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REstoring rivers FOR effective catchment Management

Deliverable	D1.4 – Inventory of restoration costs and benefits
Title	**Inventory of river restoration measures: effects, costs and benefits**
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CO	Confidential, only for members of the consortium (including the Commission Services)	

Summary

D1.4 in the framework of the EU FP7 Project REFORM reviewed the literature on costs and benefits of river restoration. Data were collected in a database in order to empirically investigate the costs of river restoration measures throughout Europe. Also, a summary of restoration planning and the specific measures which can inform the future development of cost-benefit analysis (REFORM D5.2) and their application were introduced. A non-exhaustive review of peer-reviewed literature and technical reports was conducted to elicit the effects of individual measures, providing a basis for the analysis of restoration benefits.

The non-exhaustive review of river restoration measures showed that it is extremely difficult to predict the impacts of specific river restoration measures on a European-level. The river type, based on geomorphological and functional process units, as well as the specific anthropogenic pressures are relevant for choosing suitable restoration measures. Practical limitations such as land availability, project budget, and/or stakeholder consent limit the spatial extent to which rivers can be restored. Programmes of Measures should address the type and scale of pressures in a river basin, provide long-lasting improvements, and be robust against the impacts of climate change. Independent of the type of restoration measures, considering the hydrogeomorphological processes affecting a river restoration site and implementing this information into the project design is critical to elicit the maximum ecological benefits from measures (REFORM D5.1).

Many successful river restoration measures have been reported, which support improvements to hydrology, hydromorphology, water chemistry, biota, or ecosystem services. The findings of the non-exhaustive literature review on the ecological benefits of restoration measures to the WFD Biological Quality Elements macrophytes, macroinvertebrates, and fish are presented. Although this type of clear-cut and generalized information is useful to river managers and decision makers, it does not encompass the full spectrum of complexity and uncertainty surrounding restoration impacts. The response of biota to habitat improvements may be confounded or delayed by many factors, including: migration barriers, the lack of a colonizing source population, the isolation of restored habitat reaches, long-term recovery processes, the creation of inappropriate/unsuitable habitat conditions, or biotic interference resulting from competition, predation, or invasive species. Also, the impacts of large-scale pressures which are not addressed by reach-scale restoration can override the hydromorphological improvements made by reach-scale restoration measures (e.g., catchment land use, water quality, missing source populations, etc.). Careful treatment of the environmental framework conditions and site-specific socio-economic constraints is necessary to elicit the ecological benefits of river restoration.

The cost database created was designed to gather data on the costs of the reported measures while also collecting sufficient information to enable marginal cost-benefit and cost-effectiveness analyses by way of statistics on effectiveness and monetary benefits (REFORM D5.2, forthcoming). The cost database contained cost data for 766 restoration projects from Germany (n=454), Spain (n=228), the United Kingdom (n=54), and the Netherlands (n=30). Cost data were reported as total investment cost per unit for the implementation of individual measures. Fifty-nine percent of the data (all German data)

were estimated costs (n=454), while the remaining 41% from ES, NL, and the UK were actual reported total unit costs from restoration projects (n=312). To provide a finer spatial resolution to the restoration measures in the database and to enable a scaling-up of costs, effects, or benefits (D5.2, forthcoming), project data were assigned a river typology, based on the river types developed within REFORM D2.1.

Most of the projects in the database were conducted in single thread, alluvial gravel or sand rivers. The majority of the hydromorphological measures reported in these countries concern in-channel habitats, floodplains, and longitudinal connectivity. Measures dealing with sedimentation and river planform (depth and width variation) also make up a noteworthy percentage. The four countries included in this study reported very different restoration portfolios, and the types of measures implemented in each country do not necessarily reflect the state of their river systems.

In all cited stated preference elicitation studies, the economic benefits of the hydro-morphological river restoration are proxied through the environmental benefits and services provided by restored river ecosystems and/or riparian zones. As a rule, a restoration project is considered as a bundle of use and non-use ecosystem services, which makes it very difficult to extract separate values for particular services or even their groups. The most commonly considered services (benefits) are higher wildlife and aquatic life diversity, provision of drinking water, improved water and air quality, flood protection, carbon sequestration, erosion protection, better river appearance and recreational amenities of a riparian forest, better possibilities for swimming, boating, and fishing activities, and nitrate and phosphorus cycling and retention. The majority of reviewed studies, 23 out of 30, assume that the main beneficiaries of river restoration are local households and use different forms of contingent valuation studies or discrete choice experiments to elicit their valuation of the restoration projects.

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1. Introduction

1.1 *Background*

Human impacts on freshwater ecosystems threaten the ecological resilience and the sustainability of these ecosystems to deliver the goods and services that benefit people (WHO, 2005). Balancing aquatic ecosystem needs with human uses of freshwater is one of society's greatest modern challenges, especially as pressure on aquatic ecosystems intensifies due to population increases, economic development, and climate change. In Europe, centuries of landscape alterations to support agriculture, urban development, floodwater protection, and shipping have altered the chemical, hydromorphological, and ecologic integrity of rivers and streams (EEA, 2012). Over the last 25 years, improved wastewater treatment, reductions in industrial effluents, and lower levels of nutrient pollution from atmospheric deposition and wastewater discharges have significantly decreased the effects of chemical and organic pollution in European water bodies (EEA, 2012). However, to continue improving the status of Europe's water bodies, the damage to the morphology and hydrology of water bodies needs to be reassessed.

Across Europe, major changes to watercourses caused by water abstractions, water flow regulations (e.g., dams, weirs, sluices, and locks), morphological alterations, channel straightening and canalization, and the disconnection of flood plains are the source of hydromorphological pressures. In REFORM D1.2, Garcia de Jalón et al. (2013) review the effects of pressures on hydromorphological variables and ecologically relevant processes.

- Hydrological regime pressures, including water abstraction and flow regulation
- River fragementation pressures
- Morphological alteration pressures
- Other elements and processes affected (physico-chemical)

These pressures result in changes to the natural structure and functioning of running waters by disrupting the natural flow regime (e.g., timing and magnitude of discharge) and the supply, transport, and deposition of inorganic and organic substrate, sediment, and detritus that shape and maintain a dynamic patchwork of river habitat (Garcia de Jalón et al., 2013). Thus, water bodies that are impacted by hydromorphological pressures are characterized by physical alterations modifying their shores, riparian and littoral zones, water level, and flow (ETC/ICM, 2012). The consequences of these hydromorphological alterations are simplified, structurally-deficient, fragmented river systems that can no longer host a diverse aquatic flora and fauna in a good ecological condition.

Since 2000, the EU Water Framework Directive (WFD) (2000/60/EC) charges EU Member States with the protection, enhancement, and restoration of groundwater, surface waters, and transitional water bodies. According to the WFD, all inland water bodies are to achieve **'Good Ecological Status' (GES)** or in cases of irreversible human impacts (e.g., **Heavily Modified Water Bodies, HMWB**) **'Good Ecological Potential' (GEP)** by the end of 2015 or by 2027 at the latest. Obtaining GES means meeting certain standards that have been set for the chemistry, morphology and quantity of water, and ecology; 'Good Status' refers to a condition that only slightly deviates from what would be normally expected under undisturbed conditions (ETC/ICM, 2012). The obtainment of

GES or GEP by 2015 can be extended to the end of the 2nd management cycle in 2021 or the end of the 3rd management cycle in 2027 if one or more of the following criteria apply: 1) the required improvements cannot be technically achieved within the management cycle, 2) the realization of improvements would be disproportionately expensive, and 3) the natural circumstances would obstruct the timely improvement (EEA, 2012). The aims of the WFD expand on the traditional chemical water quality focus of water legislation and encompass the hydromorphological and biological components of water bodies.

A **Programme of Measures (PoM)** is to be implemented in each river basin to achieve GEP or GES goals by the end of the WFD management cycle. There is much work needed to meet WFD goals, since the majority of rivers, lakes, and streams in all Member States will fail to achieve the environmental objectives by 2015.

The WFD's focus on GES as a final environmental target is unique in the history of water legislation in the EU, and the inclusion of hydromorphological measures in >90% of the **River Basin Management Plans (RBMPs)** reflects the need for measures to mitigate the centuries of hydromorphological alterations in river basins throughout Europe (EEA 2012). According to the WFD, the following hydromorphological elements support the **Biological Quality Elements** (**BQEs**). The following hydromorphological components are applicable for rivers:

- Hydrological regime (quantity and dynamics of flow, connection to groundwater bodies);
- River continuity (ability of sediment and migratory species to pass freely up and down rivers and laterally within the floodplain);
- Morpohological conditions (i.e., river depth and width variation, structure and substrate of the river bed, structure of the riparian zone)

The review of the first RBMPs at the end of 2009 was made for 23 out of 27 Member States and resulted in an enormous amount of data on the status, pressures, and measures being added to the Water Information System for Europe (WISE) WFD database. By May 2012, these 23 Member States had adopted their RBMPs. Analysis of the RBMPs revealed that the status of more than half of the surface water bodies were in less than GES or GEP, and that the remaining pressures from diffuse source pollution, especially nutrient enrichment from agriculture, and hydromorphological pressures resulting in altered habitats are lowering the ecological status of most surface water bodies (EEA, 2012).

1.2 *Drivers of River Degradation*

Identifying the drivers responsible for ecosystem degradation and mitigating their associated pressures is necessary to systematically rehabilitate rivers. Where chemical water quality has been improved in regulated rivers, altered hydromorphology and degraded habitats thwart biological recovery and prevent rivers from meeting environmental policy targets. Hydromorphological pressures and altered habitats can be mainly attributed to hydropower, navigation, agriculture, flood protection, and urban development, and these pressures affect over 48% of rivers and streams in the EU

(ETC/ICM, 2012). Figure 1 shows the relationships between the drivers, hydromorphological pressures, and their associated habitat and flow alterations. For a bibliographical review of the relationships of the drivers, pressures, and impacts of hydromorphological pressures, see REFORM D1.2 by Garcia de Jalón et al (2013).

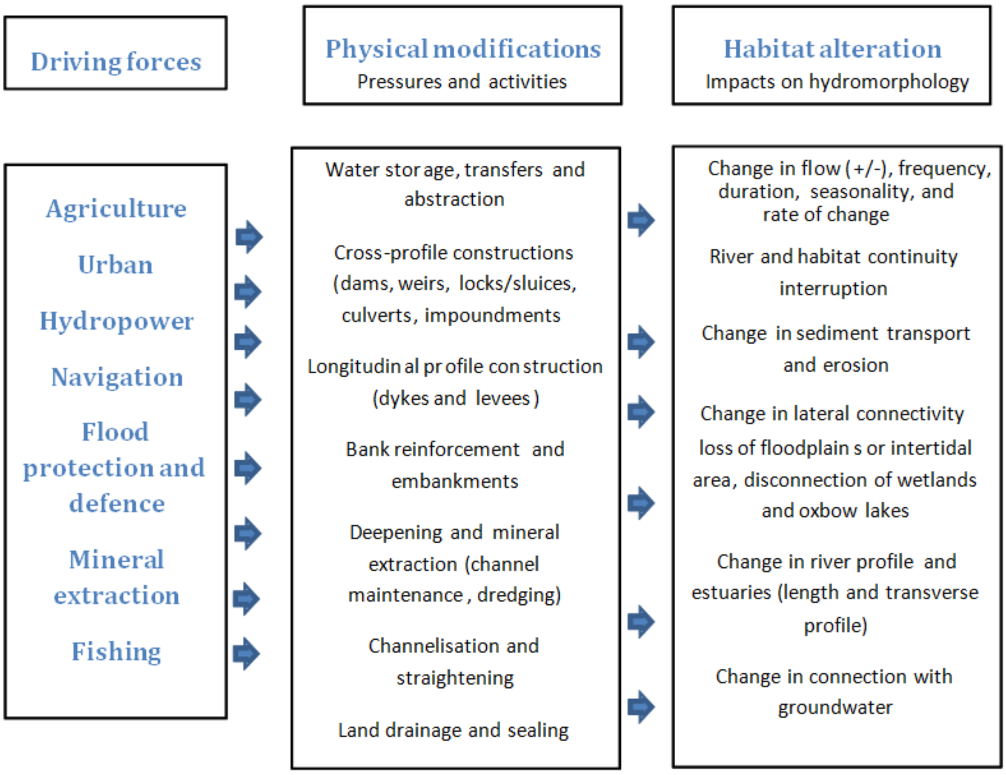

Figure 1 Conceptual overview of the relationship between drivers, hydromorphological pressures, and habitat and flow alterations. Source: ETC/ICM 2012

1.3 *Socio-economic Impacts of Anthropogenic Alterations*

As mentioned above, almost 50% of water bodies across 23 of the EU Member States are considered heavily impacted by hydromorphological alterations, with approximately 88% of these exhibiting hydromorphological degradation as a result (ETC/ICM, 2012). The major subcategories of these alterations that are present in Europe include (1) changes to the hydrological regime, including water impoundment by dams and other changes due to weirs and locks and (2) other river management practices such as dredging, land drainage, and the construction of barriers that directly affect the hydromorphological status of the watercourse. There are approximately 7,000 large dams in Europe and thousands of other smaller impoundments. Some waterways are impacted by these alterations in the extreme; for example, 91% of the water bodies in the Elbe River Basin in Germany fail to achieve GES due to hydromorphological pressures (ETC/ICM, 2012).

The benefits of altering and managing rivers accrue to society at large through the economic goods and services that these support. Three major industries or economic sectors that benefit from these alterations are agriculture (and other land uses that contribute to land drainage or the reclamation of active floodplains), transport over inland waterways, and hydroelectricity production. Although a comprehensive and accurate picture of the benefits that these economic sectors accrue through the alteration and subsequent degradation of some European waterways does not exist, a selection of economic indicators can provide context to the discussion of river alteration. For example, although transport on inland waterways only accounted for a mere 6.5% of total freight transport in the EU in 2010 (Eurostat, 2013), it is a competitive mode of inland freight transport that will likely have to grow in the future if the EU is to experience carbon emissions reductions in transport. The sector currently enjoys modal shares of up to 30% for bulk commodities (CE Delft, 2011). Transport on inland waterways produced approximately 8 billion Euros of gross value-added in the EU in 2007 and employed over 35,000 people (Ecorys, 2012). Meanwhile, agriculture produced over 405 billion Euros in value in 2012 (Eurostat, 2013). Finally, hydroelectric power accounts for 16% of electricity production and 70% of all renewable energy production in Europe (ETC/ICM, 2012). As such, it plays a major role in powering the decarbonisation of Europe's electricity sector, although most capacity has already been exploited (Kumar et al., 2011).

Clearly, these industries and the European economy as a whole depend on some river alteration to perform their activities, and the gains for these sectors and their consumers are significant. However, the costs of river alteration and degradation must also be weighed against these benefits. The socio-economic costs of hydromorphological alteration are a result of changes in the quantity and quality of water provided by rivers as well as barriers for migrating species caused by changes in the river structure. These changes may affect ecosystems, human health, and economic activities along the river. By estimating changes in production, costs of replacement, hedonic prices and by applying contingent valuation or an ecosystem services approach, the scope of these costs can be determined ex post. However, for the purposes of this investigation, one can imagine the costs of river degradation to be the foregone benefits of restoration. While this deliverable does not attempt to assess the damages caused by river alteration directly, it does propose methods for estimating the benefits to be gained from implementing certain restoration measures and thus reversing the damage done by previous hydromorphological alterations.

1.4 *Rationale for an economic analysis of river restoration*

The concern about the integrity, resilience, and sustainability of river ecosystems has turned river restoration into a multi-billion dollar, global industry (Palmer et al., 2005). In its most formal sense, the term restoration refers to returning an ecosystem to its original pre-disturbance state; but, in practice, river restoration is used to refer to habitat enhancement, rehabilitation, improvement, mitigation, creation, and other situations (Roni et al., 2005). Some common goals of river restoration are to (i) improve water quality, (ii) re-establish river type-specific habitats and ecosystem functioning, (iii) aid in species recoveries, and (iv) maintain the provision of ecosystem services. This deliverable considers the objectives of river restoration to include natural processes and their anthropogenic value (i.e., ecoysytem services), in addition to the effect on ecological status. Because decisions about river rehabilitation are societal ones, restoration projects that consider human dimensions (e.g., society's need for ecosystem services, conflicting interests of multiple stakeholders, and interactions of environmental policy, economics, and science) are more likely to meet environmental management and policy goals.

Ecological boundaries such as river basins do not conform to political and cultural boundaries, so solving water resource issues requires international understanding and cooperation. While the WFD's river basin approach should allow for increased comprehensiveness in water resources management by expanding it to include areas such as land use, flood risk mitigation, navigation, hydroelectric power production, and nature conservation, approaches for integrating these governance responsibilities within river basins and across borders are left to the Member States. Of concern for river restoration is the interplay between hydromorphological quality parameters and these other fields, including land use, navigation, and dam operation. The achievement of GES and GEP thus depends on the ability of river basin managers to balance the needs of the WFD with those of these other fields effectively (Moss, 2004).

Balancing such concerns in a transparent manner requires an economic analysis of the impacts of these measures. River basin managers and authorities responsible for the implementation of measures to achieve the WFD GES/GEP goals are challenged to prioritize measures to efficiently use limited budgets while obtaining the greatest ecological and economic returns from these investments. Achieving environmental policy and management objectives to rehabilitate the degraded physico-chemical, hydromorphological, and biological elements of rivers requires the implementation of effective restoration measures, and the need to identify and evaluate these measures is growing (Kail and Wolter, 2011). During the 1st Management Cycle of the WFD, the majority of reported RBMPs did not describe the financial commitment, the responsible parties for implementation, the planned timetable, or the expected status improvements to result from the PoMs (EC, 2012). This lack of information hinders the achievement of the WFD not only by making it more difficult to assess whether sufficient action is being taken, but also by not providing a basis to determine whether restoration resources are being used effectively. For the implementation of the WFD, a cost-effectiveness analysis of measures can help to ensure that the least-cost options for achieving GES/GEP are chosen for the PoM (Lago, 2008). Ideally, such optimization would occur in a river basin setting and not be limited to the scale of individual measures.

Tools are needed that will allow decision makers and stakeholders to assess restoration measures better ex ante. Only by assessing the full spectrum of costs and benefits can decision makers effectively allocate public and private funds and ensure the best ecological outcomes. A framework for this assessment will need to inform the creation of the second round of RBMPs. Although predicting ecological responses is of obvious importance, an economic consideration of costs and benefits is essential for rationally managing our rivers. Introducing economics as a tool for the planning, prioritization, and evaluation of restoration projects is still in its infancy (Robbins and Daniels, 2012; Naidoo et al., 2006). In a meta-analysis of 1,582 recent peer-reviewed papers dealing with ecological restoration, Aronson et al. (2010) found that restoration scientists and practitioners are failing to show the links between the socio-economics and ecology of restoration, underselling the evidence for restoration as a worthwhile environmental and societal investment. While broad overviews of restoration prioritization for river basin managers and practitioners are available in the published literature (e.g., Roni et al., 2002; Beechie et al., 2008; Roni et al., 2008), a rationalized economic analysis to guide decisions and investments in restoration measures and to elicit the greatest impact (i.e., socio-economic and environmental benefits of restoration measures) is needed.

1.5 *Statement of Purpose and Contents of the Report*

This task in the framework of the EU FP7 Project REFORM reviewed the literature on costs and benefits of river restoration. Data were collected in a database in order to empirically investigate the costs and benefits of river restoration measures throughout Europe. Also, a summary of restoration planning and the specific measures which can inform the future development of cost-benefit analysis (REFORM D5.2) and their application were introduced. A non-exhaustive review of peer-reviewed literature and technical reports was conducted to elicit the effects of individual measures, providing a basis for the analysis of restoration benefits. This report will lay the basis for a framework for valuing the ecosystem services that link ecological function to societal welfare, in order to inform the creation of tools and guidelines to help river basin managers assess the promise of restoration projects ex ante.

Following this introduction, the report is structured as follows: chapter 2 reports on how the database was structured and from which sources the data were collected. The next sections discuss which measures are investigated more deeply (chapter 3) and what their likely ecological effects are (chapter 4). Chapter 5 reports the cost typology used to assess these measures and the cost data collected. The approach for assessing the benefits of measure implementation is discussed in chapter 6. Conclusions are then drawn in chapter 7. The report closes with a references section that includes references for in-text citations as well as a list of data sources. The following overview describes how the tasks outlined in the project's Description of Work have been implemented.

Task 1.5 outline in the Description of Work	**How the tasks have been implemented**
A literature review on the costs of hydromorphological degradation, on the definition and development of cost typologies. Includes a review of the cost and benefits of physical restoration and the development of assessment frameworks. Review and compile metadata of existing cost information on hydromorphological degradation.	The deliverable presents a framework for the assessment of costs and benefits associated with river restoration. In this regard, typologies for costs and benefits have been developed and the available literature on costs and benefits of physical restoration has been reviewed (chapters 5 and 6). The costs of hydromorphological degradation have been defined as the forgone benefits of natural (restored) river environments.
Prepare information/data to conduct a sectoral analysis on the wider social and environmental costs and benefits associated with hydromorphological alterations of both degradation and restoration.	Information and data on the wider social costs and benefits of river restoration measures have been gathered in the database and discussed in chapters 5 and 6 of the deliverable. The wider social costs of river degradation can be estimated via the forgone benefits of natural (restored) river environments. The latter are included in the database and have been discussed in chapter 6.

Task 1.5 outline in the Description of Work	**How the tasks have been implemented**
	With regard to the sectoral analysis, payers and beneficiaries of (direct financial) costs and (wider socio-economic) benefits, respectively, have been identified and discussed in the introduction; the relevant information is included in the database
Review economic valuation methodologies and perform a pan-European meta-analysis in benefit transfer of hydromorphology improvement studies.	Information on economic valuation methodologies relevant for the estimation of costs and benefits associated with river restoration and river degradation are included in the database and have been discussed in chapter 5 (sections 5.1 and 5.2; Annex 2) and chapter 6 (section 6.1). Chapter 6 includes a pan-European (and beyond) meta-analysis of valuation studies related to the socio-economic benefits of river restoration. The results have been included in the database.
Explore how river typologies could be used to transfer cost and benefits exercises and results on different scales (link to task 1.1).	River types have been defined in section 3.2, taking into account the typologies developed in D2.1 and D2.3 of REFORM. Available information on river types has been linked to the cost information in the database; the same will be done for the benefits information in the further course of the project (D5.2). This information will allow to transfer (upscale) the information on costs and benefits to a larger European scale based on geospatial analysis (to be carried out under WP5).

2. Database

In the following section, a short introduction to the database used to gather data for the analysis of costs, effectiveness, and benefits of European river restoration measures is given.

Databases of river restoration measures exist in many formats, including open wikis (such as the REFORM and RESTORE wiki databases) operated by research organisations or NGOs, databases compiled by engineering or consulting firms (such as the WFD Hydromophology Measures Database of Royal Haskoning, which covers England and Wales) from previously implemented projects, and lists of approved measures gathered by various governmental agencies. They vary in scope and design based on their primary purpose, which is usually either dissemination or analysis. Those published online for purposes of dissemination generally contain less extensive cost data, while those focusing on cost estimates and analysis often contain fewer images of the restored sites and less information on the implementation of the project itself, tending to simply place the measures within categories that would facilitate analysis.

The database used in this deliverable was designed to gather data on the costs of the reported measures while also collecting sufficient information to enable marginal cost-benefit and cost-effectiveness analyses by way of statistics on effectiveness and monetary benefits (REFORM D5.2, forthcoming). These analyses require information on the costs and benefits of measures, the average unit costs of their implementation, and the relationship of these costs to the size of the project.

The database consists of four individual sheets:

- "Measure Info" was designed to collect basic information on the measures, including the necessary information to categorise within the measure typology.
- "Effects" captures any available data on the effects resulting from the reported measures.
- "Costs" was designed to collect very detailed data regarding implementation, design, maintenance, and management costs, should this data be available. More complete definitions of the costs described here can be found in chapter 5.
- "Benefits" contains existing benefits estimates for the implemented river restoration measures.

The cost database contains cost data for 766 restoration measures from Germany (454), Spain (228), the United Kingdom (54), and the Netherlands (30). Ten of the UK cost data referred to overall project costs, rather than individual measures, and therefore, these data were not included in the data analysis. Cost data were reported as total investment cost per unit for the implementation of individual measures. Fifty-nine percent of the data (all German data) were estimated costs (n=454), and the remaining 41% of the data from ES, NL, and the UK were actual reported total unit costs from restoration projects (n=312).

To provide a finer spatial resolution to the restoration measures in the database and to enable a scaling-up of costs, effects, or benefits (D5.2, forthcoming), project data were assigned a river typology, based on the river types developed within REFORM D2.1 (see chapter 3). Figure 2 and Table 1 below depict the distribution of the measures found in the database according to the FORECASTER measure typology (see Annex 1).

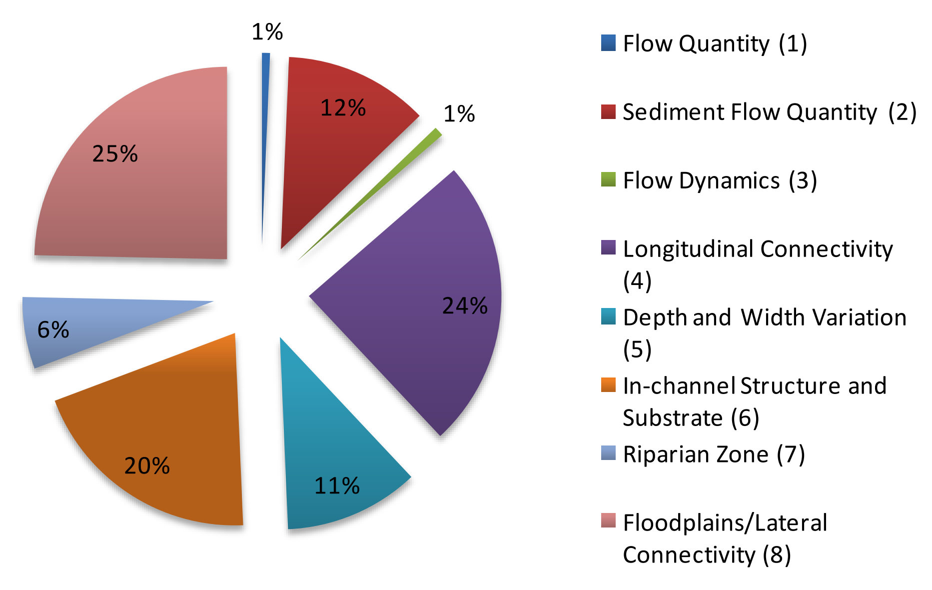

Figure 2 Distribution of all collected measures among the measure categories of the FORECASTER typology

Table 1 Distribution of measures per country according to the FORECASTER typology

Measure	**Germany**	**Spain**	**UK**	**Netherlands**
Flow Quantity (1)	1%	0%	0%	0%
Sediment Flow Quantity (2)	4%	**29%**	5%	**23%**
Flow Dynamics (3)	1%	0%	0%	0%
Longitudinal Connectivity (4)	**21%**	**32%**	7%	**55%**
Depth and Width Variation (5)	13%	0%	**53%**	9%
In-channel Structure and Substrate (6)	**27%**	7%	**19%**	9%
Riparian Zone (7)	4%	11%	7%	5%
Floodplains/Lateral Connectivity (8)	**29%**	**21%**	9%	0%
Total of Measures	453	228	45/55	30

The majority of the hydromorphological measures reported in these countries concern in-channel habitats, floodplains, and longitudinal connectivity. Measures dealing with sedimentation and river planform (depth and width variation) also make up a noteworthy percentage.

The four countries included in this study reported very different restoration portfolios, and the types of measures implemented in each country do not necessarily reflect the state of their river systems. Overall, the distribution of Germany's observations influences the dataspread of the entire database, with 77% of the measures addressing in-channel restoration, floodplains, and longitudinal connectivity. Spain's observations stem mainly from work on floodplains, longitudinal connectivity, and sedimentation. Spain shows an even higher percentage of measures relating to longitudinal connectivity than Germany (32% versus 21%), but sedimentation measures make up almost a third of Spain's reported observations, versus merely 4% in Germany.

The number of observations submitted for the United Kingdom and the Netherlands was relatively low. Approximately 50% of the measures in the UK concern river planform alterations and 50% of the Dutch measures address issues of longitudinal connectivity. Measures concerning flow volume and flow dynamics (variability) are only to be found among the observations from Germany, comprising only approximately 1%. Cost data for floodplain or lateral connectivity restoration measures were reported in all countries except for the Netherlands.

Because measures were reported with varying frequency and inconsistent data completeness, only a selection of measure categories and subclasses could be and were examined further. The overarching categories of floodplain restoration (FORECASTER category 8), longitudinal connectivity (4), in-channel habitat restoration (6), river planform alteration (5), and sediment quantity (2) make up 90% of the observations. Cost tables were developed for the measures that fit into these categories or, if a particular subcategory makes up a large proportion of that category's observations, for that subcategory. For example, approximately 80% of the observations reported for longitudinal connectivity were designed to facilitate upstream migration or remove barriers, so the cost tables for measures subclasses in this category only included measures designed to improve upstream connectivity (4.2) and weir removal measures (4.1). A list of the measures that will be investigated in the following chapters is presented in Table 2 below.

Table 2 Measure types identified for further analysis

Measure Category
Floodplain Measures (*8.1-8.9*)
Wetlands Connection (*8.3*)
Dike Modification/Removal, Backwater Reconnection (*8.2-8.4*)
Upstream Longitudinal Connectivity (*4.2*)
Weir Removal (*4.1*)
Remove Bed and/or Bank Fixation (*6.6/.7*)[a]
Re-meandering of Watercourse (*5.1*)
Sediment Control through Reforestation (*2.2*)

[a] This measure category also includes some observations of measures that involved creating riffles in river beds in addition to removing fixation.

3. Measures

Around the globe, the societal response to river degradation has triggered an increase in restoration activities in developed and developing nations. In the last 25 years, the body of knowledge and research on river restoration has grown substantially, yet river restoration as a discipline is still encumbered by a lack of standards and poor communication among scientists, practitioners, and policy makers (Palmer et al., 2005). Many restoration projects are designed by local experts, but larger frameworks to guide river restoration should be consulted to maintain a level of quality and consistency that has been developed by international restoration scientists and practitioners. Reviews of river restoration techniques and measures have been published in textbooks, technical guidelines, peer-reviewed journals, and grey literature. For example, the FAO Global Review of Effectiveness and Guidance for Rehabilitation of Freshwater Ecosystems (Roni et al., 2005) provides a good overview of the published resources available for informing river restoration activities.

An exhaustive review of the state-of-the-art for river restoration practices and measures is inherently difficult, due to inconsistencies in reporting and the fragmentation of the reported information. Such an extensive review of restoration measures is also beyond the scope of this deliverable. This chapter presents a summary of restoration planning and information about the most commonly recorded restoration measures in the cost database (chapter 2), as well as a description of the river types where they were implemented. Information about the specific restoration measures and river types where they are implemented helps to frame the discussion of costs and benefits. Also, this information will be useful to guide the application of cost-benefit analysis (REFORM D5.2, forthcoming).

3.1 *Selecting Measures to Restore Ecological Status in European Rivers*

Many river restoration techniques and measures show promise to improve ecological status; however, a lack of adequate planning, monitoring, or cost-benefit analysis impairs the understanding of the ecological benefits of specific measures (Roni et al., 2005). This lack of information and communication has been reported beyond the peer-reviewed and grey literature on river restoration (Palmer et al., 2005). In Europe, assessment of the WFD RBMPs revealed that the descriptions of measures, their costs and scope, and the expected improvements in a water body were not clearly communicated in most cases (EC, 2012). Despite this lack of information, river managers must proceed with the best-available information and also implement measures in the face of uncertainty. Therefore, PoMs to achieve GES/GEP should include 'no-regret' measures (e.g., measures with low risk and low costs that can be carried out iteratively or are easily adaptable or reversible and provide a high return).

Identifying the driving forces and accounting for their pressures at the scale at which they shape ecological processes is critical to the successful performance of river restoration measures (Beechie et al., 2010). It is recommended that restoration measures should not be implemented to address the symptoms of watershed degradation without appropriate efforts to address the larger-scale pressures causing the degradation (Bernhardt and Palmer, 2011; Hermoso et al., 2012). The pressures that potentially constrain the effects of reach-scale scale measures include (Carpenter et al., 2011):

- Physico-chemical pollution (e.g., acidification)
- Thermal pollution
- Hydrological alterations
- Hydromorphological pressures
- Nutrient pollution (e.g., eutrophication)
- Organic pollution
- Land use changes (e.g., deforestation or increased impervious surfaces)
- Biological pollution (e.g., introduced species and diseases)
- Harvesting (e.g., overfishing)
- Climate change

The type and spatial extent of river restoration measures should target the relevant pressures that are limiting the ecological status of individual water bodies as well as the entire river basin. For example, the PoM developed for a river should be based on an assessment of the current status and pressures of the water body. Restoration actions should be objective-based and incorporate regional complexity, especially regarding which processes are the most valuable to restore in a given river basin (Dufour and Piégay, 2009). This deliverable considers the objectives of river restoration to include natural processes and their anthropogenic value (i.e., ecoysytem services), in addition to the effect on ecological status, thus going beyond the original objectives of the WFD.

Restoration measures can take either passive or active forms and be implemented singly or in combination. Passive techniques (e.g., pulse flows, changes in watershed land use, creation of buffer strips, etc.) rely on natural recovery process and ‘allow the river to do the work’ (Stanford et al., 1996). Therefore, passive measures require a longer time to make an impact, whereas active techniques are used when longer recovery times are incongruent with meeting management or environmental policy goals (Wheaton et al., 2004a). Many active restoration measures attempt to mimic the form of analogous natural structures/features (e.g., a present day or historical ‘natural’ analogue) based on local knowledge, and project implementation is frequently improvised (Kondolf, 2000; Wheaton et al., 2004a).

Considering the hydrogeomorphological processes affecting a river restoration site and implementing this information into the project design is critical to elicit the maximum ecologic benefits from measures. Yet, the discussion of ‘form mimicry’ versus ‘processed-based’ restoration approaches is a contentious one. For example, the selection of an appropriate analogous condition can be very subjective, and a narrow focus on form can overshadow important considerations of hydromorphological processes (Wheaton et al., 2004b). Process-based approaches focus on the controls of habitat characteristics (Beechie and Bolton, 1999), whereas form-mimicry tends to create static habitats that are perceived to be good habitat in a dynamic environment (Beechie et al., 2010). Generally, process-based approaches are favorable over form mimicry, so long as ample consideration of the interactions between geomorphic conditions and the response of biota is given (Wheaton et al., 2004a and 2004b).

A holistic view of river rehabilitation that seeks to restore deficient hydromorphological processes at the watershed scale has been gaining traction within the restoration community. Studies by Beechie & Bolton (1999) and Beechie et al. (2010) have indicated that restoring natural hydromorphological processes that shape and sustain river habitats and biota will enhance the recovery of biodiversity and ecosystem processes in degraded rivers. However, practical limitations such as land availability, project budget, and/or stakeholder consent limit the spatial extent to which rivers can be restored (Hermoso et al., 2012). Furthermore, alterations caused by river regulation, channelization, and damming can be so significant and socio-economically important that they are irreversible in some cases (e.g., HMWB) (Strange et al., 1999; Hermoso et al., 2012). Due to financial constraints, land availability, and sociopolitical acceptance, smaller, reach-scale river restorations are more common and will continue to be more common than watershed-scale restorations (Miller et al., 2010; Hermoso et al., 2012). Ultimately, the choice of passive versus active restoration measures and the scale of restoration projects depends on the unique social, political, economic, and environmental context of individual river basins.

The socio-economic constraints affecting the choice of measures to implement in a PoM are also compounded by the environmental setting that shapes a river's geomorphic and functional processes. The following section sheds light on the river types that are most relevant for the restoration projects collected in the cost database.

3.2 *River Typology*

Due to differences in geomorphic and functional processes among rivers in Europe, it is extremely difficult to predict the suitability of individual measures across Europe. Also, the specific uses of rivers and their corresponding pressures greatly influence the appropriateness of restoration measures to undue hydromorphological degradation. For example, there are characteristic differences between large rivers exposed to multiple threats, including navigation (which sets significant boundaries for rehabilitation), and smaller rivers which are often affected by agriculture or forestry practices only. This section examines which river types are most relevant for the restoration projects collected in the cost database.

This task attempts to address rivers according to the simple classification of river types developed in REFORM D2.1 by Gurnell et al. (2013). This classification was based on river channel planform character (number of threads and planform pattern), and it was framed in the context of valley setting (degree of confinement). The simplified version of this classification yielded a typology with 8 river types (Table 3).

Table 3 Simple classification of river types based on confinement and planform. Numbers in brackets refer to subtypes. Source: Gurnell et al. 2013 REFORM Draft D2.1

No.	River type	Longitudinal slope
1	single thread, confined in bedrock or colluvial deposits (90%) (1-3))	often steep (>5%)
2	single thread, on alluvial, coarse beds (boulders to gravel) (4-7)	fairly steep (up to >3%)
3	single thread on alluvial gravel beds (sinuous, meandering) (12-14)	>0.5%
4	transitional and multiple thread on alluvial gravel (wandering, braided, anabranching) (8-11)	>0.5%
5	single thread on alluvial sand (16, 18)	<0.5%
6	multiple thread on alluvial sand (15,19)	<0.2%
7	single thread on alluvial silts and clays (20, 21)	~0%
8	multiple thread on alluvial silts and clays (22)	~0%

Providing a finer spatial resolution to the restoration measures in the database enables a scaling-up of costs, effects, or benefits per river type, which may provide useful information on the European level. For example, in REFORM D2.3 (Vermaat et al., 2013), provisioning, regulating, and cultural ecosystem services (Millenium Ecosystem Service Assessment 2005) were matched to the river types proposed in REFORM D2.1. Also, to facilitate an estimation of the benefits of restoration measures for specific river types (REFORM D5.2, forthcoming), it will be necessary to assign a river type to the restoration project data in the cost database from this deliverable.

For each country in the database (DE, ES, NE, UK), expert judgment was used to assign the project data to one of the simple classification types presented in Table 3. River planform, slope, and the bed material caliber were the most useful criteria to guide the matching of river types to the restoration data. To avoid making false judgements when assigning river types to projects with unclear or insufficient information, it was sometimes necessary to assign multiple river types to a specific restoration project. The breakdown of measures per country and river type is presented in Table 4.

Table 4 Overview of the implementation of measures from the cost databse in specific river types. Measures refer to the classes (1-8) and subclasses (1.1-8.9) of the FORECASTER measure typology (Annex 1). Only the measures subclasses occurring most often in the cost database are shown, which are the most relevant for analysis.

Country	River Type	Measures																
		1	2	2.2	3	4	4.1	4.2	5	5.1	6	6.6	6.7	7	8	8.2	8.3	8.4
Spain	2						x	x										
	3			x			x	x			x			x	x			
	5			x							x			x	x			x
	7													x	x			x
Germany	3	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x
	5	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x
Netherlands	5		x				x	x	x	x		x			x			
UK	1									x								
	2									x	x			x	x			
	3		x				x	x	x	x	x	x	x	x	x		x	
	5					x	x		x	x	x	x	x	x	x		x	
	7									x	x	x			x			

<u>Measure and Measure Subclass Names</u>

1 Water flow quantity improvement
2 Sediment flow quantity improvement; **2.2** Reduce undesired sediment input
3 Flow dynamics improvement
4 Longitudinal connectivity improvement; **4.1** Remove barrier; **4.2** Install fish pass/bypass/side channel for upstream migration
5 River bed depth and width variation improvement; **5.1** Remeander water courses
6 In-channel structure and substrate improvement; **6.6** Remove bank fixation; **6.7** Recreate gravel bar and riffles
7 Riparian zone improvement
8 Floodplains/off-channel/lateral connectivity habitats improvement; **8.2** Set back embankments, levees or dikes; **8.3** Reconnect backwaters and wetlands; **8.4** Remove hard engineering structures that impede lateral connectivity

Overall, most of the restoration projects recorded in the cost database were conducted in type 3 and type 5 rivers. The details for each country are stated below:

- Most Spanish rivers in the database could be described as type 3 or type 5 rivers. Weir removal and installation of fish passage were also implemented in type 2 rivers, and measures such as levee removal were implemented in type 7 rivers.

- Since the German restoration projects were conducted in a similar geographic area, the river types that were relevant were type 3 and type 5.

- All of the restoration projects from the Netherlands were conducted in type 5 rivers.

- The majority of the UK restoration projects in the database were conducted in river type 3 or type 5, but also, a few projects were conducted in river type 1 or 2 and type 7 rivers.

3.3 ***Detailed Description of Measures***

This section describes the river restoration measures addressed by this study and provides a summary for the measure classes and subclasses that were reported most often in the cost database (chapter 2). The summaries include the eco-hydromorphological benefits of the measure, along with information on implementation and design options and measure durability. The sources for this information were e.g., the REFORM river restoration WIKI factsheets[1], the 'Factsheets on Environmental Effectiveness of Selected Hydro-morphological Measures' for DG ENV (Kampa and Stein, 2012), as well as peer-reviewed literature found in the REFORM river restoration database and in peer-reviewed journals.

The measure typology used in this deliverable was developed for the FORECASTER project, which investigated the impacts of river restoration measures in the EU. This typology has also been adopted for the structure of the REFORM river restoration WIKI factsheets. Descriptions of measures classes that were under-represented in the cost database (chapter 2) are included in Annex 2.

The detailed descriptions of the measures in the cost databse are meant to provide supplementary information to river managers and economists, in addition to providing a logical context for the occurrence of costs and benefits related to specific river restoration measures.

Reduce undesired sediment input

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[1] http://wiki.reformrivers.eu/index.php/Category:Measures

In rivers where bed-forming discharges and flushing flows are impaired, undesired fine sediment input can degrade riverbed habitats by infiltrating and clogging the surface of the riverbed. Even small amounts of fine sediment can have severely detrimental impacts on the survival of fish eggs and larvae, as evidenced by low thresholds found in laboratory (Greig et al., 2005) and field studies (Meyer et al., 2008; Jensen et al., 2009). These threshold effects can be disproportionately impacted by even small amounts of fine organic matter in sediments (Greig et al., 2005). The most effective measure to reduce the negative impacts of sedimentation on river biota is to prevent the influx of fine sediment into rivers in the first place (Wood and Armitage, 1997; Pedersen et al., 2009) and to restore flow regimes that govern erosion and sedimentation within the river channel (Greig et al., 2005). For example, watershed reforestation and buffer strip maintenance are effective measures to reduce undesired sediment inputs. In regulated rivers, holistic catchment management (e.g., implementing best management practices) should be adopted in concert with reach-scale restoration measures to manage fine sediment (Owens et al., 2005).

Remove barrier

Artificial barriers like dams, weirs, and culverts disrupt the longitudinal connectivity of a river system and can severely impact the maintenance and timing of flow, water quality, temperature, sediment transport, and habitat conditions upstream and downstream of the barrier (Bednarek, 2001; Bunn and Arthington, 2002). Barriers that span the width of a river channel also disrupt the up- and downstream migrations and dispersal of fish and other aquatic organisms. Measures to mitigate the negative impacts of barriers, such as initiating or increasing minimum flows, enhancing fish passages, or improving dissolved oxygen levels provide only partial solutions to the impacts of dams, and barrier removal offers the most complete and reliable means of restoring longitudinal connectivity (Kampa and Stein, 2012).

Decisions to remove barriers and weirs are complicated by their socio-economic dimensions and barrier removal is not feasible in all cases (e.g., where dams are necessary for water storage, irrigation, or flood protection) (Bednarek, 2001). The social aspects of dam removal are crucial; there are many cases where removal projects did not go through due to low or negative social acceptance despite the large amount of information about the benefits (Kampa and Stein, 2012). For decision-making purposes, there is a need to find trade-offs between environmental and cultural benefits. The removal of single barriers is an important measure to provide benefits on a local scale; however, effects of single projects can be negligible on a larger scale (river basin) (Stanford and Ward, 2001). Thus, it is good practice to have a barrier removal concept that sets priorities for the whole river basin. Priority should be given to the removal of obsolete barriers, barriers whose cost of repairing outweigh the costs of removal, and barriers which are located at critical junctions for fish migration.

Install fish pass/bypass/side channel for upstream migration

The installation of fish passes for upstream migration is a mitigation measure that partially re-establishes longitudinal connectivity within river basins. Systems installed for enhancing upstream migration attract and guide fish around barriers (e.g., dams or weirs, water intakes). Installing fish passes to restore fish migrations is ecologically less beneficial than removing the artificial barriers in the first place, but fish passes are important compromises to balance river regulation for human needs with ecological integrity. Prioritizing the location of fish passes and enhancing spawning and rearing habitat for fish should be done in conjunction with improving upstream connectivity to restore fish populations (Kampa and Stein, 2012). Fish pass designs can be technical or natural, and selecting the most appropriate design for a site depends on site-specific conditions and the species requirements in accordance with historical communities (REFORM Restoration WIKI, 2010). Natural bypass channel designs can more effectively attract and pass fish, can offer additional benefits for other biological elements, and require less maintenance than technical design fish passes.

Remeander water courses

Meanders are natural features of many rivers that form via a dynamic balance of erosion along the outside of a bend and deposition of coarse gravel, boulders, and cobble along the inner bend. These sinuous features migrate laterally and longitudinally along the river corridor as the cycles of erosion and deposition continuously create and destroy meander loops. As old meander loops are cutoff from the active channel, critical off-channel habitats are formed (e.g. oxbow lakes, backwaters, and floodplain wetlands).

Remeandering aims to change the shape of a channel (sinuosity and profile) from an unnatural channelized shape to a natural or near-natural shape (Kondolf, 2006). Further objectives include water retention, elongation of flow path, and reducing channel depth incision. This measure refers to the remeandering of straightened river channels, through both creation of a new meandering course and reconnection of cut off meanders. Natural channel designs for remeandering change the sinuosity, slope, depth, and water surface elevation, as well as the quantity, quality, and diversity of instream habitat (Klein et al., 2007). In rivers with flow regulation by weirs, this measure might further affect flow patterns and lower flow velocity. Because of their aesthetically-pleasing form, meanders are a restoration measure with high social acceptance; however, they require a lot of space (Wolter, 2010). Meander bends should not be created in rivers where they were not historically present or a prominent river feature (Kondolf, 2006). Active remeandering is a costly measure and can only be effectively implemented and sustained in rivers with sufficient stream power (REFORM Restoration WIKI, 2010). Meanders can be created by forming a new channel with the desirable cross-section width, depth, and sinuosity. Passive restoration by ceasing stream maintenance or initial restoration activities can be an alternative to actively remeandering river channels. For example, initiating lateral channel migration to “let the river do the work” is an effective passive restoration technique.

Remove bank fixation

Removing bank fixation can allow the river channel to migrate laterally and reinstate processes of erosion and sedimentation, which are important for downstream habitat formation and maintenance (Zauner et al., 2001). Therefore, these measures are pre-requisite for other measures like re-meandering, widening, or riparian zone restoration. In addition to improvements in width-depth ratios and lateral connectivity, removing bank fixation can also benefit recreation in the river/floodplain and river/groundwater connectivity. It is important to consider the links between bank restoration, stream power, and river processes when planning bank restoration measures (REFORM Restoration WIKI, 2010). Generally, removing river bank fixation requires heavy machinery. Depending on the level of river regulation and uses for navigation, hydropower, or flood protection, some banks cannot be removed. In other cases, partial bank removal can be accomplished to accommodate continued use for navigation, especially in large impounded rivers (Zauner et al., 2001).

Recreate gravel bar and riffles

The creation of gravel bars and riffles is an appropriate restoration measures to restore natural channel features, spawning habitat for fish, and habitat for flowing water adapted (rheophilic) invertebrate species (Barlaup et al., 2008; Pedersen et al., 2009). These features are characterized by increased stream velocities, shallow water depths, high connectivity between the riverbed and groundwater, and coarse substrate (Sear and Newson, 2004). Gravel bars and riffles can be restored via active additions of gravel, manipulations of the river bed, or by re-establishing a natural flow and sediment regime which govern erosion and deposition (Wheaton et al., 2004a). In rivers with altered peak discharges and sediment transport, active restorations are necessary. In regulated lowland rivers with bottlenecks to fish dispersal and recruitment, artificial riffles can be implemented to improve fish passage and provide spawning habitat for gravel-spawning (lithophilic) species (Goeller, 2013).

Post-project maintenance (e.g. gravel cleaning, gravel addition) or the installation of sand traps may be necessary to support the benefits of artificial riffles (Avery, 1996; Rubin, 2004; Meyer et al., 2008). It is important to mitigate land use pressures and to establish adequate bed-flushing flows before recreating gravel bars and riffles, since accumulations of fine sediment, organic matter, and nutrients degrades the quality of these habitats (Levell and Chang, 2008; Pedersen et al., 2009). The colonization of aquatic plants can also negatively impact the long-term habitat suitability of gravel bars and riffles (Merz et al., 2008; Goeller, 2013), and weed cuttings or riparian plantings can be implemented to counteract these effects.

Set back embankments, levees or dikes

So long as bank protection/reinforcement is not in place, setting back embankments, levees, or dikes allows the river to migrate laterally, subsequently creating and maintaining different floodplain channel types and habitats. Land constraints often limit the extent to which these restoration measures can be done; therefore, setting back structures that impede lateral connectivity can offer compromises to completely removing the structures (Roni et al., 2005). Allowing for small sectors of the floodplain to be restored in some areas encourages inundation and can re-instate scour, erosion, and deposition. The floodplain where the structures have been set back can help the river to function properly by possibly creating sediment, flow, and nutrient pulses (Sparks, 1995).

Reconnect backwaters and wetlands

Backwaters, oxbow lakes, and wetlands are reconnected with the river channel to restore off-channel habitats and enhance lateral connectivity (Roni et al., 2008). Backwaters can be described as rather small water bodies with little or no current of their own that may be seasonally or permanently inundated and are connected to the main river channel (Kampa and Stein, 2012). These floodplain waters contribute to a diverse mosaic of habitats and are important for nutrient subsidies, spawning, and rearing habitat. When backwaters are reconnected, it is important to ensure that the connection remains open, since backwaters can quickly fill up with sediment (Amoros et al., 2005). Thus, a consideration of natural processes that keep the connections open or post-project maintenance to re-open connections is important for the long term provision of ecosystem benefits (Kampa and Stein, 2012).

Remove hard engineering structures that impede lateral connectivity

Removing embankments, levees, dikes, or other engineering structures that impede lateral connectivity offers a way to allow backwater habitats to be passively revitalized by restoring lateral hydrological pathways. Florsheim and Mount (2002) found that floodplain features could be successfully restored by enabling lateral channel migration. Following the removal of hard engineering structures, the channel can begin to migrate laterally and can recover habitat complexity fairly quickly (Jungwirth et al., 2002; Muhar et al., 2004). Techniques such as breaching dikes or removing embankments require that the newly or re-impounded backwaters will not pose a threat to human settlements (e.g. flooding risk or erosion) (REFORM Restoration WIKI, 2010). Other options include re-opening unprofitable polders which were embanked for agriculture, forestry, or fish culture to restore river-floodplain interactions. Once hydrological connectivity has been restored, the formation of hydric soils and the colonization of new habitats via seed banks and dispersal routes should follow as part of the natural recovery process.

3.4 *Conclusions on Selecting Measures to Restore Ecological Status in European Rivers*

It is extremely difficult to predict the impacts of specific river restoration measures at the EU level. The river type, based on geomorphic and functional process units, as well as the specific anthropogenic pressures are relevant for selecting suitable restoration measures. Within a river type, specific conditions can lead to very different restoration outcomes. Also, there are characteristic differences between large rivers exposed to multiple pressures including navigation (which sets significant boundaries for rehabilitation) and smaller rivers often affected by fewer pressures (e.g. forestry or agriculture). Thus, a river's environmental setting, its unique geomorphic and functional processes, and the anthropogenic pressures, as well as social acceptance and the economic costs must all be considered when selecting measures to improve GES.

4. Effects

Opportunities to improve future practice and to incorporate ecological considerations into river restoration measures are frequently missed, since most restoration efforts are not designed to evaluate or monitor their ecological impact or to disseminate project results (Bernhardt et al., 2005; Palmer et al., 2005; Roni et al., 2008; Cowx et al. 2013). Quantitative meta-analysis are extremely rare in the river restoration literature (Miller et al., 2010; Whiteway et al., 2010), since project evaluators inconsistently monitor and report their findings. Conclusions about the efficacy of measures are difficult to draw from even the most comprehensive restoration datasets (e.g., the U.S. National River Restoration Science Synthesis (NRRSS) with approximately 37,000 project entries) (Bernhardt et al., 2005; Follstad and Shah et al. 2007).

Evaluating the effects and effectiveness of measures to improve ecological status as prescribed by the WFD is imperative to indicate whether or not the objectives will be achieved (Kail and Wolter, 2011). REFORM D1.3 (Wolter et al., 2013) and REFORM D6.1 (Mosselman et al., 2013) concluded that quantifiable data on species response to hydromorphological changes are rather limited. Without knowing the ecological benefits of restoration measures based on the evaluations of specific projects, it is difficult to determine the real returns on the investments made in restoration. A key task in REFORM Workpackage 4 is to investigate the effects of hydromorphological restoration on river habitats, biota and ecosystem services, broken down by different restoration measures and scales[2].

Despite knowledge gaps and reporting deficits regarding the ecological impacts of restoration measures, several reviews and summaries have been assembled to assist river managers and practitioners in restoring rivers. For example, the ecological effectiveness for specific restoration measures has been investigated and summarized in the peer-reviewed literature (e.g., Roni et al., 2008; Wheaton et al., 2004a), international guidelines (e.g., Roni et al., 2005; UK – RRC's 'Practical River Restoration Appraisal Guidance for Monitoring Options' (PRAGMO), textbooks (e.g., Cowx and Welcomme, 1998; Simon et al., 2011; Roni and Beechie's (2013) 'Stream & Watershed Restoration – A guide to restoring riverine processes and habitat'), and is also a focus of the EU 7th Framework Research Project REFORM[3].

A review of the ecological response of BQEs to hydromorphological degradation and restoration in REFORM D1.3 found that only macrophytes, benthic macroinvertebrates, and fish respond sufficiently as indicators of hydromorphological changes (Wolter et al., 2013). Therefore, to provide information on the ecological effects for the restoration measures investigated in this report, a non-exhaustive literature review was conducted to summarize the impacts of specific measures on aquatic macrophytes, benthic macroinvertebrates, and fish). REFORM D4.2 (forthcoming) will provide an in-depth evalutaiton of existing studies of hydromorphological restoration on BQEs.

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[2] http://www.reformrivers.eu/results/effects-of-river-restoration

[3] http://www.reformrivers.eu/about

The non-exhaustive review of the ecological benefits of restoraiton measures is meant to compliment the analysis of socio-economic benefits of restoration measures (chapter 6). In this chapter, the methods and results of the review of the ecological benefits of restoration measures will be presented. While this type of clear-cut and generalized information is useful to river managers and decision makers, it does not encompass the full spectrum of complexity and uncertainty surrounding restoration impacts. Therefore, the limitations and uncertainties surrounding the benefits concluded for each group of measures will also be discussed.

4.1 Literature review methods for determining the ecological effects of restoration measures

Data on the ecological effects of specific river restoration measures were collected primarily from peer-reviewed journal articles published since 1980 but also from grey literature (e.g. non peer-reviewed technical reports, project evaluations, case studies, etc.). Studies included in the REFORM river restoration database provided an initial critical mass of literature, and further studies were located via the references cited therein. Appropriate literature used to assess the ecological effectiveness of restoration measures were field studies that investigated the impacts of river restoration measures on macrophytes, benthic macroinvertebrates, and fish (Wolter et al., 2013). The physico-chemical, chemical, and hydromorphological effects of measures were not included in the literature review, but nevertheless, these are important effects of river restoration (e.g., nutrient retention, nutrient cycling, water quality, etc.) and should also be considered when assessing the benefits of restoration.

To avoid making inappropriate generalizations or mistakes in regard to the ecological effectiveness of restoration measures, the general conclusions on the ecological effects of specific restoration measures were adapted from existing reviews (e.g., Roni et al., 2005; Roni et al., 2008; Wolter et al., 2009; Feld et al. 2011; Kampa and Stein, 2012) and the REFORM river restoration WIKI[4]. A semi-quantitative ranking system was adopted following Wolter et al. (2009) and the REFORM WIKI to express the expected ecological effects of restoration measures on the biological quality indicators that are relevant for the implementation of the WFD.

Table 5 provides a summary of the literature and data sources reviewed for the assessment of the ecological effects of restoration measures. No conclusions were drawn about the effects of restoration measures in specific river types, since the studies reviewed included rivers outside of Europe.

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[4] http://wiki.reformrivers.eu/index.php/Category:Measures

Table 5 Data sources used to evaluate the ecological benefits of restoration measures.

Measure Class	Measure Subclass	Study
01. Water flow quantity improvement	N/A	Wesche, 1985; Weisberg et al., 1990; Bunn and Arthington, 2002; Lamouroux et al., 2006; Soucon et al., 2008; Poff and Zimmermann, 2010; Kampa and Stein, 2012
02. Sediment flow quantity improvement	02.2 Reduce undesired sediment input	Zeh and Dönni, 1994; Bull 1997; Avery, 1996; Wood and Armitage, 1997; Harper et al., 1998; Simon and Collision 2002; Greig et al., 2005; Sarriquet et al., 2007; Barlaup et al., 2008; Pedersen et al., 2009; Jones et al., 2010
03. Flow dynamics improvement	N/A	Wiesberg and Burton, 1993; Petts and Maddock, 1996; Stanford et al., 1996; Hill and Platts, 1998; Ellis et al., 2001; Stevens et al., 2001; Annear et al., 2002; Bunn and Arthington, 2002; Speierl et al., 2002; Arthington and Pusey, 2003; Roni et al., 2005
04. Longitudinal connectivity improvement	04.1 Remove barrier	Kanehl et al., 1997; Bednarek et al., 2001; Kibler at al., 2001; Larnier 2001; Bushaw-Newton et al., 2002; Stanley et al., 2002; Roni et al., 2005; Maloney et al., 2008
	04.2 Install fish pass/bypass/side channel for upstream migration	Schmutz et al., 1998; Bryant et al., 1999; DVWK, 2002; Laine and Jokivirta, 2002; Larnier and Travade 2002; Armstrong et al., 2004; Calles and Greenberg, 2005; Hammarlund, 2006; de Leaniz 2008; O'Hanley et al., 2010; Roscoe and Hinch, 2010; Bunt et al., 2011; Gough et al., 2012
05. River bed depth and width variation improvement	05.1 Remeander water courses	Jungwirth et al., 1993; Friberg et al., 1994; Biggs et al., 1998; Friberg, 1998; Baattrup-Pedersen et al., 2000; Pedersen, 2007; Tullos et al., 2009
06. In-channel structure and substrate improvement	06.6 Remove bank fixation	Clarke and Wharton, 2000; Zauner et al., 2001; Zauner, 2003; REFORM WIKI – Case Study Aajen
	06.7 Recreate gravel bar and riffles	Edwards, 1984; Ebrahimnezhad and Harper, 1997; Merz and Chan, 2005; Walther and Whiles, 2008; Goeller, 2013
07. Riparian zone improvement	N/A	Quinn et al., 1992; Penczak, 1995; Sabater et al., 1998; Thuok, 1998; Parkyn et al., 2003; Roni et al., 2005; HIFI et al., 2010cREFORM WIKI – Case Study Aragon; Shilla and Shilla, 2012
08. Floodplains/off-channel/lateral connectivity habitats improvement	08.2 Set back levees, embankments, or dikes	Welcomme, 1985; Mann, 1996; Hein et al., 1999; Chovanec et al., 2002; REFORM WIKI – Case Study Bakenhof
	08.3 Reconnect backwaters and wetlands	Schmutz et al., 1994; Wilby and Eaton, 1996; Payne and Cowan, 1998; Schmutz et al., 1998; Thompson and Hossain, 1998; Rahman et al., 1999; Simons et al., 2001; Buijse et al., 2002; Hohausova and Jurajda, 2005; REFORM WIKI – Case Study Ven Duna
	08.4 Remove hard engineerging structures that impede lateral connectivity	Jungwirth et al., 2002; Chovanec et al., 2002; Muhar et al., 2004; Rohde et al., 2005

Note: Evaluations were focused on the measures and measure subclasses that are most represented in the cost database (Section 2).

4.2 Results of the review on the ecological effects of restoration measures

A central assumption of habitat restoration is that biota will respond to changes induced in riverine habitat (the "If you build it, they will come" assumption) (Stanford et al., 1996). Although this assumption is grounded in well-studied relationships between biota and their physical environment, the dynamics of this relationship may lead to unexpected outcomes of restoration projects (Lepori et al., 2005). For example, increases in habitat heterogeneity may not lead to recovery of the target species (Pretty et al., 2003; Schwartz and Herricks, 2007, Sundermann et al., 2011; Haaset et al., 2013). The impacts of large-scale pressures which are not addressed by reach-scale restoration can override the hydromorphological improvements made by reach-scale restoration measures (e.g., catchment land use, water quality, missing source populations, etc.) (Sundermann et al., 2011; Haase et al., 2013; Lorenz and Feld, 2013). Also, creation of unsuitable habitat for the target species (Sear and Newson, 2004; Lepori et al., 2005) or a delay in the response of biota to the habitat restoration can confound interpretations of project success. The response of biota to restoration measures is subject to uncertainties, which requires consideration when assessing the outcomes of restoration projects.

Examples of ecological benefits of river restoration include an increase in individuals of a particular species (e.g., ↑ abundance, ↑ density, ↑ biomass) and an increase in the number of species (e.g., ↑ taxa, ↑ species richness, ↑ community diversity). Changes in individual abundance and number of species alters the structure of populations and communities, and ecologically meaningful changes can be conveyed by autoecological information (e.g., % sensitive taxa, % habitat specialists, etc.). It is important to note that merely reporting increases in individual abundance or number of species does not indicate whether or not these changes were positive. For example, an increase in habitat generalists, short-lived species, disturbance-adapted species, or invasive species is likely to have negative connotation according to the existing assessment schemes. Also, despite the propensity of ecologists to publish studies with positive results, the use of statistics to determine the significance of the biological or ecological change brought about by a restoration project does not provide the full picture. In river restoration studies, statistical significance alone does not imply ecological or biological significance, and a lack of statistical significance resulting from a minor ecological or biological change can fail to capture the impact of river restoration (Feld et al., 2011).

The disturbance associated with constructing restoration measures often creates losses in species diversity and/or abundance immediately following the implementation of a measure. Therefore, many evaluations of restoration measures track the recovery of restored reaches to pre-disturbance levels (e.g., by comparison with a control reach elsewhere in the catchment or by before-and-after sampling). The inclusion of undisturbed control sites in the sampling design (i.e. BACI design) is the only way to partition the effects of restoration from natural or other sources of variation (e.g., seasonal and inter-annual variability) (Feld et al., 2011).

Reduce undesired sediment input

Reducing undesired inputs of fine sediment via the implementation of best management practices in agricultural zones can benefit river biota by preventing the clogging of the river bed by fine sediments (Zeh and Dönni, 1994; Wood and Armitage, 1997). Watershed reforestation and the maintenance of buffer strips can help to reduce the fine sediment load stemming from the surrounding land. Soft revetments can reduce soil erodability by resisting tension and increasing cohesion by the reinforcement of the bank through rooting systems (Bull, 1997; Simon and Collision, 2002). Brash revetments, like willow cuttings, brash bundles, conifer tops, pinning logs, or trees and branches, improve bank stabilisation and trap fine seciment, improving habitat for aquatic biota (Jones et al., 2010). Sand traps can be effective in-channel measures to reduce inputs of fine sediment from within the river channel, leading to improved spawning habitat for lithophilic fish species (Avery, 1996). When accompanied with spawning habitat improvement measures, managing fine sediment has been shown to improve fish recruitment (Greig et al., 2005; Barlaup et al., 2008; Pedersen et al., 2009) and the survival of benthic invertebrates and fish (Harper et al., 1998; Sarriquet et al., 2007).

Remove barrier

Literature available on the affects of barriers and barrier removal on larger rivers is plentiful, but documentation on smaller obstacles such as weirs, especially those that do not cause a permanent barrier to fish migration, is less common on smaller rivers (de Leaniz, 2008). Several studies have shown that small weirs (<5 m) can also act as a barrier across a water course regardless of their height because their passability depends upon the hydraulic characteristics, water temperature, river flow and fish species attempting to migrate (Larnier, 2001).

Dam removal is a relatively new restoration technique, and dam removal projects are rarely evaluated in peer-reviewed ecological studies (Roni et al., 2005). Bednarek et al. (2001) reviewed 22 dam removal studies in the USA to investigate the ecological impacts of dam removal and concluded that the restoration of a natural flow regime resulted in increased biotic diversity via habitat enhancement. Although fish passage is a clear benefit of dam removal, the disappearance of the upstream reservoir may negatively affect publicly desirable fisheries (Roni et al., 2005). Kibler et al. (2001) discuses the tradeoffs between the restoration benefit and the potential for disturbance due to the sudden increase in downstream flow and increased sediment load, which can displace, abrade, and smother downstream habitats and biota.

Several positive effects of dam removal have been documented for fish and benthic invertebrates. For example, Kanehl et al. (1997) reported an increase in the biomass of smallmouth bass (*Micropterus dolomieu*) from 0.6 to 4.7 kg five years after the removal of a 4.3 m high dam that created a 27 ha impoundment extending 2.3 km upstream. Bushaw-Newton et al. (2002) studied the removal of a 2 m high dam that impounded 500 m of river and found that the number of rheophilic fish species increased by 6 and the mean number of Ephemeroptera, Plecoptera, and Trichoptera Taxa (EPT) nearly tripled within one year upstream of the former impoundment. Stanley et al. (2002) monitored the removal of three dams 2.5-5 m in height in a 7 km stretch of a low-gradient river and found that the number of benthic invertebrate families increased within a year after dam removal. Maloney et al. (2008) monitored the removal of a 1.7 m high dam that stretched 105 m in length and found an increase in %EPT taxa from <2% to 17.7-60% within 2 years following the dam removal.

Install fish pass/bypass/side channel for upstream migration

The design and evaluation of fish passes for upstream migration have been thoroughly covered by international guidelines (e.g., DVWK, 2002; Armstrong et al., 2004; Gough et al., 2012), although downstream migration remains problematic (Larnier and Travade, 2002). Most studies of fish passes focus strictly on the efficiency of fishways to enable fish passage, and few have investigated whether or not the targeted fish populations are strengthened by the increased habitat availability (Roscoe and Hinch, 2010). Bunt et al. (2011) conducted a meta-analyses of 44 pool-and-weir structures, 29 vertical-slot fish passes, 7 Denil fish passes, and 21 nature-like fish pases. The findings revealed that each design had varying passage efficiencies: Denil fish passes had the highest fish passage efficiency (77%), followed by nature-like fish passes (76%), vertical-slot passes (56%), and pool-and-weir structures (55%) (Bunt et al., 2011). Denil passes are species and size-selective in favour of strong swimmers, and they are often applied to allow the migration of highly valued salmonid species, however, they may not be passable to cyprinid species. Many studies have evaluated the number of fish moving upstream through fish passes, which is a clear benefit of enhanced longitudinal connectivity and can occur immediately after installation (Schmutz et al., 1998; Bryant et al., 1999; Laine and Jokivirta, 2002; Hammarlund, 2006; O'Hanley et al., 2010). The increased number of spawning fish throughout a river system can benefit recruitment and population structure. Studies in Sweden found that the density of brown trout (*Salmo trutta*) yearlings was nearly twice as high after the construction of fishways, and the number of spawning fish and recolonization rates were expected to increase (Calles and Greenberg, 2005).

Remeander water courses

Re-meandering has been shown to lead to increases in macroinvertebrate species that are adapted to disturbance (Tullos et al., 2009). Within 1-2 years following project completion, the total abundance and density of macroinvertebrates can reach pre-restoration levels (Friberg, 1998; Biggs et al., 1998; Pedersen, 2007). The recolonization by macroinvertebrates and increases in invertebrate diversity (Jungwirth et al., 1993) are more likely if source populations are present (Friberg et al., 1994). The positive effects of re-meandering on macroinvertebrates could also benefit fish via increased food resources. Increases in fish diversity, density, and biomass have been reported for re-meandered rivers (Jungwirth et al., 1993). However, simply elongating the main channel by increasing sinuosity while keeping the existing (often overlarged) cross section may show no measurable effects (Wolter 2010). Re-meandering requires re-establishing natural cross sections, width and depth variations. The presence of upstream source populations is important for the re-colonization and species composition and growth patterns of macrophytes (Baattrup-Pedersen et al., 2000).

Remove bank fixation

The increase in shallow, low-velocity zones which are virtually absent in large, regulated rivers (e.g., the Danube) can increase the abundance of aquatic macrophytes and macroinvertebrates. Bank restoration projects in the Danube river (Austria) have resulted in increases in macroinvertebrate diversity and limnophilic (stillwater) species (Zauner et al., 2001). Improvements in macrophyte and macroinvertebrate communities were reported in the River Torne, where a series of bank re-profiling techniques were implemented (Clarke and Wharton, 2000). In the Dutch river Meuse, removing bank fixation has contributed to recoveries of rare invertebrate species and an increase in invertebrate density (REFORM WIKI – Case Study Aajen). Removing bank fixation can increase spawning and nursery habitats for fish by providing shallow gravel bars, low-velocity zones, and backwater habitats (Zauner et al., 2001). Bank removals can increase the abundance and dominance of rheophilic fish species (Zauner et al., 2001; Zauner, 2003). Removing embankments provides suitable sediments for rooting macrophytes and thus, is also a prerequisite to allow for macrophyte growth along the banks.

Recreate gravel bar and riffles

Recreated gravel bars and riffles can provide critical habitat for rheophilic invertebrate and fish species (Sarriquet et al., 2007). Even under suboptimal environmental conditions, recreated gravel bars and riffles can be successful in providing spawning habitat for gravel-spawning fish species (Barlaup et al., 2008; Goeller, 2013). Artificial riffles can also increase benthic invertebrate diversity, compared to unrestored, degraded reaches (Edwards, 1984), or increase macroinvertebrate diversity to levels similar to natural riffles (Ebrahimnezhad and Harper, 1997). Macroinvertebrate colonization of artificial riffles can occur with a few months, increasing invertebrate biomass and density to levels found at unenhanced sites (Merz and Chan, 2005). However, in rivers that are less degraded, the benefits of recreating gravel bars and riffles may be insignificant for macroinvertebrates, if the habitat-limited, sensitive taxa are already present (Walther and Whiles, 2008).

Set back embankments, levees or dikes

Setting back embankments, levees, or dikes provides ‘more room for the river’ and provides a greater diversity of floodplain habitats. The increase of floodplain habitat diversity can benefit fish populations, which use these areas for refuge, spawning, and nursery habitats (Welcomme, 1985; Mann, 1996; Buijse et al., 2002). In a stretch of the lower Rhine River where dykes have been set back, an increased diversity in vegetation and successional changes to plant community have been recorded (REFORM WIKI – Case Study Bakenhof). Setting back structures that impede lateral connectivity can also benefit invertebrates and amphibians (Chovanec et al., 2002). Hein et al. (1999) found that as lateral connectivity increased, plankton biomass increased in the reconnected habitats.

Reconnect backwaters and wetlands

Generally, the ecological benefits of reconnecting floodplain habitats increase with the area or length of physical habitat that is reconnected (Schmutz et al., 1998; Simons et al., 2001). Floodplains provide critical spawning and nursery habitat for a variety of fishes (Schmutz et al., 1994; Buijse et al., 2002; Hohausova and Jurajda, 2005). In addition to benefiting recruitment, reconnecting floodplains can lead to increases in fisheries yield (Payne and Cowan, 1998; Thompson and Hossain, 1998; Rahman et al., 1999). Reconnected backwaters also promote diversity in submerged and emergent aquatic macrophytes (Willby and Eaton, 1996). Reconnected backwaters have been found to increase benthic invertebrate specie richness and overall biodiversity (REFORM WIKI – Case Study Ven Duna).

Remove hard engineering structures that impede lateral connectivity

Removing hard engineering structures improves the habitat conditions of rivers, which supports improvements in fish and riparian diversity and age structure (Jungwirth et al., 2002; Rohde et al., 2005). Setting back levees has been shown to benefit rheophilic fishes or amphibians and dragonflies (Chovanec et al., 2002).

4.3 Summary of the review on the ecological effects of restoration measures

In this section, the expected ecological benefits of the restoration measures in the cost database are presented for macrophytes, macroinvertebrates, and fish (Table 6). These effects are based on the assumption that there are no river-network or catchmet-scale pressures which constrain the effect of the reach-scale restoration measures. While this type of clear-cut and generalized information helps funding agencies, river managers, and decision makers to gauge the idealized ecological benefits of investments in river restoration, it does not encompass the full spectrum of complexity and uncertainty surrounding restoration impacts.

The conclusions provided in Table 6 on the expected effects of restoration measures provide a reference to compare the impacts of single measures. However, the studies to draw these conclusions were often projects which included multiple measures. The combination of measures in practice could have additive or synergistic effects on the BQE, greatly affecting the ecological effects of the measures as well as the economic return on investment gained by the restoration.

Table 6 Expected ecological effects of restoration measures on aquatic macrophytes, benthic macroinvertebrates, and fish.

Measure Class	Measure Subclass	General Effects		
		Macro-phytes	Macro-invertebrates	Fish
01. Water flow quantity improvement	Measures class overall	+	++	++
02. Sediment flow quantity improvement	Measures class overall	+	++	++
	02.2 Reduce undesired sediment input	+	+	+
03. Flow dynamics improvement	Measures class overall	+	++	++
04. Longitudinal connectivity improvement	Measures class overall	0	++	+++
	04.1 Remove barrier	0	++	+++
	04.2 Install fish pass/bypass/side channel for upstream migration	0	+	+++
05. River bed depth and width variation improvement	Measures class overall	++	++	++
	05.1 Remeander water courses	++	++	++
06. In-channel structure and substrate improvement	Measures class overall	+	++	++
	06.6 Remove bank fixation	++	++	++
	06.7 Recreate gravel bar and riffles	0	++	++
07. Riparian zone improvement	Measures class overall	-	++	++
08. Floodplains/off-channel/lateral connectivity habitats improvement	Measures class overall	+	++	++
	08.2 Set back levees, embankments, or dikes	+	+	++
	08.3 Reconnect backwaters and wetlands	++	++	+++
	08.4 Remove hard engineerging structures that impede lateral connectivity	+	++	++

Legend: - negative, 0 neutral, + slightly positive, ++ moderately positive, +++ highly positive

The results of the non-exhaustive literature review of the ecological effects of river restoration measures can be summarized as follows:

1. Some restoration projects have been successful in enhancing BQEs (see reviews in Roni et al., 2005; Roni and Beechie, 2013). But, many projects have also found no or minor ecological improvements from restoration measures (Pretty et al., 2003; Sear and Newson, 2004; Lepori et al., 2005; Schwartz and Herricks, 2007; Haaset et al., 2013; Lorenz and Feld, 2013).

2. Only a minor proportion of restoration projects have been evaluated (Bernhardt et al., 2005; Follstad and Shah et al. 2007).

3. Very few restoration project evaluations used a BACI design, which allows separating the effects of restoration measurs from the general hydromorphologcail or biological trends or variability. (Feld et al., 2011)

4. Virtually all restoration project evaluations are restricted to a few years after restoration (e.g., 3-5 years), and significant uncertainties remain surrounding the long-term effects and sustainability of restoration measures (Feld et al., 2011).

5. The few scientific studies on the effects of restoration measures have shown contrasting results. In most studies, the effects of the restoration measures were low or there was no effect (Miller et al., 2010).

6. The effects of restoration measures differ between organism groups. Benefits can be greater for terrestrial biota (e.g., ground beetles, riparian vegetation) than for aquatic biota (e.g., macroinvertebrates) (Haase et al., 2013)

7. The restoration literature discusses several possible reasons for the low or no effect of restoration measures, but there is a lack of quantified evidence for these: upstream and downstream river network state, especially the presence of riparian buffer strips, diffuse source pollution (e.g., nutrients, pesticides, other xenobiotika, and fine sediment), impervious cover (e.g., urban areas), changes in the discharge regime (e.g., more extreme floods or lower baseflow), missing source populations, etc.) (Haase et al., 2013).

8. The watershed and river network conditions must be more strongly considered, and river restoration should be cone in a watershed context (Bernhardt and Palmer, 2011; Hermoso et al., 2012; Lorenz and Feld, 2013).

4.4 Discussion of uncertainties surrounding the ecological effects of river restoration measures

Acknowledging and accounting for these uncertainties is required to improve the success of river restoration measures. The development of objectives to assess the impacts of restoration on the targeted biological community is complicated by numerous sources of uncertainty (e.g., project design, hydromorphological processes, or how biota respond to restored habitat), and acknowledging and accounting for these uncertainties is required to improve the success of river restoration measures (Wheaton et al., 2004b). According to Wheaton et al. (2008), "Restoration is based on the transformation of uncertain science and uncertain notions of what is natural, ecosystem integrity and physical integrity into societal goals; however, the restoration community seems hesitant to admit that the goals and science that restoration are founded upon are uncertain." Project stakeholders and the public frequently interpret uncertainty as something negative and undesirable, shaping their expectations for science-based river restoration to yield the desired results with little deviation (Wheaton et al., 2008).

The response of biota to habitat improvements may be confounded or delayed by many factors, including: migration barriers, the lack of a colonizing source population, the isolation of restored habitat reaches, long-term recovery processes, the creation of inappropriate/unsuitable habitat conditions, or biotic interference resulting from competition, predation, or invasive species. Also, large-scale pressures that are not addressed by reach-scale restoration measures can confound the ecologic benefits of measures (e.g., catchment land use, river network-scale pressures causing point source and diffuse source pollution, including nutrients, pesticides, and xenobiotica, and hydrological alterations like increased peak flows). The persistence and maintenance of in-channel and off-channel habitat features is very dependent on the flow quantity and dynamics, thus, manipulations of stream flow can also influence the ecological benefits of restoration measures. Furthermore, the flooding-neutral design (i.e. implemented measures shall not increase flood risk) required for many restoration projects limits the hydromorphological improvements that could be made by narrowing over-dimensioned cross sections. Inadequate recognition of these factors or the timing of monitoring relative to project completion may also complicate the interpretation of restoration benefits, increasing the uncertainty surrounding restoration.

5. Costs

5.1 *Background*

The following chapter explains how European cost data was gathered and outlines the results of a preliminary economic analysis. This data will help inform a decision-making framework for river basin managers by providing examples of how cost data could be gathered and analysed, in addition to providing representative values for the costs of some restoration measures.

Knowing the economic costs of hydromorphological restoration measures is undeniably important for planning cost-effective conservation schemes that achieve the greatest positive ecological impacts with a given budget. From an economic perspective, an evaluation of the varying economic costs of restoration is equally as important as identifying where the restoration measures will be most effective. Although an economic analysis is only one way to go about prioritising restoration projects, it can yield the most efficient restoration outcomes when watershed assessments provide necessary information on ecological pressures and the costs and benefits of proposed measures (Naidoo et al., 2006; Beechie et al., 2008).

The WFD foresees economic analysis not only as underpinning for the selection of measures, but also for the justification of exemptions, so-called derogations (i.e. postponing the adoption of measures). Article 4 of the WFD cites "disproportionate costs" as a justification for not reaching targets within the foreseen timeframe. Although the perception of disproportionate costs can vary across Member States, an economic analysis should be undertaken to determine whether costs are indeed disproportionate (Lago, 2008).

A cost-effectiveness analysis would be sensible for selecting which measures should be implemented at the basin scale to achieve the GES/GEP targets set forth in the WFD. Additionally, when considering the implications for an individual firm, a water body, or a river basin, this analysis can underpin the justification for time-scale derogations. Specifically, certain measures could be postponed in order to allow for new abatement techniques to be developed that lowered the total costs of abatement. If, however, the costs are disproportionate for reasons other than financial viability, i.e., if the costs of the proposed measure are perceived to outweigh the benefits of reaching GES, then a standard-setting derogation could come into play. In such a case, a cost-benefit analysis at the margin would be necessary to identify a new optimal level of abatement (i.e. the point after which marginal costs begin to surpass marginal benefits) (Lago, 2008). Specifically, if the GES standard is too restrictive, the social benefits of some of the marginal abatement options (e.g., hydromorphological restoration measures) implemented in order to reach it may actually be outweighed by their private or societal costs (for more information on these analysis approaches, see Section 5.2).

In summary, these different types of economic analysis, applied at various scales, can help to inform river management bodies in several ways. First of all, the PoM is designed to list the measures being taken to reach an environmental target, namely the good ecological status of the relevant water bodies. As such, a cost-effectiveness analysis is suitable for managing resources efficiently. Additionally, the justification of disproportionate costs can rely on cost-effectiveness analysis to show that the achievement of the goal is not currently financially viable or cost-benefit to show that the marginal benefits of abatement are outweighed by marginal abatement costs at some point short of the good ecological standard.

Costs take on many different characteristics, including the time frames during which they must be paid, the purposes (for direct costs) they serve, and the actors who pay them. As such, costs are best reported in a more complex manner than simply a single number. The categories of cost reporting are best informed by economic theory and a sensible breakdown for administrative reasons. For example, differentiating private costs for project implementation from opportunity costs borne by others can help provide a basis for a deeper analysis. A broad breakdown of conservation costs includes (Naidoo et al., 2006):

- acquisition costs,
- management costs,
- transaction costs,
- damage costs, and
- opportunity costs.

Furthermore, the following costs must be considered specifically for restoration programmes:

- investment/construction costs.

In addition, we have the standard WFD-related cost typology which was developed for the CEA of the Programme of Measures. Article 4 of the WFD requires implementation of PoMs (including technical and policy instruments) to achieve environmental objectives (e.g., GES), which calls for a cost-effectiveness analysis. The breakdown of costs is represented below (see RPA, 2004):

- Non-recurring costs: these relate to capital costs but are one-off costs generated by a new measure/change in policy;
- Recurring costs: these include fixed costs (costs that do not vary across levels of production), variable costs (costs that vary across level of production or levels of activity) and semi-variable costs (costs that have both a fixed and a variable component);
- Non-recurring and recurring costs for regulators: these are associated with the set-up, administration and enforcement and monitoring of a new measure or a change in policy;
- Cost savings: these may arise from the adoption or implementation of a measure and include savings in materials (inputs), reduced energy requirements, the recovery or sale of by-product, reduced maintenance costs, reduced manpower requirements, etc.;
- Transfers: these are associated with taxes and subsidies. Financial costs to businesses will include transfer payments (implying that financial costs will differ from measures of economic cost);
- Non-water environmental costs/benefits resulting from implementing a measure: these include change in habitat, landscape, emissions to air, noise, etc. that may result from changes in land use (e.g. due to changes in agricultural practices or forestry), the construction of pumping stations and new water treatment plants, and other types of work, and

- Wider economic effects: any knock-on effects that are passed on or through to other sectors, organisations, etc. This includes the effects on producers and consumers in related market that are not captured by the estimation of direct non-recurring costs and recurring costs.

The costs of restoration projects are affected by many variables, some of which are project-specific, including weir height, and some of which are circumstantial, including regional variations in energy costs, labor costs, and requirements for monitoring and efficiency assessments. See for example Catalinas et al. (forthcoming) that provides a detailed overview of methods and data used for cost estimation for freshwater habitat restoration planning under the WFD in Spain.

In general, the level of detail built into the cost typologies that are currently being used in functioning river restoration databases is not as high as outlined above. Looking more specifically at river restoration in Europe, cost typologies included in existing databases generally include only total project costs. An exception is the RESTORE database set up as part of the RESTORE LIFE+ project, whose cost typology includes total cost information for the following categories: investigation and design, stakeholder engagement and communication, works (i.e., construction works), post-project management, and monitoring. In most cases, however, information is only reported for "works." Additionally, the German cost estimates outlined below (Section 5.4.1) do not represent true project costs but were reported on a per unit basis.

Looking across the Atlantic, cost reporting in restoration databases does not seem to be appreciably more complex. The US National River Restoration Science Synthesis, as reported by Bernhardt et al. (2005), gathered cost data on thousands of projects implemented across the United States but costs were only reported in terms of total project costs. Kondolf et al. (2007) worked with the same database alongside a set of interviews in California and pointed out the lack of useful project data for restoration projects, including cost data. The Utah Restoration Database[5] is an example of a state-level database that also only reports costs at the project scale.

Annex 4 presents a summary of the results of a literature review of river restoration costs. Cost references have been obtained both from scientific and (mainly) from grey literature. The literature search has been limited to documents available in English and has included the national and regional river restoration guidelines compiled as part of Work Package 6.

Costs are reported in the literature mainly for the following three types measures from the measure typology considered for the REFORM: longitudinal connectivity improvement (through weir removal and fish passage installation), in-channel structure and substrate improvement (gravel cleaning or placement and installation of habitat diversification structures), and riparian zone improvement (revegetation). The order of magnitude of the costs estimated in the literature for these measures is generally similar to those of the costs compiled for the case studies analysed in this report e.g. tens of thousands of euros per kilometre of restored river in the case of instream habitat restoration.

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[5] http://cnr.usu.edu/icrrr/htm/utah-restoration-database [Accessed May 21 2013]

Reviewing the previously mentioned typologies and factors that influence the costs of river restoration projects has led us to propose the following cost typology.

5.2 *Cost Typology*

The cost typology used for this analysis is based most closely on the one developed as part of the WFD cost-effectiveness analysis of PoM by RPA (2004). Specifically, we have adopted the non-recurring/recurring distinction in order to allow for insight into how costs develop over time. The list below illustrates the cost categories from the typology used in the database. These take account of the categories used in the case studies in WP4 of REFORM.

1. Non-recurring costs
    a. Planning and design costs
    b. Transaction costs
    c. Land acquisition costs
    d. Other construction / investment costs
2. Recurring costs
    a. Annual maintenance costs
    b. Annual monitoring costs

The proposed cost-effectiveness analysis should be possible with the financial cost data covered by these variables. Cost-effectiveness analysis allows for a determination of which restoration projects should actually be pursued given a limited budget. Financial cost data, collected in the typology both as recurrent and non-recurrent costs, are combined with effectiveness or benefits data in order to establish a ratio or costs to benefits for each individual measure. The measures are then ranked according to their cost-effectiveness, and, if the target is known, summing the potential deployment of the most effective measures will reveal which of them should be implemented to reach the goal at least cost.

The evaluation of further cost categories (beyond financial costs) can be of importance to decision makers. A full cost-benefit analysis at the margin attempts to determine the efficient level of abatement either for one individual measure class or a basin as a whole. As such, financial costs of measure implementation can be combined with the external economic costs of river restoration to understand the full social costs of implementing these measures. By plotting the total social costs (financial and economic) of measure implementation against the level of abatement, the relationship between the marginal costs of abatement (i.e., the costs of the next unit of abatement) and the level of abatement at that point can be derived (see Lago, 2008). By overlaying the marginal costs and marginal benefits of abatement action, the optimal amount of abatement can be found.

The inclusion of the other economic (i.e., external) costs of restoration measures has been considered, since it would allow for an assessment of the foregone benefits of river alteration. As discussed in chapter 1, the opportunity costs of river restoration affect primarily actors that can no longer use the river in its degraded state (Naidoo et al., 2006).

Likewise, the non-water benefits of restoration include external benefits that were lost or reduced as a result of the original degradation. For example, ecosystem services provided by flora and fauna that require pristine river habitats may once again emerge. These benefits will, however, be covered later in the report (for further discussion, see chapter 6).

The remainder of this section concerns itself with reporting financial costs and their characteristics. These cost data will be used to carry out representative analyses of the cost-effectiveness of measures and the optimal level of restoration across Europe, which can subsequently inform the decision-making tool developed in Work Package 5 and facilitate the decisions of river managers considering which measures to implement to achieve ecological targets under the WFD.

5.3 *Data Sources*

To populate our cost database, we have drawn upon other public databases, databases collected for research projects, lists of restoration cost estimates compiled by government agencies, a database compiled by an engineering firm, and a selection of government and project reports. A comprehensive list can be found in the reference section. Currently, the database covers four countries – Germany, Spain, the Netherlands and the United Kingdom – representing a range of different geographic and climatic regions in Europe.

5.4 *Data Quality*

As explained in section 2, Sheet 3 of our Excel database was designed to collect cost data along the lines of the cost typology delineated above in Section 5.2. Unfortunately, cost data for river restoration projects are not only hard to come by, but also they tend to be highly aggregated. For example, some cost data were also aggregated at the project level, which meant that they could not be differentiated by measure if multiple measures were implemented as part of a project. Of those cost data reported for individual measures, anything more specific than total implementation/investment costs was generally not reported. Only eight observations reported recurring costs, and only a handful reported any information on the amortisation time-frame. Therefore, no attempt was made to analyse the costs over time. Investment costs were assumed to be one-off and costs per year were not calculated. While this simplifies the following analysis, it also reduces the insight into how costs and benefits might develop over time.

Additionally, no data could be collected on wider economic costs. This information would only be available after an extensive analysis of the impacts of river restoration on nearby land and river users (e.g., loss of farm income due to reduced arable land) and producers and consumers in other sectors, so its absence is not altogether surprising. However, including these costs could increase the accuracy of a cost-benefit analysis.

Given that these projects will be evaluated ex ante, an analysis of the risk of incorrectly estimating costs and benefits up front needs to be included in the discussion. For example, cost estimates can be regarded as more reliable than benefit estimates that rely on ecological effectiveness predictions because these tend to be less reliable ex ante (Catalinas et al., forthcoming). The sources, the overall quality, and the reliability of the cost data are explained in more detail in the following subsections.

5.4.1 Germany

In Germany, no national overview of the costs related to river restoration measures exists. One reason for this is that the implementation of the Water Framework Directive takes place at the regional level under the auspices of the authorities of the 16 federal states. It is not known how many federal states actually collect cost data for internal use. If cost data are collected at all, it usually takes place at the river basin level. In most cases, these data are not publicly available. One can assume that the costs are usually not estimated by the authorities, but rather by the planning offices that are in charge of implementing the measures. In such cases, these data are typically not publicly accessible.

Most of the German cost data that are included in the database are estimates that have been compiled by the Hessian Agency for the Environment and Geology (HLUG). They stem from four regional authorities within the German state of Hesse and include lower-bound, average, and upper-bound cost estimates for a range of restoration measures. The figures do not include land acquisition costs. We trust that these estimates are reliable, since they have gone through an intense review process within the Agency and beyond.

The state of Lower Saxony maintains a project database[6] that contains, inter alia, cost data for 33 rivers. However, most of the stated costs are overall project costs and do not reflect the costs of individual restoration measures. Nonetheless, cost reports for a few individual measures were found. The state of Baden-Wuerttemberg has also published some figures, but a broad overview of relevant cost data is not available.

Additionally, the restoration measure database compiled as part of Work Package 1 contained a few observations from Germany with relevant measure cost data available at the unit scale. This database was populated primarily by drawing upon peer-reviewed and grey literature, and, although many observations referred to project implementing several different measures, some narrowly focused projects handled only one measure and were able to be included in our database. Another database compiled as part of a restoration assessment sponsored by the German Federal Foundation for the Environment (Deutsche Bundesstiftung Umwelt) was consulted as well. This database yielded several observations with unit costs broken down to include planning and land acquisition costs.

Overall, however, cost estimates make up the overwhelming majority of the observations in Germany.

5.4.2 Spain

The most useful sources for the analysis of recent restoration costs in Spain are projects budgets developed prior to project implementation. Costs provided do not include land acquisition or taxes, and are updated as of December 2009 by means of the consumer price index. Ideally, data relative to actual project expenditures after project completion should be analyzed, but, such data are very difficult to obtain. The projects that we have included in our literature review have been funded or are to be funded mainly by Spanish

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[6] http://www.wrrl-kommunal.de/content,33.html

environmental authorities, and they frequently comprise activities pertaining to more than one measure. Generally, the documentation related to these projects is generally not readily available to the public. The budgets analyzed can comprise activities pertaining to one or more measures, and so they have been broken down at the measure level. In general, Spanish RBMPs and PoMs include the total budget that is planned to be dedicated to restoration actions, but detailed project descriptions are not generally included in the planning documents. Other sources for the evaluation of restoration costs available in Spain are listed rates commonly applied by contractors, which can also be useful for the comparison/contrast of restoration costs throughout Europe.

In Spain, there is limited information available about observed effects and benefits. Regarding other data gaps, there is less information regarding the more novel restoration techniques (e.g. levee removal and instream habitat restoration) as compared to those that have been frequently implemented (e.g. riparian revegetation, reforestation, wastewater treatment, etc.).

We believe that the cost data are reliable and transferable for the estimation of restoration costs in Spain at the planning stage (CEDEX, 2011). Different degrees of uncertainty are associated to cost estimations derived for the different measures. Given the great variation of relevant costs such as manpower and energy throughout Europe, we do not expect our compilation of restoration costs to be directly transferable for cost estimation in other countries. However, we do expect the orders of magnitudes of the costs of measures to be comparable to those in other countries.

5.4.3 United Kingdom

The UK has a good compilation of recorded restoration projects, which can be accessed through the River Restoration Centre’s (RRC) website. However, the RRC’s website contains limited information on restoration costs. Further projects and project information (project name, river, length location, break down of aims and objectives, comments of success and failure, catchment and cost information) can be found through the RRC National River Restoration Inventory (NRRI), in which over 2,000 river projects are recorded. Only a subset of these projects in the NRRI can be accessed by those who pay membership, and generally, data availability is limited.

The majority of the restoration projects recorded at the RRC are typically those that were designed and applied through river trusts. The UK Environment Agency (EA) is also involved in river restoration projects, but these are not as well documented or easily accessible. Collaboration between the RRC and EA has recently been improved as part of the LIFE+ RESTORE project to support the collection of UK river restoration projects by collating the majority into one inventory[7] that is freely available to view online.

Overall, the literature review on UK restoration projects has highlighted that cost/benefit is overlooked in the majority of river restoration projects, or at least not well documented. Costings that were documented were grouped as ‘total’ cost for the whole project, and therefore, in most cases, restoration measures were not individually recorded. The ‘benefit’ or ‘success’ of restoration projects was also poorly documented and one of the main reasons for this can be attributed to a lack of project monitoring. Therefore, the

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[7] http://riverwiki.restorerivers.eu/wiki/index.php?title=Main_Page

combination of poor documentation of project costs and monitoring results in large data gaps regarding cost/benefit of river rehabilitation.

The majority of the cost data from the UK contained in this deliverable's database stems from restoration projects in England and Wales (Environment Agency WFD Hydromorphology Project).

5.4.4 The Netherlands

Publicly available estimates of river restoration costs were very difficult to come by in the Netherlands. The observations reported in the database came primarily from a report prepared by DHV Consulting in 2006, which collected costs from a number of other sources and consolidated them. These costs are estimates of unit costs for various measures, rather than direct project costs.

5.4.5 Summary

The cost data collected in this deliverable's databse were very heterogeneous, in terms of data source and cost type (e.g. estimated vs. reported project costs). The observations collected from Germany and the Netherlands are generally simple cost estimates, while those from Spain and the United Kingdom represent actual reported project costs, albeit at a fairly aggregated level. Project costs were also available in some cases from within Germany. The sources of these data are diverse: German observations came mainly from governmental sources, while Dutch observations were difficult to find and could only be drawn from a database created by an engineering consultancy. A large number of observations were found in project budget proposals from Spain, and the cost data originating from the United Kingdom were taken from yet another kind of source, a database put together by a non-governmental organization.

The accuracy of these costs for European river managers in general deserves attention. This sample of cost data contains observations from two continental European countries bordering the North and Baltic seas, the islands of Great Britain, and one Mediterranean country. This might lead one to believe that the data are slightly skewed toward non-Mediterranean, Northern and Western European contexts. However, the overall distribution of observations is centred primarily on Germany and Spain, providing a nice coverage between Northern Europe and the Mediterranean. Additionally, the representative countries have price levels that are near the EU-27 average (Kurkowiak, 2011), so the cost data are unlikely to represent abnormally high or low prices in European comparison.

Given that many of the measure observations refer to cost *estimates* rather than *reported* costs from projects that can be linked to a certain project size for reference, the danger exists that, by according the estimates a project size of simply one unit, data points would become bunched at the low end of the distribution. This could potentially lead to extreme heteroskedasticity if a wide range of values are all plotted as estimates—values, which almost certainly refer to the unit costs of projects at various scales. As such, plotting these values not only increases heteroskedasticity, but also it could bias the functional form of the total abatement cost curves. This is discussed in more detail in Section 5.6, which addresses cost reporting.

5.5 *Cost Unit Selection*

For those restoration measure categories or subcategories for which cost tables were made, the inevitable issue of differing cost reporting needed to be addressed. Observations for comparable measures were often reported in varying, non-comparable units (e.g., by volume of the dike removed or by length of the dike removed). In order to make use of the most data possible, the cost reporting option that promised to return the most observations was chosen for each measure. Where possible, costs were converted into different units in order to increase the number of observations and thus the completeness of the analysis. Constructing cost tables for measures aiming to remove weirs and other obstructions, for example, involved converting some cost data from €/weir to €/m (weir height). The final list of cost units (table 7 below) includes discrete project units (e.g. per connection), distances, areas, and volumes, making a direct comparison of measures on the basis of cost units impossible.

The final cost tables contained costs in the following units represented in Table 14. All costs reported are non-recurring, i.e. they reflect simple investment costs. The numbers in brackets represent the measure classes covered in the FORECASTER measure typology (see Annex 1).

Table 7 Units used for cost analysis of restoration measures

Measure Category	**Cost Units**
Floodplain Measures (*8.1-8.9*)	*€/ha*
Wetlands Connection (*8.3*)	*€/connection*
Dike Modification/Removal (*8.1/.2/.4*)	*€/m*^{3} *dike volume*
Upstream Longitudinal Connectivity (*4.2*)	*€/m (weir height)*
Weir Removal (*4.1*)	*€/m (weir height)*
Remove Bed and/or Bank Fixation (*6.6/.7*)*	*€/m*
Re-meandering of Watercourse (*5.1*)	*€/m*
Sediment Control through Reforestation (*2.2*)	*€/ha*

* This measure category also includes some observations of measures that involved creating riffles in river beds in addition to removing fixation.

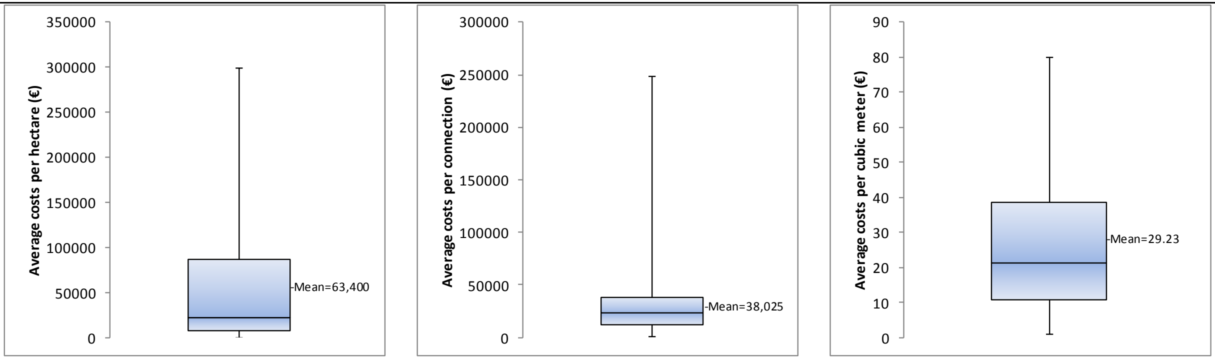
5.6 *Cost Reporting: A Preliminary Illustration*

This section reports a preliminary analysis of the cost data for the measures listed in Table 7. This section aims to provide a first illustration of the possible application of the cost analysis to advice decision making in river restoration. Many caveats remain at this stage with the database and reported cost information in order to allow for an accurate analysis. A full cost analysis was not the intention of this deliverable and will be presented in D5.2 "*Cost effective restoration measures that promote wider ecosystem and societal benefits*". The section "recommendations for further cost analysis" at the end of the chapter includes a discussion of the modifications needed (section 5.6.3).

Two specifications were developed for the assessment of total and average abatement costs for each measure. One specification (expanded) includes all comparable cost observations, including cost estimates from Germany and the Netherlands that have by necessity been assigned a project size of one unit. Their inclusion does not bias the cost data presented as average unit costs. The other specification (restricted) includes only those observations that are reported from actual project implementation. This specification was used for plotting the relationships between costs and project size.

5.6.1 Box-plot reporting of unit costs

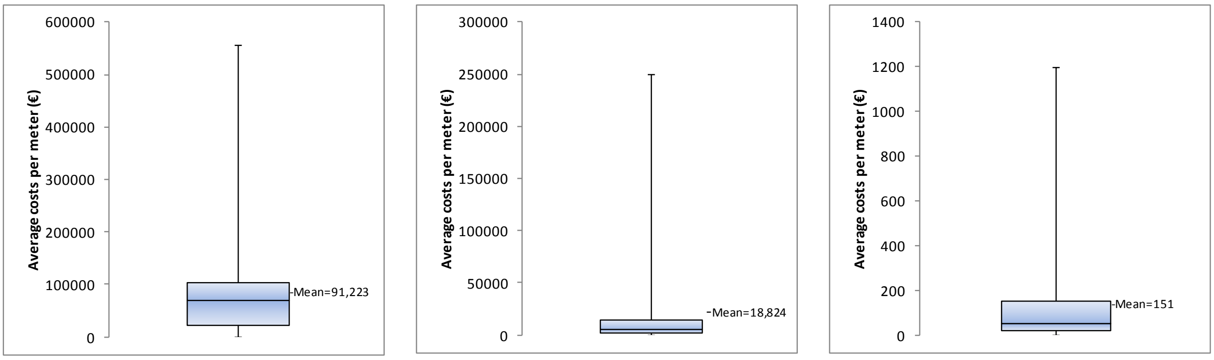
Reported in Figure 3 are average unit costs that include all comparable observations—in other words, the expanded sets. All costs are non-recurring. Figure 3 displays cost unit information for each of the assessed measures (graphs A to H), allowing for a direct comparison of the reported costs. The findings are discussed below. For the analysis, cost estimates (lower-bound, average, and upper-bound) and reported project costs have been combined. The cost database also allows for a restricted analysis of the individual cost types.



A. Floodplain measures

B. Wetlands connection

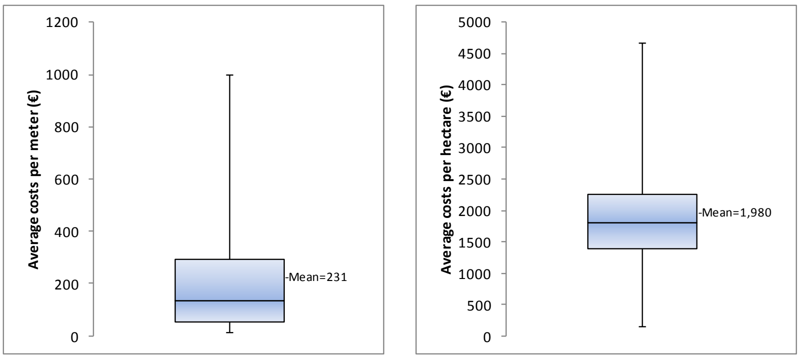
C. Dike works



D. Upstream longitudinal connectivity improvements

E. Weir removal

F. Bed and bank fixation removal



G. Re-meander a watercourse

H. Controlling sediment input through reforestation of catchment

Figure 3 Unit costs for selected measures

Floodplain Measures

This category includes all floodplain-related restoration measures that were reported on a per-hectare basis. The median unit cost was 22,734 €/ha, while the maximum and minimum were 300,000 and 109 €/ha, respectively (Figure 3.A). The data exhibit several outliers at the upper end; the standard deviation is €82,277.

Wetlands Connection

This category includes just those floodplain-related restoration measures that involve reconnecting a watercourse to existing floodplains, including oxbow lakes and wetlands. Note that this does not include the removal of dikes or levees that impede connection; those measures are covered in the next category. The median unit cost was 25,000 €/connection, while the maximum and minimum were 250,000 and 1,964 €/connection, respectively (Figure 3.B). The data exhibit several outliers at the upper end; the standard deviation is €48,369.

Dike Modification/Removal

This category of measures was the only one reported in terms of volume, specifically the volume of the dike modification needed (including removal, lowering, or relocation). This measure aims to reconnect watercourses with their natural floodplains by removing man-made impediments. The median unit cost was 21.60 €/m^3, while the maximum and minimum were 80 and 1 €/m^3, respectively (Figure 3.C). The data are distributed fairly evenly; the standard deviation is €24.60.

Upstream Longitudinal Connectivity

Measures to improve upstream longitudinal connectivity, in other words migration possibilities for fauna, include primarily the construction or renovation of fish passes. These measure costs were reported based on the height (m) of the weir or dam in question. The median unit cost was 70,000 €/m (height), while the maximum and minimum were 557,531 and 1,000 €/m (height), respectively (Figure 3.D). The data exhibit several outliers at the upper end; the standard deviation is €104,362.

Weir Removal

Measures to remove weirs are designed to improve longitudinal connectivity both upstream and downstream as well as restore natural sediment transport. The costs for these measures were reported in the same units as for fish ladders and passes, namely per meter of weir or dam height. The median unit cost was 5,473 €/m (height), while the maximum and minimum were 250,000 and 540 €/m (height), respectively (Figure 3.E). The range of the data exhibits a strong upward skew, with several outliers very high at the upper end; the standard deviation is €39,006. This can also be explained due to the fact that an important variable for the cost determination is the weir length, not only its height.

Remove Bed and/or Bank Fixation

This measure category covers the removal of bed and bank fixation that attempts to permanently alter the form and in-channel habitat of a watercourse. The costs of removing bed and bank fixation were reported per meter of restored watercourse. The median unit cost was 55.12 €/m, while the maximum and minimum were 1,200 and 1.50

€/m, respectively (Figure 3.F). The range of the data exhibits several outliers at the upper end; the standard deviation is €215.

Re-meandering of Watercourse

Measures to re-meander rivers that have been straightened by humans in the past are included in this category. The median unit cost was 137 €/m of river stretch recovered, while the maximum and minimum were 1,000 and 15 €/m, respectively (Figure 3.G). The range of the data is exhibits several outliers at the upper end; the standard deviation is €253.

Sediment Control through Reforestation

Measures to reduce sediment input into rivers can take many forms. In this case, the costs reported here belong to measures for reforestation in watersheds that are pressured by deforestation. The median unit cost was 1,819 €/ha, while the maximum and minimum were 4,668 and 156 €/ha, respectively (Figure 3.H). The data are distributed fairly evenly; the standard deviation is €889.

Conclusions

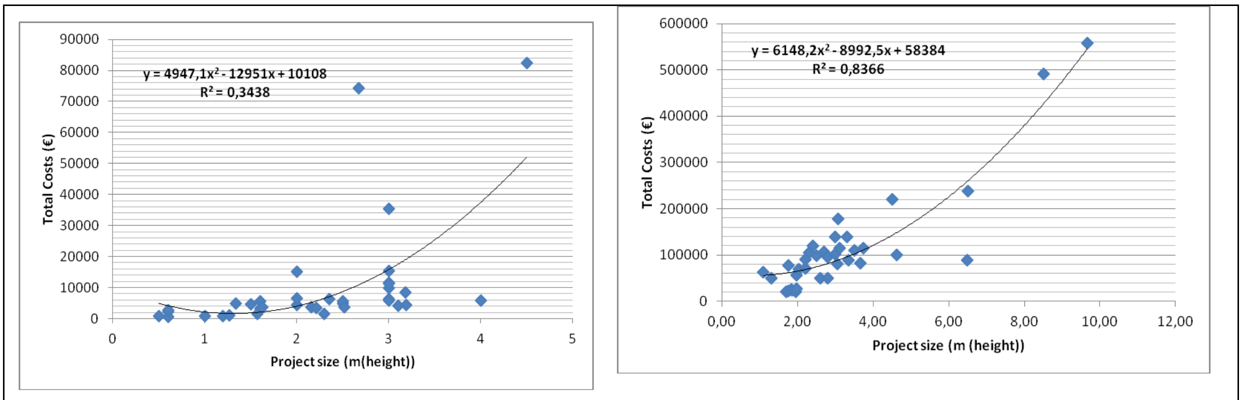
Aside from the level of the costs, their variability is of great importance for planning restoration measures. As noted by Naidoo et al. (2006), the variability of the costs or benefits determines the cost-benefit ratios of individual measures considered in cost-effectiveness analysis. In other words, focusing solely on the benefits of restoration projects as a criterion for selection in the presence of very variable costs will lead to inefficient restoration decisions and thus should be avoided. The cost data collected here exhibit great variability both within measure categories as well as overall: many measure groups exhibits coefficients of variance greater than 1, and the mean project costs for the various measures are also very disparate. Although the variability of benefits estimates will first be discussed in chapter 6, several proxies (including indicators for species richness) tend not to vary by one order of magnitude (Naidoo et al., 2006). An assessment of the relative variability of the cost and benefit data must inform the general cost-effectiveness analysis to be undertaken in REFORM D5.2 (forthcoming), and high cost variability relative to the spread of benefits would provide another basis to suggest that any decision-making tool designed for use by water managers must be sensitive to the costs of restoration options.

5.6.2 Reporting of cost curves

Additionally, the data allowed for the construction of cost curves for four measures using the *restricted* specifications mentioned above. Below, the relationship between total costs and project size is plotted for 1) weir removal (Figure 4.A); 2) measures that improve upstream longitudinal connectivity (Figure 4.B); 3) measures for watershed reforestation (Figure 4.C); and 4) measures that aim at bed and bank fixation removal (Figure 4.D).

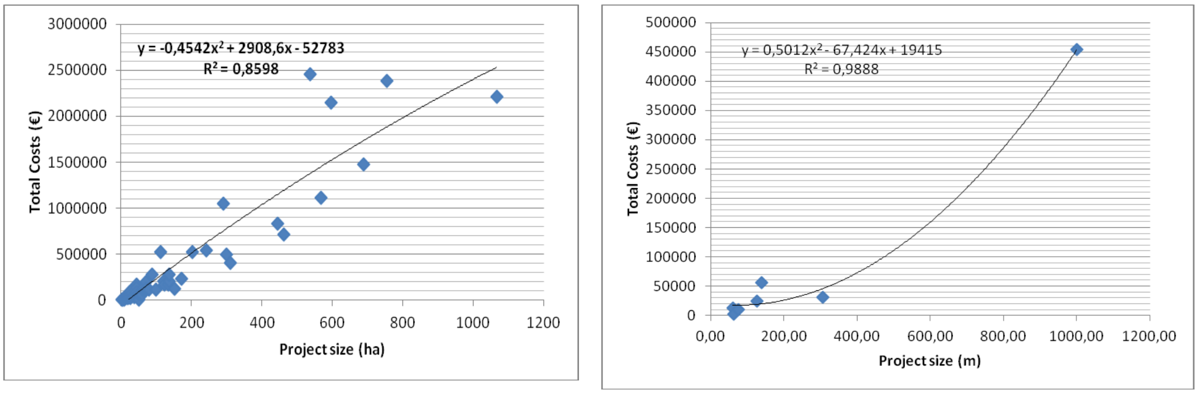
With the coefficients of the TAC curves, it is possible to derive marginal abatement cost (MAC) curves. The first derivative of the total abatement cost function is the marginal abatement cost function (Varian, 2003). Using a quadratic polynomial form for the (TAC) curve implies that the mathematical relationship between TAC and MAC can be described as follows:

$TAC = y_0+aX+bX^2$ ↔ $TAC' = MAC = a+2bX$



A. Weir removal

B. Upstream Connectivity -



C. Watershed Reforestation

D. Bed and Bank Fixation Removal

Figure 4 Total cost curves for selected measures

Despite the low R^2 values calculated to assess the fit of the functions reproduced above, a clear upward trend can be seen in all four graphs, indicating that increased project size does not necessarily result in lower average total costs for either of these four broad types of measures.

A variety of factors influence the costs of these restoration measures. The country in which restoration takes places undoubtedly influences the final investment costs for a number of different reasons. These could include varying labour costs, energy costs, and construction standards and reporting. Due to the lower number of observations submitted for the United Kingdom and the Netherlands, cost comparisons across regions will only be between Germany and Spain. Between Spain and Germany, cost comparisons can also only be undertaken for measures that have enough observations reported in similar cost units.

Another factor that could influence the implementation costs for any particular measure is the type of river in which the work is being done. Since the vast majority of restoration projects from the database were conducted in Type 3 or Type 5 rivers (see Table 3 & Table 4), we generalized this information to conclude that our cost analyses are relevant for these two river types only.
Additionally, other geographical considerations play a role in determining the costs of restoration measures. Mountainous and densely populated areas present logistical challenges for implementing river restoration measures. While densely populated areas

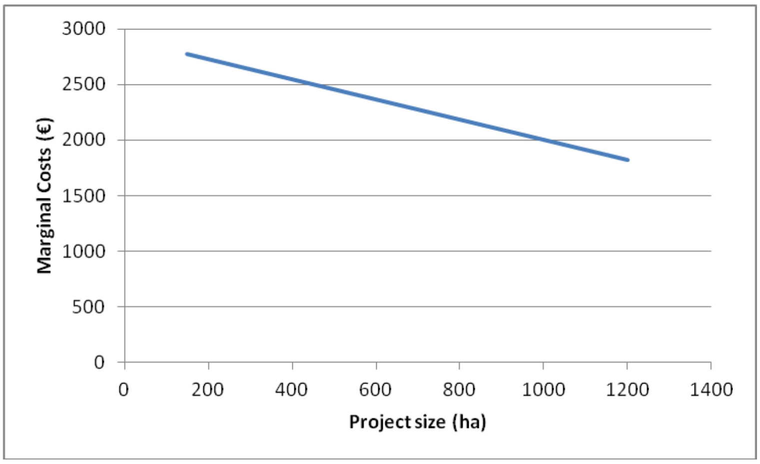
generally have higher land values that drive up the opportunity costs of restoration, mountainous or more remote areas are likely to exhibit lower land values (Naidoo et al., 2006). The accessibility of the restoration site, as well as the existence of transportation infrastructure, can greatly influence total project costs. Unfortunately, the current data availability does not allow for a more detailed investigation.

In marginal cost-benefit analysis, plotting the relationship between the total costs of measure implementation and the project size allows for a derivation of the marginal costs of implementing the measure. When combined with information on the marginal benefits for measure implementation, these marginal costs could, in theory, enable a river manager or another institution carrying out restoration to determine the optimal level of abatement using certain measure types.

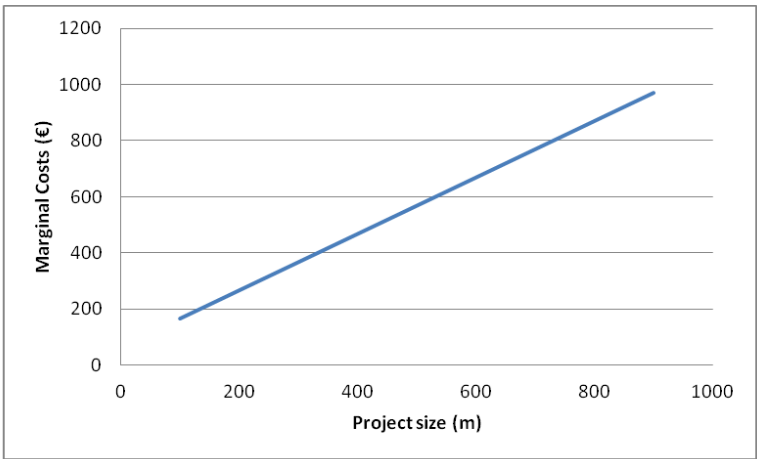
However, the cost units used to report, for example, on fish pass construction and weir removal show ex ante the futility in applying this to some measures. The cost units reported are €/m of weir height, which can deliver some insight into the average costs of removing smaller versus larger weirs, but the idea of building a fish pass that only reaches part of the way up a dam or other barrier is unlikely to generate many benefits, while it is also impossible to remove more of a weir than actually exists in reality. In practice, the project size is given exogenously by the previous human impacts. So, attempting to equalize marginal costs and marginal benefits within the context of the implementation of a single measure does not represent a relevant analysis in this case.

For other measures, though, this approach may be useful. For example, comparing the marginal costs of reforesting watersheds with the marginal benefits associated with reducing sediment input may allow for the determination of an optimal level of watershed reforestation.

These graphs presented below are meant to serve as an example of how marginal cost-benefit analysis can be used for restoration measures (Figure 5). In practice, this would more likely be carried out at the scale of the drainage basin or water body in order to determine whether the benefits of a cost-effective set of measures to achieve good ecological status exceed the costs at the margin. For specific water bodies, the analysis should include all available abatement options to address the identified hydromorphologic pressures. This reflects the cost-benefit analysis that could potentially be used to justify standard-setting derogations as mentioned in chapter 5.1.



A. Watershed Reforestation



B. Bed and Bank Fixation Removal

Figure 5 Marginal cost curves for selected measures

In figure 5.A, the marginal cost curve represents the relationship between project size and the cost of reforesting one more ha of land for watershed reforestation. Combined with data on the marginal benefits of reforestation projects, these marginal costs can be used to identify the optimal size for sediment input abatement projects, although more specific investigations should be undertaken on a case-by-case basis that include all available abatement options to address the identified hydromorphologic pressures. This marginal cost curve indicates that costs for additional ha of reforestation become increasingly more affordable as project size increases, potentially reflecting increasing returns to scale. The decrease in marginal costs is linear, dropping from over 2,500 €/ha to approximately 1,750 €/ha for projects of 1200 ha.

In figure 5.B, marginal costs illustrate the relationship between project size and the cost of removing bed or bank fixation for one more meter of watercourse. Again, these marginal costs can be used to identify the optimal size for fixation removal projects. This marginal cost curve indicates that costs for an additional meter of fixation removal constantly increase. It must be noted, though, that the cost curve has been developed from only six observations, and that the existing extent of fixation will determine exogenously the upper bound of project size, so a case-by-case assessment is necessary.

5.6.3 Recommendations for further cost analysis

Regarding the boxplots graphs presented in figure 3, the following steps have been identified in order to improve the cost analysis of the eight presented measures; these items will be taken up in the cost analysis that will be necessary for the development of Deliverable 5.2 "*Cost effective restoration measures that promote wider ecosystem and societal benefits*":

1. Need to assess the final number of observations.
2. Evaluate the countries from where the costs have been obtained for each of the measures.
3. A discussion analysis on the minimum description of the measures that are needed to understand cost reporting, both regarding the overall description of the measure (i.e. measures subclasses considered, especially for "floodplain measures", which is a very broad category), and the activities included in the measure where available (e.g. weir removal costs for Spain do not include debris management or river diversion costs, for example). It would be interesting to provide further information regarding the expected reasons for the variability of costs within each measure (e.g. feasibility or not of on-site disposal of excavated spoil) and to further investigate the outliers.
4. Further analysis and differentiation between cost estimates (i.e. German data) and real project costs (i.e. Spain) in the boxplots.
5. Further evaluation of the regressions models for the estimation of the cost curves is necessary, e.g. for weir removal, the observation corresponding to the lowest total cost seems to have a high leverage, and it would be interesting to see the change in the equation and the R2 value should it be eliminated. Additionally, the selection of different types of models (linear, etc.) should be justified, should it be in fact deemed necessary to use different types of models. In the case of weir removal, weir height does not fully represent project size, as weir length / river width is also relevant; in the case of watershed reforestation, planting density is also highly relevant as regards project size. In addition to this, increased project size is expected to be associated to higher average costs in the case of barrier removal (e.g. removal of large dams has an average cost that is way higher than the removal of low weirs, as it can be much more complex technically).

5.7 *Summary*

In conclusion, the data collected to populate this cost database came from a variety of countries and sources, many of the data were estimates, and only few could be disagregaded beyond total investment costs. These conditions restricted the level and accuracy of the analysis that could be used to identify the determinants of measure implementation costs as well, as the possibility to determine functional forms for the development of abatement cost curves.

Nonetheless, the cost data provide us with a basis for analysis. The cost data for most measures are quite variable, indicating that investing efforts in gathering and incorporating cost information into decision making will increase the efficiency of river restoration activities significantly. Marginal cost curves were developed for two measure categories in order to enable a future hypothetical marginal analysis of their costs and benefits with the purpose of illustrating the principle of economic efficiency applied to river restoration. Additionally, it was acknowledged that applying marginal cost-benefit analysis to measure types whose project size or extent is determined by existing anthropogenic alterations is not a useful form of analysis. However, they could still be included in a basin-wide assessment that includes all mitigation options for the identified hydrmorphological pressures. This cost data and the basic analysis performed here can provide ex ante information for the case studies in addition to serving as an example of how cost data can be collected and analyzed for individual water bodies.

6. Benefits

6.1 *Background*

It is difficult to quantify the effects of river restoration on human well-being in monetary terms, especially when attempting to compare the 'substantial costs' of rivers restoration (good ecological status) and the 'opportunity costs' of river modification (heavily modified waterbodies). Therefore, it is important to have a comprehensive and quantitative overview of the relevant costs and benefits (in monetary terms) to inform policy and decision-makers about what is 'economically efficient', i.e., to restore or to keep a water course in its current condition (Pearce, 1998). In this case, 'economically efficient' indicates whether the current and future benefits of river restoration exceed the current and future costs involved, including both the investment costs of restoring a water course and the opportunity costs of alternative land and water use (Brouwer and van Ek, 2004). An economic cost-benefit analysis of river restoration tries to capture all the relevant costs and benefits to society as a whole, not only those that incur or accrue directly in monetary terms to private parties (e.g., the investment costs for the central government or the regional water manager, the revenues from power generation for the hydropower company, or the revenues from commercial navigation for the transportation sector). A cost-benefit anaylsis also includes welfare effects that fall outside existing economic or commercial markets and for which market prices are not directly available.

Enhancement of the natural dynamics (flora and fauna) of a water course through hydromorphological rehabilitation, where the key purpose is to capture economic benefit (navigation and hydropower), typically has positive impacts on the ecological functioning of the watershed, in addition to recreational use and regulating services (e.g., functioning as a buffer for storm water (flood control) and a sink for pollutants emitted from different sources, such as agriculture or wastewater treatment plant (pollution control)). A more diffused group of public stakeholders benefits from flood and pollution control, but does not necessarily pay for these benefits (the stakeholders may even be unaware of receiving or reaping these benefits). Similar to flood and pollution control, recreational access to water courses is usually free of charge, excluding travel time. Furthermore, water utilities who extract water from a clean river may benefit from significant cost reductions of water purification before it is distributed as drinking water to households.

This chapter provides an overview of the existing scientific (environmental economics) literature in an attempt to capture the non-market benefits of river restoration. These are usually the most difficult to quantify and monetize, but may play a crucial role in the cost-benefit analysis informing policy and decision-making with respect to river restoration. Besides the scientific rigor (methodological validity and reliability) with which these non-market benefits are estimated in monetary terms, the legitimacy and transparency of the valuation and estimation procedure are important criteria for their acceptability in cost-benefit analysis.

6.1 *Benefits typology*

The typology of river restoration benefits is closely related to the typology of the economic values involved. The standard taxonomy of value in environmental economics is given by the concept of Total Economic Value (TEV), which consists of two main categories: use value and non-use value (e.g., Pearce and Turner, 1990; Hanley and Spash, 1993; Figure 6).

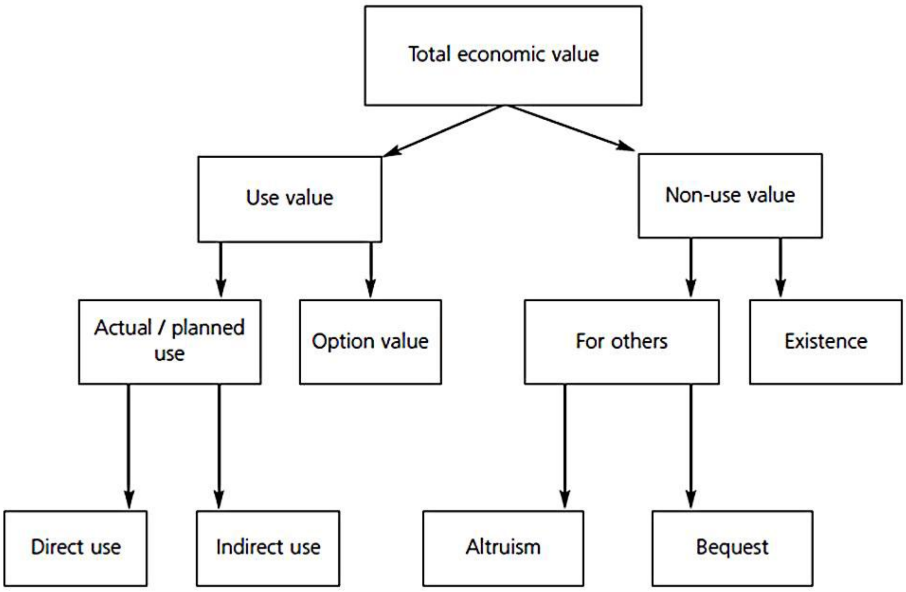


Figure 6. Taxonomy of total economic value (TEV, from DEFRA, 2007).

Use value is the value attached to the current, future, or potential use of a function or service. It comprises the direct and indirect use value and a category of values called option (and quasi-option) value. Direct use value refers to the value of current and expected future use of final services, such as the value of recreational fishing. Indirect use value refers to the indirect use of ecosystems, which occurs mainly through the positive externalities that ecosystems provide (Munasinghe and Schwab, 1993), such as flood protection by aquatic ecosystems. Option value (and quasi-option) value relates to uncertainty. Given that individuals are uncertain about their future use of ecosystem services, they attach value to having the option to use those services in the future. Non-use value is the value that society assigns to the pure existence of an ecosystem, independent of the use of its services. Non-use value comprises existence, bequest, and altruistic value. Existence value is based purely on knowing that the ecosystem exists or mere existence itself, regardless of use by others. Bequest value refers to the value of knowing that the ecosystem may provide value to future generations. Altruistic value refers to the value of knowing that the ecosystem may provide value to others within the current generation. It is important to realize that in the concept of TEV, a value is attached to the ecosystem as a bundle of final services provided by the ecosystem, and not to the ecosystem itself. Thus the aggregation of all values of a river corridor, following the composition of TEV in Figure 6, provides the TEV of that corridor.

The next step is to link specific final services provided by the river corridor to the various components of the TEV (see Table). All categories of final services provide option values because each service may be used at a later moment in time, although currently undetermined. Direct use values can be assigned to the category of provisioning services, such as the supply of freshwater and fish. Indirect use values are typically assigned to the category of regulating services because these are not enjoyed directly, but affect individuals' welfare. Non-use values are typically assigned to the category of cultural services.

Table 8. Matching the MEA ecosystem service typology to categories of TEV.

MEA service	Direct use	Indirect use	Option value	Non-use value
provisioning	x		x	
regulating		x	x	
cultural	x		x	x
supporting	No final service, hence valued through the other categories			

A range of methods to value specific ecosystem services, or monetary valuation methods, exists: discrete choice (random utility) models, market prices, averting behaviour, hedonic pricing, travel cost method, contingent valuation, and choice modelling. Depending on the final service, these methods make use of revealed (or observed) or stated preferences, where the preferences refer to the value individuals attach to the service. Ideally, services are valued through revealed preferences since revealed behaviour gives an objective estimate of individual's valuation. Nevertheless, observation of revealed preferences requires a market to exist for the respective service (in case of direct use values) or a surrogate market for other goods or services that it affects (in case of indirect use values). Very often, such markets do not exist, and therefore one has to rely on methods that elicit stated preferences. In addition, it is possible to use existing value estimates from previous studies by using the so-called benefits transfer method. This method applies earlier results to a new setting so that a new original valuation exercise is unnessesary. Such benefit transfer can be done with relatively small errors for services in comparatively similar settings, while this is more difficult for other services.

6.2 *Data sources*

Since the beginning of the 21st century, hundreds of studies on the valuation of river ecosystem services have been published in academic journals (Brouwer et al., 2009). Those valuation studies cover both existing and hypothetical river ecosystems. The spatial scope of the studies also varies considerably – from the services provided by ecosystems of the entire river catchment basins that span the area of hundreds square kilometers to the services provided by a few square kilometres in an urban district. The scope of the proposed changes to the rivers and affected ecosystem services under valuation is similarly broad, from improving water quality by reducing river pollution, to changes in water flow regimes, to complex hydro-morphological restoration measures that impact river beds, banks, and riparian zones. Finally, quite often the assessment of the consequences of changes to river ecosystems is carried out in terms of ecological changes, e.g., an increase in biodiversity, and not in monetary terms.

Taking into account the diversity of the literature on river ecosystem services valuation, the criteria used to select studies for the cost-benefit database were necessarily narrowed down to include papers on monetary valuation of ecosystem services and benefits of river restoration projects. The river restoration here signifies any changes to a river's status that involve changes to its flow, river bed, banks, and adjacent riparian or floodplains zones.

The database consists of papers published in academic journals during the period of 2000-2013, with most being published after 2005. Such a short time period results in a rather limited number of studies available for the analysis. Nevertheless, a clear advantage is that the resultant database reflects modern results on public perceptions of river restoration projects. Overall, there are 30 studies in the database. The majority of the papers are related to European river restoration projects (19 papers, including 5 on Spain and 4 on the British Isles rivers), although several studies on American (7 papers) and Asian (4 papers) rivers are also included.

6.3 *Data quality/uncertainty*

Various scientific uncertainties enter the equation when valuing non-market goods and services associated with river restoration. In principle, the valuation should be based on a sound biophysical (environmental) impact assessment. This allows the economic valuation to be directly linked to the expected physical changes in the watershed as a result of river restoration. This is often one of the first and main sources of uncertainty due to the limited scientific knowledge and (monitoring) information about the direct and indirect impacts of river restoration on the ecological functioning of a watershed, ecosystem habitats, and wildlife. In the literature review, we pay special attention to the scientific underpinning of the estimated economic values.

A second source of uncertainty is found in the translation of physical changes in the watershed and river system into human well-being and welfare. Biophysical changes may be observed and even monitored, but it is not always easy to directly assess their social welfare implications in terms of the goods and services involved to which people attach value. General classifications are quickly made, but it is often more complicated to relate a specific environmental and ecological change (which may occur over time with various spatial and temporal lapses) to a particular good or service.

A third source of uncertainty is found in the valuation exercise self, especially if this is based on stated preference research. In this case, possible beneficiaries are presented in a survey with hypothetical changes in their natural surroundings and asked to provide a value statement related to the change in the environmental good or service provision. Familiarity with paying for non-priced environmental goods and services is often limited and respondents in such surveys may therefore experience significant preference uncertainty.

Related to this, several possible biases may result (e.g., anchoring of value statements on value cues). On the other hand, similar uncertainties may arise in market prices due to volatility in demand and supply.Cost estimates are also often qualified by at least some degree of uncertainty. Typically, the different types of uncertainties vary across the different stages during the policy and decision-making cycle. They are usually higher during policy formulation and lower during policy implementation.

Finally, an additional source of uncertainty about ecosystem services valuation is the intertemporal change of respondents' preferences, analyzed by Meyer (2013). According to his findings, the estimated willingness to pay (WTP) for environmental improvements in the Minnesota River Basin is reduced by 45% if the river restoration is postponed for five years after the survey. If unaccounted for by the policy makers, the time-related decline in WTP will result in biased estimates of the river restoration benefits.

6.4 *Benefit unit selection*

As mentioned above, the studies on the valuation of river restoration projects are performed with different goals and, consequently, using different valuation techniques. As a result, the available monetary estimates are very different and not always directly comparable. In particular, while the value of ecosystem services per meter of restored river would be an ideal measurement unit that allows the comparison of costs and benefits of river restoration, the majority of the available valuation studies provide WTP estimates per household derived from stated choice experiments. Moreover, the studies assume different payment vehicles and thus, the estimates of the value of ecosystem services are stated not only as monthly or annual payments during a particular period (usually five or ten years), but also as one-time contributions or daily access fees. There are also several simulation-based cost-benefit analysis studies that calculate the net present value (NPV) or the net social benefit of river restoration projects, which are quite often based on individual WTP estimates scaled by the population in the study region. Yet another approach in modern literature is to derive the value of restored ecosystem services from available market data, e.g., through changes in house prices for housing along the restored river parts, or through the harvest value of fishing, etc. Overall, the benefit valuation derived from the stated preference studies seems to be the best available option that allows, albeit imperfectly, to base the policy decisions on the preferences and values of people who benefit from a particular river restoration project.

6.5 *Benefit reporting*

The results on the river restoration studies are summarized in the following table. The table includes references to the corresponding papers, timing and geographic details, valuation methods and monetary estimates of benefit valuations. It should be noted that the monetary values are given in purchasing power parity (PPP)-stated in 2008 Euros - with the aim to improve the comparability of the results.

Study ID	Author(s)	Year of publication	Valuation technique	Attributes	Welfare measure	Monetary value (EUR 2008, PPP)	Beneficiaries	Country
1	Hanley et al.	2006	CE	ecological improvement, flow rate, employment, cost	WTP	75.66-167	local households	Scotland
2	Bliem et al.	2012	CE	flood frequency, water quality, cost	mWTP	0.19-78.34	local households	Austria
3	Bliem & Getzner	2012	CE	flood frequency, water quality, cost	WTP	26.39-33.59	local households	Austria
4	Grossmann	2012	replacement cost; cost minimization	nitrogen, phosphorous			general public	Germany
5	Grossmann & Dietrich	2012	travel cost		WTP, CS		general public, visitors	Germany
6	Hanley et al. (2)	2006	CE	ecology, aesthetics, river banks, cost	mWTP	15.87-55.93	local households	England
7	Nardini & Pavan	2012	extended CBA	engineering constructions, ecological status, social impact, cost	net social benefit	122 mln	general public	Italy
8	Paulrud & Laitila	2013	CE	accessibility, congestion, distance, expected fish harvest, bag-limit, fee per day	mWTP	21.44-57.20	anglers	Sweden
9	Jørgensen et al.	2013	CV, model, non-user	water quality, substitutes, travel distance, cost	WTP	26.53-137.7	local households	Denmark
10	Ramajo-Hernandez & del Saz-Salazar	2012	DCCV	ecological status, cost	WTP	4.66-6.31	local households	Spain
11	Stichou et al.	2012	CE	river life, water quality, recreation, river bank conditions, cost	WTP	23.32-75.56	local households	Ireland
12	Solino et al.	2013	DCCV	environmental changes, affordability, use of environment, attitudes, geography, cost	WTP	72.80-80	local households	England, Wales
13	Del Saz-Salazar et al.	2009	CV	water quality, cost	WTP, WTA	27.4-52.8	local households	Spain
14	Gomez et al.	2013	simulation, opportunity cost		opportunity costs			Spain
15	Grazhdani	2013	CV	dilution of wastewater, natural water purification, erosion control, nature habitat, cost	WTP	25.2	local households	Albania
16	Honey-Roses et al.	2013	avoided cost modeling	stream temperature, shading scenarios, cost	savings			Spain
17	Perni et al.	2012	CE	water quality improvements, restoration measures, cost	mWTP	27.06-57.37	local households	Spain
18	Meyerhoff & Dehnhardt	2007	CV, RCA	biodiversity, user status, attitudes, past behavior, cost, nutrient sinks	WTP, indirect use values	8.7-252 mln	locals, general public	Germany
19	Acuna et al.	2013	CBA	fish provision, organic and inorganic matter retentions, tourism, erosion control, costs	NPV	1.81	general public	Spain

Study ID	Author(s)	Year of publication	Valuation technique	Attributes	Welfare measure	Monetary value (EUR 2008, PPP)	Beneficiaries	Country
20	Alam	2013	CBA	housing and value, water use, navigation, health benefit, value of recreation and tourism, fish production, costs	NPV	82.1 mln	locals, general public	Bangladesh
21	Alam	2013	CV	state of river, water quality awareness, uses of resources	WTC	2.3-2.32	locals, general public	Bangladesh
22	Han et al.	2008	CE	forest, flora, fauna, historical remains, price	WTP	2,63	general public	Korea
23	Kenney et al.	2012	CV	high/low, wet/dry stream bank, forest/meadow, cost	WTP	13.26-109	local households	USA
24	Holmes et al.	2004	CV	game fish, water quality, wildlife habitat, water uses, ecosystem naturalness, cost	WTP	4.42-41.93	local households	USA
25	Zhao et al.	2013	PCCV, DCCV	landscape and recreational use, wildlife and fish habitat, flood control, cost	WTP	4.15-31.07	local households	China
26	Loomi et al.	2000	DCCV	fish and wildlife habitats, dilution of wastewater, water purification, recreation, erosion control, cost	WTP	16.38	local households	USA
27	Weber & Stewart	2009	CV, CE	fish and wildlife, vegetation density, tree type, natural river processes, cost	WTP	36.50-122.15	local households	USA
28	Qui et al.	2006	CV, hedonic price	riparian buffer proximity, cost	change in house prices	1267-5349	local households	USA
29	Meyer	2013	CE	percentage of basing cleaned, cost of policy per year, time when cleanup is fulfilled	WTP	15.17-27.60	local households	USA
30	Ojeda et al.	2008	DCCV	environmental services, scenarios, cost	WTP	5.55-7.91	local households	Mexico

6.6 *Summary of the results*

In all of the cited stated preference elicitation studies, the benefits of the hydro-morphological river restoration are proxied through the environmental benefits and services provided by restored river ecosystems and/or riparian zones. As a rule, the restoration project is considered as a bundle of use and non-use ecosystem services, which makes it very difficult to extract separate values for particular services or even their groups. The most commonly considered services (benefits) are higher wildlife and aquatic life diversity, provision of drinking water, improved water and air quality, flood protection, carbon sequestration, erosion protection, better river appearance and recreational amenities of a riparian forest, better possibilities for swimming, boating, and fishing activities, and nitrate and phosphorus cycling and retention. However, the attributes of contingent valuation or choice experiment studies are usually multidimensional, defined rather broadly, and often combine several services in one notion. Apparently, such broad attribute definition comes as a compromise between the need to reflect the multi-faceted character of the impact of any river restoration project and the limited scope of a typical preference elicitation survey. A few typical examples of environmental attributes are ecological improvement, ecological status, water quality, aesthetics, river life diversity, and so on.

The majority of reviewed studies, 23 out of 30, assume that the main beneficiaries of river restoration are local households and use different forms of contingent valuation studies or discrete choice experiments to elicit their valuation of the restoration projects. The benefits of re-introduced or expanded ecosystem services provided by a restored river are equalized to welfare improvements resulting from the changes, and are calculated as a willingness to pay for river restoration.

In Europe, the academic papers included in the database report valuation results for rivers in the UK, Germany, Austria, Spain, Sweden, Denmark, Ireland, and Albania. Most WTP estimates are within the 25-80 EUR range, with 25-40 EUR being the median range. In addition, several studies report the marginal WTP for attributes, which allows, at least tentatively, the evaluation of improvements in selected individual environmental benefits, e.g., higher water quality –25-30 EUR, or better aesthetics –16-25 EUR. It should also be taken into account that there is a clear difference in WTP estimates between developed and developing countries. For example, in China, Bangladesh, Mexico, and also in selected studies in Spain, the WTP estimates are in range of 2.3-7.9 EUR (PPP adjusted). At the same time, in the USA, the reported WTP values are within the 13-122 EUR range. Overall, these findings are close to earlier valuations of ecosystem services.

7. Conclusions

For the implementation of the WFD, a cost-effectiveness analysis of restoration measures can help to ensure that the least-cost options for achieving Good Ecological Status are chosen for the Programmes of Measures (PoM). Only by assessing the full spectrum of costs and benefits can decision makers effectively allocate public and private funds and ensure the best ecological outcomes of investments in river restoration. A rationalized economic analysis to guide decisions and investments in restoration measures and to elicit the greatest impact (i.e., socio-economic and environmental benefits of restoration measures) is needed. Such a framework will be useful to inform the creation of the second round of River Basin Management Plans for the implementation of the WFD.

Knowing the economic costs of hydromorphological restoration measures is undeniably important for planning cost-effective conservation schemes that achieve the greatest positive ecological impacts with a given budget. The data collected to populate the cost database came from a variety of countries and sources, many of the data were estimates and only few could be disaggregated beyond total investment costs. These conditions restricted the level and accuracy of the analysis that could be used to identify the determinants of measure implementation costs, as well as the possibility to determine functional forms for the development of abatement cost curves.

The cost data for most measures were quite variable, indicating that investing efforts in gathering and incorporating cost information into decision making will increase the efficiency of river restoration activities significantly. This data will help inform a decision-making framework for river basin managers by providing examples of how cost data could be gathered and analysed, in addition to providing representative values for the costs of some restoration measures.

With regard to the economic benefits of the hydro-morphological river restoration, it has been shown that the most commonly considered services (benefits) are higher wildlife and aquatic life diversity, provision of drinking water, improved water and air quality, flood protection, carbon sequestration, erosion protection, better river appearance and recreational amenities of a riparian forest, better possibilities for swimming, boating, and fishing activities, and nitrate and phosphorus cycling and retention. The majority of the studies reviewed assume that the main beneficiaries of river restoration are local households, and use different forms of contingent valuation studies or discrete choice experiments to elicit their valuation of the restoration projects.

The information gathered in the context of this deliverable will provide the basis for further analysis on the cost-effectiveness of river restoration measures under WP5 of REFORM. The objective will be to upscale information on the costs and benefits of selected river restoration measures in certain river types to the European level. This exercise will contribute to the ongoing work (e.g. European Environment Agency, Joint Research Centre) on the mapping and valuation of ecosystem services across EU Member States. On a regional and local level, the results will help to inform decision-making on the cost-effective implementation of river restoration measures.

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8.2 *Sources of Cost Data*

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Annex 1 – FORECASTER Measure Typology

Measure Code	Measure Description	Measure Subclass	Measure Class
M01	Reduce surface water abstraction without return	01.1	01. Water flow quantity improvement
M02	Reduce surface water abstraction with return	01.2	
M03	Improve water retention	01.3	
M04	Reduce groundwater extraction	01.4	
M05	Improve/Create water storage	01.5	
M06	Increase minimum flows	01.6	
M07	Water diversion and transfer	01.7	
M08	Recycle used water	01.8	
M09	Reduce water consumption	01.9	
M10	Add/feed sediment	02.1	02. Sediment flow quantity improvement
M11	Reduce undesired sediment input	02.2	
M12	Prevent sediment accumulation in reservoirs	02.3	
M13	Reduce erosion	02.4	
M14	Improve continuity of sediment transport	02.5	
M15	Manage dams for sediment flow	02.6	
M16	Trap sediments	02.7	
M17	Ensure minimum flows	03.1	03. Flow dynamics improvement
M18	Establish environmental flows / naturalise flow regimes	03.2	
M19	Modify hydropeaking	03.3	
M20	Increase flood frequency and duration in riparian zones or floodplains	03.4	
M21	Reduce anthropogenic flow peaks	03.5	
M22	Favour morphogenic flows	03.6	
M23	Shorten the length of impounded reaches	03.7	
M24	Link flood reduction with ecological restoration	03.8	
M25	Manage aquatic vegetation	03.9	
M26	Remove barrier	04.1	04. Longitudinal connectivity improvement
M27	Install fish pass/bypass/side channel for upstream migration	04.2	
M28	Facilitate downstream migration	04.3	
M29	Modify culverts, syphons, piped streams	04.4	
M30	Manage sluice and weir operation for fish migration	04.5	
M31	Fish-friendly turbines and pumping stations	04.6	
M32	Remeander water courses	05.1	05. River bed depth and width variation improvement
M33	Widen water courses	05.2	
M34	Shallow water courses	05.3	
M35	Allow/increase lateral channel migration or river mobility	05.4	
M36	Narrow water courses	05.5	
M37	Create low flow channels in over-sized channels	05.6	

Measure Code	Measure Description	Measure Subclass	Measure Class
M38	Initiate natural channel dynamics to promote natural regeneration	06.1	06. In-channel structure and substrate improvement
M39	Remove sediments	06.2	
M40	Modify aquatic vegetation maintenance	06.3	
M41	Introduce large wood	06.4	
M42	Add sediments	06.5	
M43	Remove bank fixation	06.6	
M44	Recreate gravel bar and riffles	06.7	
M45	Remove or modify in-channel hydraulic structures	06.8	
M46	Reduce impact of dredging	06.9	
M51	Adjust land use to develop riparian vegetation	07.1	07. Riparian zone improvement
M52	Revegetate riparian zones	07.2	
M53	Remove bank fixation	07.3	
M54	Remove non-native substratum	07.4	
M55	Adjust land use to reduce nutrient, sediment input or shore erosion	07.5	
M56	Develop riparian forest	07.6	
M47	Lower river banks or floodplains to enlarge inundation and flooding	08.1	08. Floodplains/off-channel/lateral connectivity habitats improvement
M48	Set back embankments, levees or dikes	08.2	
M49	Reconnect backwaters and wetlands	08.3	
M50	Remove hard engineering structures that impede lateral connectivity	08.4	
M58	Restore wetlands	08.5	
M59	Retain floodwater	08.6	
M60	Improve backwaters	08.7	
M63	Construct semi-natural/articificial wetlands or aquatic habitats	08.8	
M65	Isolation of water bodies	08.9	
M64	Other measures	09.1	09. Other aims to improve hydrological or morphological conditions

Annex 2 – Detailed descriptions of FORECASTER measure classes

This section describes the measure classes in the cost database (chapter 2). The summaries include the eco-hydromorphological impacts of the measure, along with information on implementation and design options and measure durability. The sources for this information were e.g., the REFORM river restoration WIKI factsheets[8], the 'Factsheets on Environmental Effectiveness of Selected Hydro-morphological Measures' for DG ENV (Kampa and Stein, 2012), as well as peer-reviewed literature found in the REFORM river restoration database and in peer-reviewed journals.

1 Water flow quantity improvement

Streamflow is a "master variable" that governs the ecological status of rivers and streams (Poff et al., 1997; Bunn and Arthington, 2002). The magnitude, frequency, duration, timing, and rate of change of water flows directly influence water quality, energy sources, physical habitat, and biotic interactions in rivers. The amount of water flowing through a river is a result of the geologic features, climate, and vegetation of a river basin which shape the interactions between atmospheric, surface, and ground water sources. Modifications to the natural flow regime via dams, diversions, urbanisation, tiling, draining, levees, or channelization impairs streamflow dynamics and negatively impacts the hydromorphological and biological status of rivers (Poff et al., 1997; Bunn and Arthington, 2002).

Completely restoring all elements of the natural flow regime is not applicable in rivers where water abstractions, diversions, and retention measures support important economic sectors or provide other benefits like flood control or drinking water supply. Where complete restoration of streamflow is not possible, mitigation and management measures like increased minimum flows or well-timed irrigation can provide some ecological benefits (see Poff et al., 1997 and sources cited therein). When setting goals to restore a more natural flow regime, it is important that cooperation among the appropriate stakeholders, scientists, and managers is achieved to adequately address the impacts of the new flow regime.

2 Sediment flow quantity improvement

Another master variable that significantly impacts the ecological status of rivers is sediment flow. The interplay of geological conditions, topography, soils, and vegetation determines the type, source, and supply of sediment in a river basin (Allan, 2004). How much sediment can be transported through a river system depends on the natural flow regime, and together with the flow regime, the processes of sediment erosion and deposition shape the geomorphic character and habitat dynamics in rivers.

Managing sediment dynamics is contingent on river flows, land use pressures (e.g., inputs of fine sediment), river regulation (e.g., dams and riverbed and bank fixation

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[8] http://wiki.reformrivers.eu/index.php/Category:Measures

disrupt supply, erosion, and transport), sand and gravel mining, and natural catastrophes (e.g., severe floods, landslides, etc.). Depending on the specific pressures, a variety of sediment-related restoration measures can be effective to improve the sediment flow quantity in rivers.

3 Flow dynamics improvement

As with water flow quality improvement, improving flow dynamics is a key part of restoring a more natural flow regime. River biota are adapted to the disturbances caused by variations in flow dynamics, and disruptions to the frequency, duration, timing, and rate of change of water flows impairs the hydromorphological and biological status of rivers (Poff et al., 1997; Bunn and Arthington, 2002). Generally, measures to improve flow dynamics must compromise between existing land use pressures and pressures from river regulation structures and activities, striving for a desirable level of flow dynamics by mitigation and management measures like pulsed discharges and controlled flooding. When setting goals to restore a more natural flow regime, it is important that cooperation among the appropriate stakeholders, scientists, and managers is achieved to adequately address the impacts of the new flow regime.

4 Longitudinal connectivity improvement

Longitudinal connectivity is one of the central tenets of river ecology and restoration (Vannote et al., 1980). It refers to the hierarchical upstream-downstream linkages that serve as pathways for the delivery and distribution of water, sediment, and biota throughout a river system. Disruptions to longitudinal connectivity via water abstractions, dams and weirs, road crossings, and other hydromorphological alterations impact the processes that are responsible for river habitat creation and maintenance and can also create barriers for the dispersal of freshwater organisms (REFORM Restoration WIKI 2010).

Determining whether or not improving longitudinal connectivity is necessary and which measures are appropriate depends on the environmental and socio-economic conditions within a river basin. The ecological and environmental benefits of longitudinal connectivity must often be weighed-out against competing interests for climate protection (e.g., hydropower as a source of renewable energy) and indirect effects such as water storage for flood control or irrigation (Kampa and Stein, 2012).

5 River bed depth and width variation improvement

Modifications to the in-channel habitat via alterations in riverbed width and depth are meant to increase habitat heterogeneity and provide a diverse range of hydrological conditions. In regulated rivers, channelization, channel straightening, dredging, bank stabilization, and other hydromorphological pressures disrupt the hydromorphological processes that shape and maintain a wide range of spatially- and temporally-variable in-stream habitats. To counteract these pressures, active restoration, including removing engineering works or un-doing river regulation can be done to re-create a variety of depth, flow, and substrate conditions that serve as mitigated habitat (REFORM Restoration WIKI, 2010). The desirable alternative to active restoration is to passively restore habitats by re-establishing the hydromorphological processes that shape and maintain them. However, process-based restoration requires more land and stakeholder cooperation than active-based habitat restoration, and often, the recovery timescales are much longer and therefore less favourable to meeting environmental policy and management goals (Hermoso et al., 2012).

6 In-channel structure and substrate improvement

Many river channels have been historically straightened to increase conveyance, improve navigability, to secure agricultural production near the banks and in flood plains, to promote faster drainage, and to allow for development. However, these large-scale alterations disconnected the rivers from their floodplains, leading to uniform channels with low substrate diversity, low current velocity variability and low depth variability (Kondolf, 1996; Pretty et al., 2003). Consequently, ecologically important habitats like large woody debris accumulations or backwaters nearly disappeared.

7 Riparian zone improvement

Intact riparian zones serve a variety of functions, including filtering surface water, trapping sediments, shading the river, providing inputs of detritus and woody debris, and serving as floodplain and terrestrial ecotone habitats with substantial exchange of nutrients and biota across river and terrestrial ecosystems (Kauffman et al., 1997; Naiman and Décamps, 1997; Clary, 1999; O'Grady et al., 2002; Baxter et al., 2005). Common riparian restorations include fencing to exclude livestock, removal of grazing, planting trees and vegetation, and thinning or removal of the understory (Roni et al., 2008). These measures seek to restore riparian vegetation and processes and to improve stream bank stability and instream habitat conditions. These measures can be limited by the amount of land available for restoration and by the cooperation of ranchers, farmers, or other riparian land owners and users. Unless the channel is deeply incised, riparian zone improvements can recover bank stability, channel geometry, and habitat complexity within a few years after project completion (Elmore and Beschta, 1987; Myers and Swanson, 1995).

8 Floodplains/off-channel/lateral connectivity habitats improvement

Lateral connectivity- the linkages between in-stream and off-channel habitats (e.g., oxbow lakes, side channels, and wetlands in the floodplain), increases habitat heterogeneity and species diversity by providing a dynamic gradient of habitats that are permanently or temporarily inundated (Roni et al., 2008). In addition, floodplain / off-channel habitat connectivity is important for nutrient subsidies in the form of inputs of terrestrial nutrients, detritus, sediment, and biota, as well as providing spawning and rearing habitat for river biota with specialized habitat demands (REFORM Restoration WIKI, 2010). Revitalizing natural river processes by the river "flood pulse" is an important part of restoration schemes of river corridors (Junk et al., 1989).

9 Other aims to improve hydrological or morphological conditions

Also other restoration measures have been developed to improve river hydromorphology. Due to the broad nature of this measure class, no description of these measures or their effects will be provided in this task, and this measure class will not receive further treatment in this deliverable.

Annex 3 – Ecological effects of restoration measures

Data on the ecological effects of specific river restoration measures were collected primarily from peer-reviewed journal articles published since 1980 but also from grey literature (e.g. non peer-reviewed technical reports, project evaluations, case studies, etc.). Studies included in the REFORM river restoration database provided an initial critical mass of literature, and further studies were located via the references cited therein. Appropriate literature used to assess the ecological effectiveness of restoration measures were field studies that investigated the impacts of river restoration measures on macrophytes, macroinvertebrates, and fish (Wolter et al., 2013). The physico-chemical, chemical, and hydromorphological effects of measures were not included in the literature review, but nevertheless, these are important effects of river restoration (e.g., nutrient retention, nutrient cycling, water quality, etc.) and should also be considered when assessing the benefits of restoration.

The measure classes presented below were under-respresented in the cost database.

Water flow quantity improvement

Overall, there is a lack of documentation on the effects of minimum flow on aquatic biota (Kampa and Stein, 2012), and there is a need for monitoring the effects of the implementation of net flow requirements on biological elements (Lamouroux et al., 2006; Souchon et al., 2008). Poff and Zimmerman (2010) reviewed the ecological responses to flow alteration and found strong and variable responses by biota. For example, macroinvertebrate abundance and diversity were found to both increase and decrease in response to elevated flows and to reduced flows (Poff and Zimmerman 2010). Minimum flows can protect biota by eliminating dewatering and reducing the magnitude of flow fluctuation (Weisberg et al., 1990). Establishing minimum flows or flushing flows can benefit fish recruitment by improving spawning habitat conditions (Kampa and Stein, 2012). Lamouroux et al. (2006) reported a significant change in the relative abundance of fish species preferring fast-flowing and /or deep macrohabitats following the implementation of minimum flows in the Rhône River, France. Macroinvertebrate distribution and community diversity are strongly influenced by flow velocity, which affects the rate of oxygen renewal and the exchange rate between the organism and its water supply, thereby influencing food acquisition and respiration (Wesche, 1985). Aquatic macrophyte assemblage structure is also shaped by flow velocity and water level fluctuations (e.g., disturbance frequency and intensity) (Bunn and Arthington 2002).

Flow dynamics improvement

Improving flow dynamics by e.g., restoration of flood flows or increasing minimum flows are relatively new techniques, and the limited information on the effectiveness of such measures has been very positive (Roni et al., 2005). Improving flow dynamics benefits aquatic and riparian habitat, as well as aquatic ecosystem production and biota (Weisberg and Burton, 1993; Petts and Maddock, 1996; Stanford et al., 1996; Annear et al., 2002; Arthington and Pusey, 2003). Also, activities to improve flow dynamics can result in changes in the natural colonization patterns of riparian vegetation (Ellis et al., 2001; Stevens et al., 2001). These riparian zone improvements and changed flow regime can benefit fish populations (Rood et al., 2003) by increasing fish abundance and species diversity (Hill and Platts, 1998; Speierl et al., 2002). However, flow regime alterations can also benefit the dominance of invasive fish species and lead to failure and loss of biodiversity of native species (Bunn and Arthington, 2002).

Riparian zone improvement

The ecological benefits of riparian zone improvement can be detected within a few years after project completion, and the extent of these benefits largely depends on the area and extensiveness of the improvements (Roni et al., 2005). In an investigation of replanted riparian buffers in New Zealand, riparian fencing and replanting led to improvements in water quality and channel stability, but there was no accompanying improvement detected in the macroinvertebrate community (Parkyn et al., 2003). Other studies have found that macroinvertebrate communities are sensitive to the shade, temperature changes, and detritus inputs provided by riparian zones and that the quality of functional riparian zones positively influences benthic invertebrate diversity (Quinn et al., 1992; Shilla and Shilla, 2012). The restored vegetation (terrestrial and aquatic) not only enhances community diversity, but can also provide habitat for semi-aquatic and terrestrial fauna (e.g., mink, beaver, turtles, etc.) (REFORM WIKI Case Study Aragon). Regeneration of riparian vegetation has been shown to increase fish species diversity (Penczak, 1995). By offering spawning, rearing, and feeding areas, rehabilitating seasonally flooded riparian forests can serve as an effective fisheries rehabilitation measure (Thuok, 1998). Due to their influences in nutrient regulation and shading, riparian restorations can also shift the community composition of benthic algae and plankton (Sabater et al., 1998).

Annex 4 – Available evidence on the costs of river restoration

Cost	**Cost description**	**Reference**
03. Flow dynamics improvement		
198,000 USD	Flow modification (project median cost)	Bernhardt et al. (2005)
04. Longitudinal connectivity improvement		
< 10,000 USD/ weir	Removal of small dams	CDFG (2004)
100,000 USD/ dam (up to 1 million USD)	Removal of larger dams (e.g. 15-20 feet in height)	CDFG (2004)
98,000 USD	Dam removal/retrofit (project median cost)	Bernhardt et al. (2005)
2,000-16,000 €/ weir	Weir removal in Cantabria (Spain)	García de Leániz (2008)
2,000-126,000 USD/ metre height	Weir removal in the United States (average cost (69,000 USD, or 23,000 USD/ metre height)	García de Leániz (2008)
10,000-30,000 AUD/ vertical metre	Rock ramp fishway installation (up to 2 m vertical)	Rutherfurd et al. (2000)
60,000-100,000 AUD/ vertical metre	Vertical slot fishway installation (3-6m vertical)	Rutherfurd et al. (2000)
10,000 USD/ vertical foot of dam height (plus 5,000 USD if height > 8 feet)	Steeppass fishway construction (for dams up to 12 feet in height)	CDFG (2004)
20,000-30,000 USD/ vertical foot of dam height	Denil fishway construction	CDFG (2004)
150,000 - 1.6 million USD/ dam (mean cost: 900,000 USD/ dam)	Improvement of fish passage at dams by installing ladders and pumps	CDFG (2004)
30,000 USD	Fish passage (project median cost)	Bernhardt et al. (2005)
05. River bed depth and width variation improvement		
6 USD/ cubic yard of material	Excavation/ fill of material for adding/moving a meander	King et al. (1994)
10-45 USD/ linear foot	Bank reshaping	Cramer et al. (2004)
20 - well over 1000 USD/ foot of channel	Channel modification (reconstruction and relocation projects including reconstructed banks and dewatering)	Saldi-Caromile et al. (2004)
120,000 USD	Channel reconfiguration (project median cost)	Bernhardt et al. (2005)

Cost	**Cost description**	**Reference**
06. In-channel structure and substrate improvement		
26,000-29,000 USD/ mile	Improvement of in-channel salmon habitat	CDFG (2004)
11 USD/ cubic yard	Gravel bedding	King et al. (1994)
18 USD/ cubic yard	Gravel placement	CDFG (2004)
50-70 USD/ m^3	Gravel placement	Cramer (2012)
5-20 USD/ m^2	Gravel cleaning (mechanical scarification)	Cramer (2012)
20-50 USD/ m^2	Gravel cleaning (hydraulic)	Cramer (2012)
583 USD	Placement of ten boulders	MDEWMA, 2000 (based on King et al., 1994)
100 USD/ cubic yard	Rock placement	CDFG (2004)
20,000 USD/ project	Placement of boulders/woody debris	Bernhardt et al. (2005)
100-160 USD/ cubic yard	Placement of rocks	Cramer (2012)
12.90-164.50 USD/ meter of channel length	Large woody debris placement	Cederholm et al. (1997), cited in Fischenich & Morrow (1999)
500-700 AUD/ large log	Large woody debris placement	Rutherfurd et al. (2000)
10,000-50,000 USD/ mile	Engineered log jams/ large woody debris placement (small project)	Evergreen (2003)
10,000-80,000 USD/ structure	Engineered log jams/ large woody debris placement (large project)	Evergreen (2003)
21,000-30,000 USD/ mile	Large woody debris placement	CDFG (2004)
1,000 - over 50,000 USD/ jam	Construction of logjam	Saldi-Caromile et al. (2004)
600-1,000 USD/ log	Placement of 40-foot-long fir logs (18-24 in diameter)	Cramer (2012)
352 USD/ shelter	Log and bank shelter	King et al. (1994)
406 USD/ wing vane	Installation of log vanes or log and/or stone deflectors	MDEWMA, 2000 (based on King et al., 1994)
395 USD/ log dam	Low profile log [& rock] drop structures	MDEWMA, 2000 (based on King et al., 1994)
1,212 USD/ structure	Low profile rock weirs or cross vanes	MDEWMA, 2000 (based on King et al., 1994)
75-100 USD/ linear foot	Porous weir construction	Saldi-Caromile et al. (2004)

Cost	**Cost description**	**Reference**
1,500-3,000 USD/ structure	Drop structure installation	Saldi-Caromile et al. (2004)
2,000 USD/ linear foot	Construction of step-pool/ weir below culvert	CDFG (2004)
<5-45 €/ m^3	Treatment and disposal of contaminated sediments; ranges provided depending on technology used	Netzband et al. (2002), cited in SedNet (2004)
07. Riparian zone improvement		
11 USD/ shrub	Riparian revegetation (shrubs)	King et al. (1994)
12 USD/ tree	Riparian revegetation (bare root trees)	King et al. (1994)
20 USD/ tree	Riparian revegetation (container trees)	King et al. (1994)
12,000 AUD/ km	Riparian revegetation	Rutherfurd et al. (2000)
3 AUD/ tree	Riparian revegetation (tree)	Rutherfurd et al. (2000)
5,000-135,000 USD/ acre	Riparian revegetation; more specific ranges provided depending on site accessibility, materials cost and level of site preparation needed	Evergreen (2003)
25,000-30,000 USD/ acre	Woody Plantings (at 3 feet spacing)	Cramer et al. (2004)
30,000-60,000 USD/ acre	Riparian revegetation	CDFG (2004)
0.15-3 USD/ square foot	Reestablishment of native riparian vegetation; approximate costs are provided for woody plant materials, labour time for various types of plant material, fencing per linear foot, organic erosion control fabrics, temporary irrigation systems and alternative water source development costs for livestock excluded from the stream	Cramer (2012)
1-4 USD/ stake	Live stake installation	MDEWMA, 2000 (based on King et al., 1994)
2,500 USD/ acre	Grasses seeding	King et al. (1994)
3,000 USD/ acre	Herbs seeding	King et al. (1994)
7-15 USD/ acre	Herbaceous Cover	Cramer et al. (2004)
0.25-0.50 USD/ square yard	Hydroseeding	Cramer (2012)
08. Floodplains/off-channel/lateral connectivity habitats improvement		
5,000-80,000 USD/ acre	Floodplain tributary reconnection; more specific ranges provided depending on the extent of earthmoving and the type of materials used	Evergreen (2003)
20,000-300,000 USD/ acre	Side channel reconnection; more specific ranges provided depending on the extent of earthmoving and the type of materials used	Evergreen (2003)

Cost	Cost description	Reference
1-3 USD/ cubic yard	Excavation and handling costs for levee modification and removal, excluding material disposal costs; hauling cost: additional 30-50 USD/ hour of rental of dump truck	Saldi-Caromile et al. (2004)
207,000 USD	Floodplain reconnection (project median cost)	Bernhardt et al. (2005)

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