and management (Gurnell et al., 2015a).

- In the journal River Research and Applications, 6 papers are published in a special issue: “Hydrogeomorphology – ecology interactions in river systems” (Grabowski & Gurnell, 2015).
- In the journal Hydrobiologia, a special issue regarding the “Effects of large- and small-scale river restoration on hydromorphology and ecology” is under preparation and should be available soon (Muhar et al. 2015). It will contain 9 papers on restoration effects on hydromorphology, fish, benthic invertebrates, aquatic macrophytes, floodplain vegetation, riparian ground beetles, food webs, ecosystem services and a synthesis. The integrating paper of this study has already been published (Hering et al., 2015).

The complete overview of all published scientific papers is given at the REFORM website (Results -> Scientific Publications). For each publication the full reference, abstract and DOI (Digital Object Identifier) is given.

Further reading

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

Angelopoulos et al. (2015a) Effects of climate and land use changes on river ecosystems and restoration practices. REFORM deliverable 5.3


http://dx.doi.org/10.1007/s12665-014-3558-1

http://dx.doi.org/10.1007/s00027-015-0430-7

Brouwer, R., H. Gerdes, P. Reichert et al. (2015) Valuing the ecosystem services provided by European river corridors – an analytical framework. REFORM deliverable 5.2.


Friberg, N. (2014) Impacts and indicators of change in lotic ecosystems. WIREs Water 2014
http://dx.doi.org/10.1002/wat2.1040


Garcia de Jalon et al. (2013) Review on pressure effects on hydromorphological variables and ecologically relevant processes. REFORM deliverable 1.2.
Relevant processes. REFORM deliverable 1.2.


Gurnell et al. (2014a) Multi-scale framework and indicators of hydromorphological processes and forms I. Main report. REFORM deliverable 2.1 part 1

Gurnell et al. (2014b) Influence of Natural Hydromorphological Dynamics on Biota and Ecosystem Function, Part 1. REFORM deliverable 2.2 part 1


Mosselman et al. (2013) Synthesis of interim results for practical application to support the compilation of the 2nd RBMPs. REFORM deliverable 6.1.
http://dx.doi.org/10.1002/rra.2940
Reichert, P. et al. (2015a) Risks and Uncertainty in River Rehabilitation. REFORM deliverable 5.4
http://dx.doi.org/10.1016/j.jenvman.2015.01.053
Verdonschot, P. et al. (2015a) Evaluation of candidate indicators for case studies including uncertainty. REFORM deliverable 3.3.
Verdonschot, P. et al. (2015b) Fact sheets for restoration projects. REFORM deliverable 4.5
Wolter et al. (2013) Review on ecological response to hydromorphological degradation and restoration. REFORM deliverable 1.3.

Potential Impact:
Dissemination has been an essential part of the REFORM project, as it is widely recognized that results of the research need to be communicated to all relevant stakeholders to enable the project to leave a long-lasting legacy and impact. A specific work package has been dedicated to dissemination; in addition, several of the tools produced are part of the project’s dissemination strategy. The main target group for dissemination activities have been and still are public authorities, water managers and citizens and the organisations involved in the formulation, implementation, monitoring and evaluation of river restoration policies at the European, national and catchment levels. A detailed communication and dissemination strategy has been designed at the start of the project to maximize on the coverage and uptake of the outputs (Figure 6).
First an overview is given what REFORM has done to communicate its results and to obtain feedback from stakeholders and end-users. Thereafter its future relevance and socio-economic impact are described.
Main dissemination activities and exploitation of results

The partners of the REFORM project have used a wide range of communication forms to interact with and inform people about its objectives, results and final outcome.

FACE-TO-FACE communication

Face-to-face communication of the knowledge and experience gained in the project occurred predominantly at the national and European level:

- At the national level, the results have been presented during three national stakeholder workshops (Netherlands, Spain, Italy), one special session at the RRC annual conference (UK) and keynote presentations at river restoration seminars (Norway). Participation of the applied partners (ISPRA, CEDEX, EA) and members of the Advisory Board, who are also national government agencies in close connection to authorities in charge of implementing EU policy, has facilitated and still will the uptake and direct application of the project findings.

- At the European level, the project results have been presented to policy makers and European level working groups during multiple occasions (CIS ECOSTAT 2012, 2015; CIS PoM 2014, 2015; CIS Floods 2012). REFORM organised a stakeholder workshop in the early phase of the project (Brussels February 2013) to present initial results, but much more to gain feedback on its work programme. Uptake of data, information and policy assessments from the project by the European Environment Agency will be ensured through the participation of partners such as Ecologic in the European Topic Centre in Water.

- To inform and interact with the international scientific world presentations by numerous partners of REFORM have been given (see the overview of dissemination activities for further details). The most prominent being Ecohydraulics (Vienna 2012; Trondheim 2014), ERRC (Vienna 2013), Aquatic Plants (Edinburgh 2015) IS.Rivers (Lyon 2015) and German Limnological Society (Essen 2015). Moreover, REFORM organised its own scientific conference ‘Novel approaches to Assess and Rehabilitate Modified Rivers’ attended by 170 participants (Wageningen 2015). Connected to the conference a summer school for young scientists and Ph.D. students was organised.

Stakeholder Workshop on River Restoration

At the interactive Stakeholder Workshop on River Restoration to Support Effective Catchment Management (Brussels, February 2013), ca. 110 participants from 23 European countries and various stakeholder groups were informed about the first results of REFORM and gave their feedback and recommendations on the outputs and plans for the next stages of the project. The workshop was the main external event in the first phase of the REFORM project, providing a platform for consultation and exchange between REFORM scientists, European technical experts working on river degradation and restoration, and members of the Working Group A Ecological Status (ECOSTAT) of the Common Implementation Strategy of the WFD. The workshop’s format was very interactive, with parallel sessions addressing different types of European rivers (e.g. highland/midland, lowland, and Mediterranean river systems), as well as the impact of hydromorphological pressures in multiple-pressure settings, designing programmes of measures, and heavily modified water bodies (Figure 18). The REFORM stakeholder workshop provided a very good model of early two-way communication between an EU research project and water managers. The findings are documented in the summary report of the workshop (Kampa et al.
National stakeholder workshops

In total three national stakeholder workshops have been organised by different partners of the REFORM project. The first has been held in the Netherlands (Zutphen, November 2013), the second in Spain (Seville, June 2014) and the third in Italy (Rome, September 2015). In Spain and Italy the advantage having several key people from REFORM together was taken to organise back-to-back a national stakeholder workshop. To improve the two-way communication and tackle language barriers both events were supplied by simultaneous translation into respectively Spanish and Italian. The stakeholder workshop in the Netherlands was organised jointly with the Dutch platform for stream and river restoration. All events not only helped to inform people on REFORM’s objectives and results, but also stimulated the internal national discussion how to better assess the hydromorphological status of rivers and plan and evaluate river restoration. Impressions of these workshops are covered in various newsletter items.

Final conference “Novel Approaches to Assess and Rehabilitate Modified Rivers”

The REFORM Final Conference on “Novel Approaches to Assess and Rehabilitate Modified Rivers” was successfully organised on 30 June to 2 July 2015 in Wageningen (Netherlands). 170 participants from 26 countries shared experiences, aspirations, challenges, analytical frameworks and new approaches to enhance the success of river restoration and to come to a better understanding of the consequences of hydro-morphological changes to the ecological status of running waters (Figure 19). The conference offered 15 keynote lectures from Europe, North America and New Zealand, 58 oral presentations in breakout sessions and 38 posters. The conference closed with a field excursion, attended by 100 people, to two ‘Room for the river’ projects. The proceedings of the International Conference on River and Stream Restoration “Novel Approaches to Assess and Rehabilitate Modified Rivers” were published in August 2015 and are online available (Angelopoulos et al. 2015).

Summer school “Restoring regulated streams linking theory and practise”

The REFORM Summer School was successfully organised on 27 to 29 June 2015 and was held in Wageningen (Netherlands) back-to-back to the REFORM Final Conference. The topic of the Summer School was “Restoring regulated streams linking theory and practise” and in total, 12 participants attended the event. The 3 day programme was interactive, it encouraged group discussions and participants applied theory to practice by drafting a restoration strategy. The complete PowerPoint presentations and the video-recorded lectures of the Summer School are available online (see Summer Course | REFORM Rivers | 2015) and can be used for teaching and training purposes. The lecture notes of the summer school were published in July 2015 (Cowx et al. 2015).

CIS ECOSTAT workshops

CIS ECOSTAT organised two workshops dedicated to hydromorphology during the project life span of REFORM. The first took place when REFORM had just started (June 2012) and created to opportunity to inform representatives of EU member states on the ambitions and scope of the REFORM project and to
inform representatives of EU member states on the ambitions and scope of the REFORM project and to announce the REFORM stakeholder workshop in 2013. By organising a regular meeting back-to-back CIS ECOSTAT enlarged the possibility of people to attend REFORM’s stakeholder workshop. In October 2015, the CIS working group ECOSTAT and REFORM jointly organised a workshop on “Hydromorphology and WFD classification” hosted by the Norwegian Environment Agency in Oslo, Norway (70 participants). This workshop on hydromorphology was timely organised in the final month of the REFORM project. The workshop was held back-to-back with the 30th ECOSTAT meeting. The outcome of the REFORM project was one of the main motivations for the working group ECOSTAT to organise this workshop. The findings of the workshop are covered by an item in final newsletter. It can be concluded that the back-to-back approach for meetings has been extremely effective to meet and interact with national representatives. In particular, because these representatives do less frequently have the opportunity to attend scientific conferences or prefer or require another set up of events (more demand-driven, practical or interactive). For research projects it is therefore essential to organise other events besides scientific symposia to get into contact with stakeholders and end-users.

Policy briefs and policy discussion papers

REFORM has prepared three policy briefs. The first was meant to inform river managers how the initial results of REFORM could be used immediately to support drafting the 2nd river basin management plans, which had to be ready by December 2015. The REFORM project had planned and organised its work in the first phase that those results became available on time (November 2013). The overview of these initial results is given in Mosselman et al. (2013). The second brief presented the next set of results in particular the hydromorphological assessment framework (September 2014). The third and final brief summarised the key results, conclusions and recommendations over the whole project (December 2015). All policy briefs are available online on the project website.

In total three policy discussion papers have been produced. The first was the discussion paper prepared as input for the stakeholder workshop (February 2013). The topics for the two other discussion papers were selected following the feedback of the participants attending this stakeholder workshop. Participants generally were very pleased by the scope and ambitions of REFORM covering their needs and expectations, but were also asked to prioritise additional topics. From these topics groundwater and environmental flows were selected and addressed in two specific workshops. The outcome of these workshops has been documented in these discussion papers. The 2nd policy discussion paper ‘Bringing Groundwater to the Surface’ makes a first step in combining groundwater characteristics and pressures with stresses on rivers, floodplains and wetland ecosystems and was published in August 2015. Its content is based on discussions held at a REFORM expert workshop on the role of groundwater for river ecosystems (Poland, September 2014). The 3rd policy discussion paper ‘Linking e-Flows to sediment dynamics’ and was published in December 2015. Its content is based on discussions held at a REFORM expert workshop on the linkage of e-flows to sediment dynamics (Italy, September 2015). The REFORM project strongly recommends that e-flow rehabilitation measures are accompanied by sediment management plans.

Project website and wiki

The REFORM project website became online mid 2012 in the first year of the project.
The REFORM project website became online mid 2012 in the first year of the project (www.reformrivers.eu). Since then it served as a knowledge platform for the target audiences and as a place to provide open access to REFORM deliverables, scientific publications, case studies and project related news. Documents have been uploaded throughout the course of REFORM. Furthermore, the website has been used to announce and prepare the REFORM end-user event (stakeholder workshop) in 2013 and the final conference and summer school in 2015. The content of the REFORM project website has been regularly updated and its structure improved based on the needs of the project outcomes. Next to the project website a wiki on hydromorphology, ecology and restoration of rivers supports the dissemination of knowledge and know-how (http://wiki.reformrivers.eu/index.php/Main_Page; Figure 5). The Water Framework Directive commits European Union member states to achieve good ecological and chemical status of all water bodies. Hydromorphological degradation is one of the causes why many rivers do not achieve this status, thus necessitating river restoration. This has promoted restoration activities and scientific research across Europe. Practitioners, however, face the difficulty of finding information on the experiences from restoration and the findings from research. That is why REFORM developed a web-based information system or “wiki”. The contents of REFORM’s wiki can support the planning process and design of cost-effective and hydromorphologically relevant restoration and its benefits. It has been structured around the phases of the river basin management planning cycle (Figure 4). A prerequisite of planning is a good understanding of how a river works and an evaluation of status by asking, “What’s wrong?” An integrated planning framework supports the design of river restoration measures and addresses the question, “How can we improve?”, including risk analysis, the wider benefits of restoration and the restoration potential of other human interventions. This framework is cyclic for both programmes of measures in entire river basins and the planning and evaluation of individual projects. Both the website and the wiki will remain active up to three years after the end of the project (2018) allowing everybody to explore and use the results of REFORM for a number of years after the project’s lifespan. To update or expand the present contents of the wiki in the future connection with new projects have already been established (FP7 MARS - http://www.mars-project.eu ; Freshwater Information Platform - http://www.freshwaterplatform.eu ) and new opportunities will be looked for. The Freshwater Information Platform aims to overcome the problem that the outcome of research projects is no longer available once projects have ended. Several REFORM partners support this initiative.

General Dissemination: newsletter and leaflets

In total eight newsletters has been produced. The newsletters covered new results of REFORM, interviews with key persons regarding river management, restoration or research, REFORM case studies, related projects and REFORM or external events. All newsletters are online available at the REFORM website (Kampa et al. 2015).

The REFORM project leaflet has been made available in 11 languages (English, French, German, Italian, Spanish, Czech, Danish, Dutch, Finnish, Polish and Swedish) and has been used throughout the project to support dissemination at European, national and regional levels.

Social media

REFORM has used Linkedin to inform relevant groups when results were available and to announce its final conference and summer school. The main Linkedin target groups with the present number of members were
Members were
- Stream Restoration Professionals - 4,169 members
- River Restoration Professionals – 2,444 members
- Restoring Europe’s Rivers – 409 members
- EU Water Framework Directive (WFD) Implementation – 408 members

Future relevance and socio-economic impact

Providing input for future River Basin Management Plans

REFORM places 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. The logical framework of the wiki systematically guides practitioners through two main planning stages of river restoration: catchment planning and the project cycle. Both the REFORM website and the wiki will remain available online after the end of REFORM.

More specifically REFORM recommends using its outcome for the following aspects of river basin management:

- Hydromorphological assessment should consider physical processes and appropriate temporal and spatial aspects beyond river restoration project boundaries and project life span. The methods developed by REFORM (open-ended hydromorphology framework; Morphological Quality Index (MQI) are extremely useful for understanding river dynamics, analysing and interpreting critical problems and causes of alteration. Such diagnosis is the basis to identify to most appropriate restoration and mitigation measures.
- Current biological 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. This includes sampling of habitats (e.g. the riparian) that are in particular impacted by HYMO degradation. Hydromorphological assessment covering the entire range from high to bad should be a quality element in its own right in the WFD status assessment.
- Much more attention should be given how vegetation and plants can help to improve river ecosystems. They can play a cost-effective and significant role as physical ecosystem engineers.
- Rivers are more than main channels and restoration benefits not only aquatic biota. Riparian and floodplain ecosystems crucial to river morphodynamics and ecology are too much ignored. Direct measurements of hydromorphological processes and riparian vegetation are likely to be better in assessing hydromorphological degradation than in-stream biota. Terrestrial and semi-aquatic species benefit and should be considered in assessments. This adaptation will contribute to connect the ambitions of Floods directive, Natura 2000 network and the WFD.
- Restoration projects should adopt a synergistic approach with other resource users to secure win-win scenarios and have well-defined quantitative success criteria e.g. ranging from hydromorphological 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.
- Improvement of ecological status and ecosystem services of streams and rivers may benefit from both small and large projects. There is no single best measure. It is important to select measures that restore specific limiting habitats at relevant scales. As the outcome is often still too uncertain it is essential to monitor and adjust restoration projects.
Rehabilitating rivers is expensive and public opinion is of course critical. Regularly there are disagreements among experts about scientific predictions and of stakeholder groups about preferences. Clearly separating scientific predictions and societal valuations is an essential element of any decision support procedure and cost-benefit analysis can help in prioritizing restoration measures and plans. There is a need to gather and incorporate information on costs and uncertainties in a more systematic way to widen public support for the need and benefits of restoration. REFORM considers the CIS working groups as the most important bodies to disseminate the outcome of REFORM and the need to adapt current approaches for hydromorphological assessment and planning and evaluation restoration of rivers and associated wetlands. It is clear that a bulk of information has been generated, which might feel as an obstacle to filter the relevant content. To this end the wiki should be the guide for end-users.

Improving the science policy interface

With its dissemination activities and its close cooperation with policy groups, decision makers, and stakeholders, REFORM has performed targeted and policy relevant scientific research. Over 60 scientific publications have significantly expanded the knowledge base for assessing and improving river ecosystems in Europe. Feedback from policy and decision makers and stakeholders at several strategic times in the project helped to validate the methodology and the envisaged results against experience and knowledge needs of the end-users. The involvement of partners directly responsible for river management has greatly contributed to the applicability of REFORM’s results. It facilitated the communication at the European level through CIS and at the national level through stakeholder workshops.

Contributing to capacity building

REFORM has enlarged the capacity for appropriate assessment and successful river restoration by compiling existing knowledge and filling identified knowledge gaps with targeted research. With its results being available as a complementary package of guidelines, models, interactive web-tools, and evaluation tools, it will enable water managers to add to their existing methodologies and instruments if necessary and arrive at the state-of-the-art successful and cost-effective river restoration. The recorded lectures and lecture notes resulting from the summer school can be directly used to train not only young scientist and students, but also water managers and consultants.

Added value to national monitoring programmes

The conclusions of REFORM are clear regarding present monitoring. Monitoring approaches require adaptation to assess the hydrological and morphological status adequately. This is a prerequisite to identify the appropriate measures to improve the ecological status. Furthermore the intercalibrated biological assessment methods do give insight in the overall status, but lack the resolution to pinpoint the causes for deterioration. Thus to diagnose river ecosystems new methods need to be developed. REFORM recommends to improve and develop trait-based approaches and in various European countries experience does already exists. CIS in its future work programmes could consider fulfilling a role to share experiences on diagnostic tools besides status assessment.
Balancing socio-economic functions and ecological functioning

Rivers and streams have been regulated and floodplains reclaimed to support socio-economic functions for centuries and decades. Improving ecosystem services and conserving biodiversity do not necessarily go hand in hand and may even have conflicting demands. It thus was and still is a significant challenge to balance the use of river ecosystems with achieving good ecological status. There has been excellent progress to tune Floods directive with environmental objectives of the WFD and Natura 2000: nature-based solutions to retain and store water. Challenges are larger and solutions in an infant's stage for managing reservoirs used for water storage and energy production. Not only to design effective environmental flows, but in particular because the consequences for sediment transport are insufficiently acknowledged and addressed. REFORM has clearly demonstrated that hydromorphology is the interplay between water, sediment and vegetation. Ignoring one of these components may give a wrong diagnosis and choosing ineffective restoration measures. The next aspect, which to date has received too little attention are the riparian zones and floodplains i.e. riverine wetlands. Tree on riparian zones provide shelter and shadow and enlarge habitat diversity in streams. Floodplains are spawning and nursery areas for fish and of great importance for the Natura 2000 network in Europe. WFD assessment based on the biological quality elements in main channels of rivers and streams only gives insufficient guidance how to improve unconfined rivers with floodplains. Riparian zones and floodplains can function as the ideal buffer zones i.e. green infrastructure between agriculture and rivers. REFORM has produced many results to support to take this to the next stage. Thus more effort is needed to tune demands of agriculture and river ecosystems and WFD and Natura 2000 assessment should consider to develop status indicators for riverine wetlands. The results of REFORM are thus of particular relevance to support the debate how to define the ecological potential of heavily modified water bodies. We recommend that this topic remains in the CIS ECOSTAT work programme for a considerable number of years.

Changing the focus for planning and evaluating restoration

What may be known to few, but will be a surprise to many is that the majority of restoration projects meant to improve hydromorphological conditions comprise more than one measure. The extensive reviews in REFORM have demonstrated this. The consequence is that generic information about individual measures has its value, but much more emphasis is needed on the benefits of restoration programmes in the catchment or basin context. REFORM did address this only in a limited way. Another unbalance with present restoration practice is the general lack of explicit and measurable goals and of proper monitoring design to conclude whether the project does what it is supposed to do: improved ecological status. There are too many projects realised of which we know too little. This jeopardises future programmes because not being able to show the benefits may seriously undermine public support.

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.
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


Cowx, I.G. et al. (2015) Lecture notes of the summer school ‘Restoring regulated streams linking theory and practice’. REFORM deliverable 7.4

Kampa, E. et al. (2013) Summary report REFORM stakeholder workshop. REFORM deliverable 7.3

Kampa, E. et al. (2015) REFORM newsletters and leaflets. REFORM deliverable 7.6

Mosselman, E. et al. (2013) Synthesis of interim results for practical application to support the compilation of the 2nd RBMPs. REFORM deliverable 6.1

List of Websites:
http://www.reformrivers.eu

Verwandte Dokumente

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