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REstoring rivers FOR effective catchment Management

Deliverable	D5.1 Measuring river restoration success
Title	Measuring success of river restoration actions using end-points and benchmarking
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Summary

With an increasing emphasis on river restoration comes a need for new techniques and guidance. These are tools to assess stream and watershed condition, to identify factors degrading aquatic habitats, to select appropriate restoration actions, and to monitor and evaluate restoration actions at appropriate scales. Unfortunately, despite the rapid increase in river restoration projects, little is known about the effectiveness of these restoration efforts. Restoration outcomes are often not fully evaluated in terms of success or reasons for success or failure. This seems an anomaly if restoration measures are to be carried out in an efficient and cost effective manner. This report (REFORM Task 5.1) strives to meet this need by developing a protocol for benchmarking and setting specific and measurable targets for restoration and mitigation.

Specific objectives of the task were:

- Identify endpoints and benchmarks against which to measure performance - reviewed against reference conditions (from WP2), to determine appropriate targets for restoration activities.
- Use metadata analysis to quantify strategic endpoints (focussing on ecological indicators sensitive to the functional response of rivers) that are consistent with WFD objectives and can serve to evaluate the outcomes of restoration measures.
- Compare quantifiable indicators of end-points in project proposals against realised endpoints – SMART analysis.
- Establish a protocol to set realistic quantifiable endpoints for restoration projects that are socially acceptable, ecologically appropriate and economically feasible.

The task was broken down into three main components:

- Review of concepts to measure the success of river restoration
- Review of river restoration case studies to assess measures of success
- Development of river restoration planning protocol.

The review of concepts to measure the success of river restoration found that despite large economic investments in what has been called the "restoration economy", many practitioners do not follow a systematic approach for planning restoration projects. As a result, many restoration efforts fail or fall short of their objectives, if objectives have been explicitly formulated. This often appears not to be the case. Some of the most common problems or reasons for failure include:

- Not addressing the root cause of habitat degradation
- Upstream processes or downstream barriers to connectivity and habitat degradation that affect ecosystem functioning
- Not establishing reference condition benchmarks and success evaluation endpoints against which to measure success
- Failure to get adequate support from public and private organizations
- No or an inconsistent approach for sequencing or prioritizing projects
- Poor or improper project design

- Inappropriate use of common restoration techniques because of lack of pre-planning (one size fits all)
- Inadequate monitoring or appraisal of restoration projects to determine project effectiveness
- Improper evaluation of project outcomes (real cost benefit analysis)

The second component explored case studies where procedures for measuring restoration success had been developed. The review specifically identified best practice and procedures for measuring performance and determining appropriate targets for restoration activities. One of the first steps is to establish benchmark conditions against which to target restoration measures. This requires i) assessment of catchment status and identifying restoration needs before selecting appropriate restoration actions to address those needs, ii) identifying a prioritization strategy and prioritizing actions, iii) developing a monitoring and evaluation programme, and iv) participation and fully consultation of stakeholders. The third topic requires that objectives of the restoration programme are established against which the success can be measured. These targets or endpoints of any restoration project should be specific, measureable, attainable, relevant and timely.

To support this process, REFORM has developed a protocol in WP 5.1 for restoration project planning that incorporates benchmarking and setting specific and measurable targets for restoration and mitigation measures. The restoration planning approach developed uses project management techniques to solve problems and produce a strategy for the execution of appropriate projects to meet specific environmental and social objectives. It provides knowledge of the technical policy and background to conflicts of multiple users of resources and develops a plan for comparison of status with objectives. Such restoration planning should become an integral part of the river basin management, and full consultation with all user groups is essential to promote optimal, sustainable use of the water body whilst meeting WFD targets.

In using this strategy it is important to recognise that each restoration scheme proposal should be treated individually as no situation is alike i.e. not 'one size fits all'. It is therefore impossible to provide threshold criteria on which to make decisions. In addition, sufficient information should be provided to evaluate the overall risk of a scheme not having environmental, economic and social benefits that is commensurate with costs. The decision support tools allow the proposal to be evaluated at different levels and stages and will effectively curtail a proposal at an early stage should the proposal be potentially impractical or unviable.

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Definitions

Goals - statements of vision that define project intent.

Objectives - statements of specific and measurable outcomes.

Reference conditions - the ideal or pristine state, with conditions unaltered by human activities.

Control - identical to the treatment condition, with the exception being the treatment or rehabilitation action.

Benchmarks - a measurable target for restoring degraded sections of river within the same river or catchment.

Endpoints – a target level of restoration, whether this is an ecological (to restore a level of function/species), social (delivery of services to society) or physico-chemical (river morphology, water quality) endpoint, usually linked closely to project objectives.

Measures - The range of rehabilitation actions that mitigate the issues with hydromorphological and chemical degradation of the environment

Success - When objectives have been achieved to the standard required by the benchmark and its endpoints

Success criteria – ecological (to restore a level of function/species), social (ecosystem services) or physio-chemical (river morphology, water quality)

Programme of measures - integrated set of environmental, economic and social measures required under the Water Framework Directive to achieve environmental objectives for water bodies in River Basin Districts.

Drivers (Driving force) Social, demographic and economic developments in societies and the corresponding changes in lifestyles, overall levels of consumption and production patterns.

Pressures – anthropogenic actions (agriculture, urbanisation, industry, water supply, flood protection, navigation and transportation, fisheries and recreation) or climate change, which alters the state of the river and its floodplain in an undesired direction. Includes the release of substances (emissions), physical and biological agents, the use of resources and the use of land. Pressures are direct consequences of drivers transported and transformed into a variety of processes which provoke changes in environmental conditions (for example changes in flow or in the water chemistry of surface and groundwater bodies).

State Abiotic condition of soil, air and water, as well as the biotic condition (biodiversity) at ecosystem/habitat, species/community and genetic levels. Represents the external manifestation or expression of the river ecosystem in terms of how it appears and functions.

Impacts - Consequences for human and ecosystem health, resource availability and biodiversity from adverse environmental conditions. In practice, impacts reflect the negative environmental effects of pressures (e.g. fish killed, ecosystem modified).

Response – The actions (measures) taken to mitigate or reduce the impact of adverse human activities.

1. Introduction

1.1 Background

Anthropogenic pressures on European rivers are often driven by societal needs for agricultural and urban development, flood protection, water resource development, hydropower generation, water abstraction and transfer, waste disposal and recreational amenities, such as navigation. As a result, the majority of freshwater ecosystems in industrialised countries, and rivers in particular, are considered impacted or degraded from modification of river channels. These modifications have altered the transport of water and sediment, morphology and physical characteristics of the river including the availability of instream habitat (Schweizer, 2007), have disrupted migratory pathways (Poff, 1997; Lucas & Marmulla, 2000; FAO, 2008), and led to a general homogenisation of the channel (Giller, 2005; Schweizer, 2007). All of which contributes to the disruption of ecosystem functioning and loss of ecosystem services (Postel et al*.* 1996; Sala et al*.* 2000; Tilman et al. 2001).

As a consequence of the degradation of rivers and other inland waters, there have been considerable changes in environmental legislation and regulation across the world to address these problems (Boon & Raven, 2012). For example, there are a number of European Directives in place to support the ecological health of rivers such as the Water Framework Directive (WFD (2000/60/EC)) and the Habitats Directive (HD (92/43/EEC)) in addition to global initiatives such as Agenda 21 of the Rio Convention and the Convention of Biological Diversity. These have driven the management of inland waters towards rehabilitation of rivers and lakes to improve the aquatic environment for biodiversity and allow for sustainable exploitation of the resources (Eden & Tunstall, 2006; Pasternack, 2008; Hobbs et al. 2011). Consequently, nature conservation, and in particular river restoration (aka river rehabilitation – see definitions above), are increasingly considered as part of a much wider framework of environmental policy and practice (Arlinghaus et al. 2002). The costs of these restoration projects vary from a few Euros to many millions depending on the scale and intensity of the engineering works taking place.

With this increased emphasis on restoration has come the need for new techniques and guidance for assessing stream and watershed condition, identifying factors degrading aquatic habitats, selecting appropriate restoration actions, and monitoring and evaluating restoration actions at appropriate scales (Rumps et al. 2007). Several texts have been produced over the last few decades to assist with various aspects of river restoration. Most have focused on habitat improvement techniques specific to trout and salmon (e.g. Hunter, 1991; Mills, 1991; Hunt, 1993; Beechie & Bolton 1999; O'Grady, 2006) or design considerations for specific techniques (Iversen et al. 1993; Ward et al. 1994; Brookes & Shields 1996; Slaney & Zoldakis, 1997; Katz et al. 2007). A few have provided more comprehensive regional overviews of riverine and wetland restoration planning and techniques (e.g. UK - Ward et al. 1994 – The New Rivers and Wildlife Handbook; UK – RRC's 'Practical River Restoration Appraisal Guidance for Monitoring Options' (PRAGMO); Europe - Cowx & Welcomme, 1998; US – FISRWG, 1998; CIRF, 2006 - Italy), while others have been overviews of key concepts and principles (e.g. Brierley & Fryirs, 2008; Clewell & Aronson, 2008). Roni & Beechie's (2013) 'Stream & Watershed Restoration – A guide to restoring riverine processes and habitat' is the most up to date guidance on tools, techniques and concepts needed for restoration planning and draws heavily on experiences in North America and Europe. Collectively these publications cover many of the tools, techniques and concepts needed for restoration activities, but not the planning and integration of restoration process from initial assessment to monitoring of results. Restoration outcomes have rarely been evaluated and information about project motivations, actions and results are not necessarily available (Bernhardt et al. 2007). The 'benefit' or 'success' of restoration projects is poorly documented. One of the main reasons for this is probably the uncertainty of how to determine success at a local and catchment scale. Many past and recent papers have highlighted a lack of information on the success of restoration projects leading to this paucity in data (Tarzwell, 1937; Reeves et al. 1991; Roni et al. 2002; Bernhardt et al. 2005; FAO, 2008; Roni et al. 2008). This is in part because current scientific understanding of river restoration is generally poor (Vaughan et al. 2009). But also because of a weak understanding of ecological processes making implementation of the WFD problematic (Boon & Raven, 2012). Consequently, numerous river restoration projects tend to take an opportunistic approach through trial and error and it is considered bad practise to continue in this manner (Buijse et al. 2005). Thus, evaluating how successful the restoration measures have been, as well as determining reasons for success or failure, seems essential if restoration measures are to be carried out in an efficient and cost effective manner, which is a requirement under the European WFD. This will require detailed consideration of regulations and socio-economic constraints at local, regional and national levels. Indeed, the restoration of streams, rivers and watersheds has become a growth industry in Europe and North America in the 21st Century, with an estimated one billion dollars spent annually in the US alone (Bernhardt et al. 2005).

In terms of simple improvements in say the status of a fishery, improved catch or increasing species diversity, it is unlikely that these schemes are economically justifiable. This argument associated with Article 4.7 of the WFD is used to marginalise the amount of activity in this direction. In addition, there is considerable conflict between land drainage and flood prevention works and the environmental lobby, because of arguments about increased flood risk brought about by restoration activities.

In addition, and over-riding this debate on conflicting stakeholder need and aspirations, is the growing pressure on European Union countries to improve the status of rivers and lakes in the future to meet their obligations under the WFD, as well as needs to contribute towards protection of biodiversity under the HD. Currently, the expertise is weak to make such judgments' and plans towards the common WFD goal of GES or GEP because an integrated approach to the restoration of rivers, which takes place across the ecological, physical, sociological and economic domains, is limited and rarely accounts for social and economic dimensions (Collares-Pereira & Cowx, 2004). This is particularly important because it is likely to cause arguments that will circumvent measures to restoring rivers to their full potential and therefore not represent good value for money.

REFORM strives to meet this need for an integrated approach through WP 5 and WP 6 in particular by integrating the information from WPs 1-4 and linking catchment assessment and problem identification to identification of appropriate restoration measures, project selection, prioritization, project implementation, and effectiveness monitoring.

1.1.1 What is 'restoration'?

The increase demand for river restoration to support nature conservation (Waal et al. 1998) has expanded the field of ecological and environmental river restoration practice worldwide. River restoration recreates rivers that have suffered anthropogenic disturbances by re-introducing connectivity and habitat diversity to further support ecological diversity (Eden & Tunstall, 2006; Pasternack, 2008; Hobbs et al. 2011). Many pressures on rivers can be mitigated through careful restoration planning and management. At the same time, however, it has become clear that as our knowledge about river restoration increases, the more intricate the subject matter has become.

Restoration ecology brings considerable confusion over its terminology (Buijse et al. 2002; Omerod, 2004; Young et al. 2005; Roni & Beechie, 2013). Ecological restoration, including river restoration, means different things to different people. This is true for all groups of river stakeholders, including scientists, civil engineers, regulatory authorities, property owners, recreational users, and the general public. The only meaning that is held in common is the vague concept that restoration will result in "improvement". The temporal and spatial scales, aesthetics, ecological functionality, financial costs, and social value of restoration are all understood differently by each stakeholder group and often by members of the same group.

Because REFORM is a European Union project with a large variety of stakeholder groups spread across a highly diverse physical and cultural landscape, it is very important that a common definition of 'restoration' be used. Part of the problem is the imprecise use of language (Buijse et al. 2002; Omerod, 2004; Young et al. 2005; Roni & Beechie, 2013).

The terms "protection", "restoration", "rehabilitation", "improvement", "reclamation", "creation" and "mitigation" are some of the terms used interchangeably. For the purposes of this document, the definitions in Table 1 are used, except in direct quotes where the original language is used.

Language may dictate expectations, so precision in language may clarify expectations. The purpose of WP 5.1 is to describe how to measure the success of river restoration actions using end-points and benchmarks. Success can only be measured in terms of expectations (e.g. the presence of a sustainable fishery in a particular river). The end-points are the specific, realistic goals to be achieved to address the expectation (e.g. the presence of a population of a particular, cold-water fish species) and the benchmarks are those measures used to determine progress (e.g. the size of a particular age cohort). To measure success using end-points and benchmarks, expectations must be clear and, therefore, language must be precise.

Table 1. Commonly used restoration terminology and general definitions (taken from Roni & Beechie, 2013).

Term	Definition
Protection	Creating laws or other mechanisms to safeguard and protect areas of intact habitat from degradation.
Restoration	Returning an aquatic system or habit to its original, undisturbed state. This is sometimes called 'full restoration,' and can be further divided into passive (removal of human disturbance to allow recovery) and active restoration (active manipulations to restore process or conditions).
Rehabilitation	Restoring or improving some aspects or an ecosystem but not fully restoring all components. It is also called 'partial restoration' and may also be used as a general term for a variety of restoration and improvement activities.
Improvement	Improving the quality of a habitat through direct manipulation (e.g. placement of instream structures) or enhancing productivity (e.g, addition or nutrients). Sometimes referred to as habitat enhancement and sometimes also considered as 'partial restoration' or rehabilitation.
Reclamation	Returning an area to its previous habitat type but not necessarily fully restoring all functions (e.g. removal of fill to expose historic estuary, removal of a levee to allow river to periodically inundate a historic wetland). Sometimes referred to as compensation.
Creation	Constructing a new habitat or ecosystem where it did not previously exist (e.g. creating new estuarine habitat, or excavating an off-channel pond). This is often part of mitigation activities.
Mitigation	Taking action to alleviate or compensate for potentially adverse effects on aquatic habitat that have been modified or lost through human activity (e.g. creating of new habitats to replace those lost by a land development).

In the context of much of Europe with its long history of overlapping land uses, the possibility exists that physical process thresholds in catchment boundary conditions have been crossed and cannot be reversed (Findlay & Taylor, 2006) in the modern climatic and cultural period. In fact, both passive and active "restoration" activities may be considered as addressing only the most recent disturbance events, the results of which will be affected by all previous disturbances in ways that cannot be predicted and are unlikely to achieve a pre-disturbance state over predictable temporal and/or spatial scales (Bernhardt& Palmer, 2007).

In WP 5, the term "rehabilitation" will be used, with its meaning of improved ability to support higher functional levels of aquatic living resources (Roni & Beechie, 2013) as defined by the biological quality elements of the WFD. By so doing, the countless scientific debates on the expectations of river restoration to a pristine, pre-disturbance condition (Haslam, 1996; Schouten, 1996; Dobson & Cariss, 1999; Pretty et al. 2003) may be avoided. The use of the term "rehabilitation" includes programmes and projects that improve the "health" of an ecosystem using processes and structures that occur in nature (Rhoads et al. 1999). "Improvement", "reclamation", "creation", and "mitigation" are all specialized forms of rehabilitation. "Protection" is a management term.

Another important distinction between the terms "restoration" and "rehabilitation" is the expectation of future intervention, or operation and maintenance activities. "Restoration" implies that eventually the system will be self-sustaining. The realization that some level of operational and maintenance effort (e.g. energy, finances, materials, regulation and enforcement) will be required for the foreseeable future to maintain the end-points may lead to the determination that a project has not been successful. The term "rehabilitation" implies ongoing human intervention. Too many, the term "restoration" implies that some or all human activities will be precluded and restoration proposals are often rejected as a result. "Rehabilitation" does not imply this and proposals may be more easily accepted.

Many different activities may be included under the rubric hydrogeomorphological rehabilitation and all affect some element(s) of water and sediment flow regimes and their impacts on the ecological functions of rivers. They may be passive (stop streambed gravel mining) or active (introduce coarse sediment), hard engineering (rock diversion structures) or soft engineering (willow fascines on banks, sediment supply), instantaneous (dam removal) or incremental (upland reforestation), local (pool-riffle construction) or regional (restored seasonal flow regimes), and are often used in combination.

It is the tendency of river managers to want to "do" something visible and on-the-ground to address a perceived problem and, as a result, many of these activities have been implemented without sufficient pre-design study and with little or no post-implementation, success monitoring. River rehabilitation is a complex procedure, the results of which may often be unpredictable, and should be used within the context of sound science, engineering, and planning (Roni & Beechie, 2013).

River rehabilitation projects must focus on improving natural processes to ameliorate the ecological health and status of rivers (Rhoads et al. 1999). To do this, the pressure(s) on the fluvial system must be identified and rehabilitation efforts must be chosen that remove or mitigate against these pressures (Findlay & Taylor, 2000). A 'one size fits all' engineering approach to hydrogeomorphological rehabilitation is inadvisable. Spatial and temporal scales, climate, and geology must all be considered Transferability of restoration measures is not only difficult because the physical processes in each river system are different, but also because the end-points for each project may also different, adding a level of complexity to an already complex situation (Palmer et al. 2005).

1.1.2 Why is rehabilitation needed?

River rehabilitation practise endeavours to recreate and rehabilitate rivers that have suffered human impact by re-introducing habitat diversity (Eden & Tunstall, 2006; Pasternack, 2008; Hobbs et al. 2011). Reasons for rehabilitation vary widely among stream reaches, watersheds, regions and countries (Roni & Beechie, 2013). Common techniques for enhancing and creating habitat range from large scale, physical modification, for example channel narrowing, re-meandering and re-profiling to create features such as pool-riffle and backwaters (Cowx & Welcomme, 1998; RRC, 1999; Pretty et al. 2003; Wolter et al. 2013 [Reform D1.3]) to more small scale, instream habitat methods involving the placement of a variety of artificial and natural structures to recreate habitat diversity within a channel such as logs, wood, boulder and gravel (Roni et al. 2008). It is essential that river rehabilitation is acknowledged as a complex procedure that is often unpredictable and is therefore not applied as a simple reversal for degradation, thus must be used with caution. River rehabilitation programmes should focus on enabling natural processes to improve the health and status of rivers (Rhoads et al. 1999). Any future rehabilitation schemes must first aim to identify the pressure(s) on the system and then work towards relieving the river of this pressure to what is seen as an achievable goal (Findlay & Taylor, 2000). Understanding pressures at a catchment scale are important to advance from small-scale river rehabilitation actions to a large-scale catchment approaches (Jansson et al. 2007), although this does not always occur. There have been many cases where rivers are rehabilitated to look appealing, otherwise known as 'cosmetic rehabilitation' or 'gardening', with little or no intention of providing any environmental benefit. For instance, creation of meanders even if there is no historic proof that the river was previously of this form, as has occurred at Deep Run, Maryland (Smith & Prestegard, 2005). It is vital to not take the 'one size fits all' approach when considering restoring stretches of river, but this is not to mean that we cannot learn from each other planning and findings although it should be noted that river restoration is not easily transferable between different freshwater ecosystems (Eden & Tunstall, 2006). Perhaps examples from others can give a foundation of mitigation ideas and actions to overcome degraded freshwater ecosystems, but it is essential that the pressures are identified and that it is the processes within a river that are revitalised rather than creating structures that are perceived as good habitat (Beechie et al. 2010).

Any proposal for river rehabilitation should derive from sufficient understanding of the ecology, hydrology, morphology and pressures acting upon a system, and should be customised to the target river (Stanford, 1996; Lucas & Marmulla, 2000; FAO, 2008). Failed restoration attempts are often a consequence of poor geomorphological understanding (Moss, 1998). In addition, there is a need to understand ecological responses to changes in physical habitat as a result of anthropogenic pressures (Vaughan et al. 2009), because loss of structural complexity will have further implications on biota. For instance, fish utilise an extensive selection of habitats within a river system; many species show signs of distinct preferences (Pretty et al. 2003) for their daily and seasonal requirements, for each of their life stage (Cowx et al. 2004, Geist, 2010). Understanding the habitat requirements of fish species through knowledge of their life history traits is fundamentally important; spawning, feeding, nursery and refuge habitats are the main functional units required for specific life stages as part of the life cycle of the species (Figure 1) (Cowx & Welcomme, 1998; Bain & Stevenson, 1999). Not only is the availability of each of these functional units important, but the connectivity between them is vital for a fish species to complete their life cycle (Cowx & Welcomme, 1998).

River rehabilitation is needed to address channel degradation by introducing diversity back in to the river channel by improving habitat for aquatic biota. To understand what 'best practice' measures are needed for successful river rehabilitation requires knowledge of habitat suitability criteria for individual species (FAO, 2008). Habitat suitability criteria are based on the assumption that a species' preferred habitat is influenced by the most favourable conditions, and, as the favourable conditions decrease so will the species abundance (Petts, 2008). Life history studies and habitat preference from the literature can be used to produce habitat suitability criteria for individual invertebrate and fish species (Barbour et al. 1996; Cowx et al. 2004; Geist, 2010), but the viability of life history studies is directly related to the diversity and extent of natural habitats and related processes within a river basin (Cowx et al. 2004). Consequently, preference may be influenced by limitations in or absence of habitat.

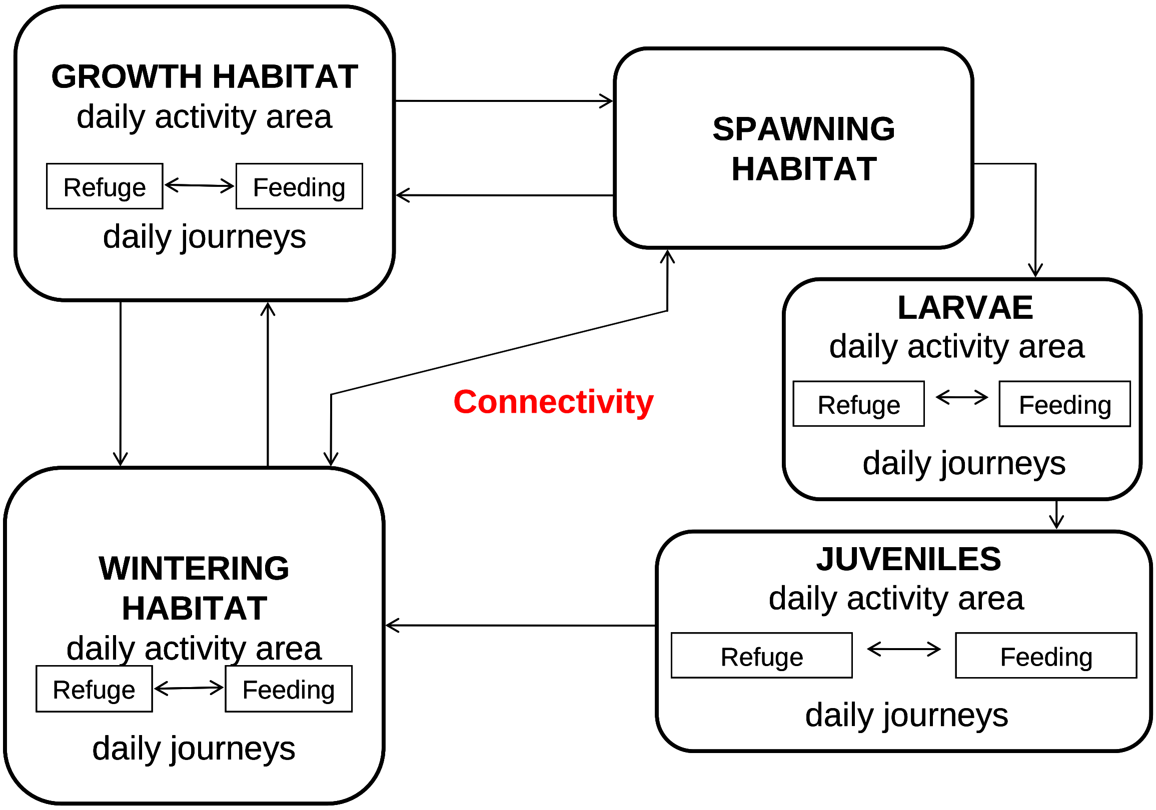

Figure 1. Functional units for fish (Cowx & Welcomme, 1998).

Some species can thrive under extreme conditions, including habitats that have been drastically degraded by anthropogenic causes and it must be recognised that many species may can survive under sub-optimal habitat conditions (Cowx et al. 2004). The relationship between fish community structure and the functional complexity of riverine habitat makes the use of functional ecological guilds (a group of species that exploit the same class of environmental resources in a similar way (Root, 1967)) more suitable than the use of single species habitat preferences. Thus, it is imperative that river rehabilitation projects aim to benefit species on a whole ecosystem level by improving all the functional units used by the fish population at various life stages, because the risk of managing species on an individual level could lead to population decline (Nehlsen et al. 1991; Lichatowich et al. 1995; Reeves et al. 1995; Frissell et al. 1997; Cowx & Welcomme, 1998; Beechie & Bolton, 1999; Palmer et al. 2005). For example, rebuilding anadromous fish populations (e.g. salmon, lamprey) requires habitat rehabilitation that covers the entire watershed because their life cycle includes headwater spawning reaches, mid river spawning and rearing habitats, and estuarine rearing habitat (Beechie et al. 2010). The use of benthic macroinvertebrates has been proposed for biological assessments of the habitat enhancement of reach-scale stream restoration (Brown, 2000), as they represent local conditions due to the restricted migration that characterizes many of these organisms (Potter et al. 2004), and play an important role in the food web of river systems (Covich et al. 1999). However, while it is recognized that benthic macroinvertebrates have distinct habitat preferences independent of water quality conditions (Barbour et al. 1996), the direct use of benthic macroinvertebrates for detecting habitat enhancement by stream restoration activities has been under debate (Tullos et al. 2006).

Overall, when planning river rehabilitation schemes, understanding the links between hydromorphology and ecology is of paramount importance owing to the provision of "physical habitat" for biota. Physical habitat emphasises the importance of understanding linkages between physical conditions and processes within the river channel and the habitat requirements of target fish and invertebrate species and has seen a recent growth in importance in river management (Newson, 2002). Rehabilitation can be identified as being successful when the ecosystem contains sufficient biotic and abiotic elements to be self sufficient, sustaining itself both structurally and functionally (SER, 2004).

1.1.3 **History of Stream and Watershed Restoration**

Stream and watershed restoration has increased rapidly in the last few decades, especially in North America, Europe and Australia (Roni & Beechie, 2013). European river rehabilitation/restoration efforts largely began in the 1980s and increased dramatically during the 1990s (Cowx & Welcomme, 1998) as legal mechanisms developed through increased environmental awareness, stronger environmental regulations and declines in species of fish and aquatic organisms that are of high socioeconomic and cultural value (Roni & Beechie, 2013). Attempts to mitigate pressures and impacts are increasingly popular as demands increase to improve problems arising from use and misuse of freshwater resources and habitats (Giller, 2005). Measures generally focused on rehabilitation of channelized, straightened and engineered channels and floodplains, with the exception of some early erosion reduction efforts to reduce declining production of agricultural lands in the 1970s (Roni & Beechie, 2013). Fortunately techniques used in river rehabilitation have advanced over time with the idea to restore natural features using physical instream methods such as channel narrowing, bank re-profiling and reinstating riverbed features to stabilize substrate or modify flow conditions (Cowx & Welcomme, 1998). The science of re-meandering of rivers and recovery of floodplains was largely pioneered in Europe and much of the literature on this topic comes from European case studies (e.g., Brookes, 1992; Iversen, 1993; Brookes, 1996; Palmer et al. 2005). Hydro-geomorphological restoration or enhancement can be undertaken 'passively' or 'actively' (Boon et al. 1992 *in* Malavoi, 2009). The increasing ambition of ecologists and geomorphologists have transformed our understanding of river restoration, permitting river management to progressed from the belief that engineering was the key component of river rehabilitation, towards a more multidisciplinary approach that considers the importance of hydrological, physical, biological and physio-chemical factors (Figure 1; Figure 2) (Hooke, 1999; Findlay & Taylor, 2006; Mainstone & Holmes, 2010)). It is essential that a hierarchical view is taken when identifying these four important ecological components for habitat integrity because their understanding can help alleviate impacts (Sear, 1994; Beechie & Bolton, 1999; Mainstone & Clarke, 2008; Beechie et al. 2010). The idea of 'passive' methods of river rehabilitation have been considered since the mid-1980s and are still integrated into current approaches to allow the natural hydrological processes of erosion and deposition to restructure rivers slowly, naturally reinstating channel heterogeneity (Brookes, 1985, 1992; Hey, 1992 *in* Pretty, 2003; Gillilan, 2005; Giller, 2005). However, 'active' methods are more dynamic and use specific measures to modify channel configuration and increase heterogeneity and variations in stream flow (Gillilan, 2005; Giller, 2005). Active methods of rehabilitation are often required as natural recovery from channel modification may be limited, particularly in reaches where stream power is insufficient to transport sediment and form instream features (Pretty, 2003). The importance of watershed processes has become more widely accepted (Chovanec et al. 2000; Hillman & Brierely, 2005; Beechie et al. 2010).

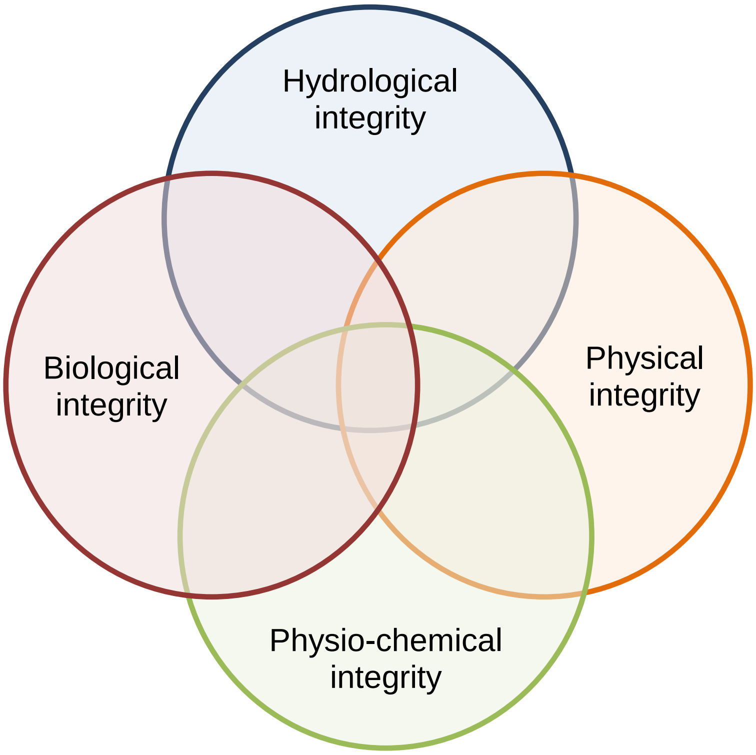

Figure 2. The four main ecological components that constitute river form and function (adapted from Mainstone & Holmes, 2010).

Over recent history a series of Directives and legislations, and changing social and environmental philosophies, have led to an increase in demand for river restoration across the European Union to mitigate negative impacts of physical modifications. The focus in the 1980s and 1990s was based on improving water quality, but promulgation of European directives that followed promoted the concept of structural integrity of water bodies and how this integrity affects the functioning of water bodies as a habitat (EEA, 2012). Consequently, the HD and the WFD were applied in water legislation to support the ecological health of rivers; the assessment of status and pressures was also a new field of development for Member States. Both Directives require maintenance, enhancement or restoration of habitats as a legal requirement, recognising that physical structure and ecological functioning is the key to habitat conservation (Clarke et al. 2003). The implementation of the WFD is considered to symbolise a significant shift in management concepts used on European rivers, placing greater weight on ecosystem functioning through amalgamation of biological and physical elements and processes requiring future management and restoration work to be centred around ecological and hydromorphological principles with recognition that hydromorphology is a key factor in defining habitat quality (Harvey & Clifford, 2008).

Since the 1990s, river restoration efforts have generally focused on small scale approaches but as knowledge has continually advanced, potential benefits of implementing river rehabilitation and conservation at a catchment-scale are being increasingly recognised as an essential component of future practise (Beechie & Bolton, 1999; Roni et al. 2002; Hillman & Brierely, 2005; Hodder et al. 2010; Roni & Beechie, 2013). After all, the river is one component of the whole catchment system and consideration should be given to processes occurring at scales further up the hierarchy (Moss, 1998; FAO, 2008) especially because potential impacts of any measure must be considered from a catchment perspective prior to implementation to prevent unfavourable impacts elsewhere in the system (Cowx, 1994). Freshwater river ecosystems are intrinsically linked and have a natural habitat continuum between river and landscape (May, 2006). As a consequence, it is difficult to conserve a small reach of river by simply using rehabilitation practice at a local level. The importance of scale in river conservation and management has grown over the past 20 years, advancing from Wards (1989) concept on the 'four dimensional nature of lotic ecosystems' (Boon & Raven, 2012), to more recent advances in integrated catchment management (ICM) to support the WFD. There are also various strategies that can be applied at different spatial scales and can be considered in river restoration (FAO, 2008):

- Basin approach: aims to rehabilitate the river basin as a whole or rehabilitate representative ecosystems within the basin and the connections between them.
- Ecosystem approach: aims to restore the processes that create and maintain habitat sustainably.
- Species approach: concentrates on one or more species with particular economic or social value.
- Scale: projects can be carried out at a number of scales depending on target biota or communities –habitat/reach/sector scale (FAO, 2008).

River rehabilitation programme goals often only address problems on single rivers at a small scale and therefore have limited impact on catchment-scale processes (Buijse et al. 2005; Eden & Tunstall, 2006). While ICM has started to be applied within Europe, single, small scale rehabilitation exercises are still employed most frequently with no association to catchment plans at a larger scale. Consequently, there is still a requirement to understanding pressures at a catchment scale to advance from small scale river rehabilitation to large scale, ICM.

Current river restoration tends to encounter obstacles as a result of societal demands, particularly through a select number of ecosystem services, such as provisioning and regulating services like flood protection, navigation and agriculture (Table 2. Some ecosystem services identified during studies in river basins (Van der Meulen & Brils, 2008; Vermaat et al. 2013)Table 2). Also, ecosystem services are also an intuitive way for people to relate to ecosystems such as cultural and supporting services (Table 2). Recent developments in flood protection have resulted in the EU Floods Directive (FD) and the national flood and water management legislation. These are directives and legislation that are potentially at conflict with the WFD, but are necessary to support river management from a socio-economic perspective. The UK Department for Environmental, Food and Rural Affairs (Defra) consultation document 'Making Space for Water' (Defra, 2004) emphasises the need for a more holistic approach to flood risk management (FRM) that delivers the greatest environmental, social and economic benefits (England et al. 2007). Both the FD and national legislation recognise the need to include elements of the WFD to support this holistic approach and include river rehabilitation within sustainable flood risk management and water resource management (Mainstone & Holmes, 2010). However, integrating river rehabilitation into FRM is still in its early stages and much more research is needed to identify best practises.

Table 2. Some ecosystem services identified during studies in river basins (Van der Meulen & Brils, 2008; Vermaat et al. 2013)

Provisioning	Regulating	Cultural	Supporting
Food & goods	Regulation of wastes [Bioremediation, dilution, carbon sequestering, Nutrient removal	Recreation and community activities, information and knowledge	Habitat
Biomass for renewable energy	Flow regulation [Flow of air, water or mass]	Aesthetic, heritage, religious and spiritual	Biodiversity Nutrient cycling
Water supply	Flood protection		Soil formation
Fish production	Groundwater recharge		Pollination
Fibre & fuel	Pollution control		
Hydroelectric power	Regulation of the biotic environment [Life cycle maintenance and habitat protection, pest and disease control, gene pool protection]		
Transportation			

The current issues surrounding river rehabilitation are the lack of knowledge to identify project success due to a scarcity of follow up monitoring and evaluation of biological and physical effects of river rehabilitation (Cowx, 1994; Gillilan, 2005; Wohl et al. 2005; FAO, 2008; Sawyer, 2009). Advances from decisions based largely on subjective judgements to those supported by scientific evidence are greatly needed as our understanding of the design and implementation of river rehabilitation schemes progresses. River rehabilitation projects should aim to reinstate natural fluvial dynamics within the system (Stanford, 1996; Lucas & Marmulla, 2000; FAO, 2008), but there is a lack of understanding of these fluvial processes by those formulating rehabilitation projects. As a consequence many river rehabilitation attempts provide ineffective and undesired outcomes (where an outcome has been defined and monitoring has been undertaken to determine such effects) and it has become apparent that there is paucity of rehabilitation projects that measure success in terms of hydrogeomorphological and biological outcomes. This is mainly attributable to a lack of understanding of how to measure success and because of this there is a requirement to define benchmarking and endpoints and to create a protocol to guide users to set realistic, quantifiable criteria for river rehabilitation. In addition, river rehabilitation programme goals often only address problems on single rivers at a small scale and therefore have limited impact on catchment-scale processes. Fortunately potential benefits of implementing river rehabilitation and conservation at a catchment-scale are being increasingly recognised as an essential component of future rehabilitation practise, especially through the WFD RBMPs.

For ecological restoration to be effective socio-economic factors need to be included as part of the decision process, in addition to environmental factors. The need for assessing river rehabilitation costs and benefits is widely appreciated (Kondolf, 1995; Kondolf & Micheli, 1995; Bash & Ryan, 2002; Downs & Kondolf, 2002; Palmer et al. 2005; Ruiz-Jaen & Mitchell Aide, 2005), but rarely applied. Overall the literature on restoration projects has highlighted that cost/benefit is overlooked in the majority of river restoration projects, or at least not well documented (Reviewed by Ayres et al. 2013). Costings that are documented are generally grouped as 'total' cost for the whole project and restoration measures are not individually recorded in most cases, although some examples of individual costings are available (see Ayres et al. 2013 [D1.4]). The 'benefit' or 'success' of restoration projects are also poorly documented and one of the main reasons for this again, can be narrowed down to a lack of project monitoring and evaluation. Therefore the combination of poor documentation of project costings and monitoring, insufficient knowledge in large data gaps regarding cost/benefit of river rehabilitation.

1.2 Objectives of this study

One key issue that needs to be addressed is moving from decisions based largely on subjective judgments to those supported by scientific evidence (Boon & Raven, 2012). Restoration outcomes have not really been evaluated and information about project motivations, actions and results are not necessarily available (Bernhardt et al. 2007). This is, in part, due to weaknesses in the design and implementation stages of project planning for rehabilitation schemes, and, despite the rapid increase in river restoration projects, little is known about the effectiveness of these efforts (Rumps et al. 2007). Setting benchmarks and end points that are linked to clearly defined project goals is considered the most appropriate approach to help measure of success (Buijse et al. 2005). The limited number of papers that address restoration success, benchmarking and endpoints are a consequence of poor project monitoring, evaluation and dissemination that should play a vital role in rehabilitation programmes to determine the effectiveness of rehabilitation actions to support the WFD (Roni, 2005; Wolter, 2010). Overall, evaluating how successful restoration measures have been, as well as determining reasons for success or failure seem essential if restoration measures are to be carried out in an efficient and cost effective manner, especially in the European context with respect to meeting obligations under the WFD. This will require detailed consideration of regulations and socio-economic constraints at local, regional and national levels. Consequently, the objective of this task is to establish procedures that provide validated, verifiable benchmarks and end points that appraise restoration outcomes to measure success.

Specifically the actions of the task are:

- To identify endpoints and benchmarks against which to measure performance. This needs be reviewed against reference conditions, to determine appropriate targets for restoration, rehabilitation and mitigation activities. In this context, the response lags in space and time will need to be incorporated into the effective measurement of success.
- Using information collected in WP1 and WP4, various LIFE and Interreg projects, case studies collected by the CIS – HYMO, and previous benchmarking practices (e.g. Austrian Danube, Kissimmee River – Florida, environmental flows), we will use metadata analysis techniques to quantify strategic endpoints (focussing on ecological indicators sensitive to the functional response of rivers) that are consistent with WFD objectives and can serve to evaluate the outcomes of restoration measures. This analysis will compare quantifiable indicators of end-points in project proposals against realised endpoints. Such bench-marking would consist of a comparative analysis of the SMARTness (i.e. specific, measurable, attainable, realistic and time-limited) of endpoint criteria (both qualitative and quantitative) for the restoration projects incorporated in WP4 and beyond, from the local to basin scale.
- Establish a protocol to set realistic quantifiable endpoints for restoration projects that are socially acceptable, ecologically appropriate and economically feasible.

As such, Task 5.1 is designed to cover one of the first steps in improving the design and evaluation of river and catchment restoration - that of establishing benchmark conditions against which to target restoration measures. This requires assessment of catchment status and to identify restoration needs before selecting appropriate restoration actions to address those needs, identify a prioritization strategy and prioritize actions (WP6), and develop a monitoring and evaluation programme. In addition to these steps, a basic understanding of the social dimension of watershed restoration is needed (Tasks 1.4, 5.2 and 5.4).

2. Concepts to measure the success of river restoration

2.1 *Key Steps for Planning and Implementing Rehabilitation Projects*

Many pressures on rivers can be mitigated through careful rehabilitation planning and management. Despite large economic investments in what has been called the "restoration economy" (Cunningham, 2002) and increasing literature on restoration planning, many watershed councils, river management agencies, and other restoration practitioners do not follow a systematic approach for planning restoration projects throughout a watershed or basin and therefore, fail or fall short of their objectives (Beechie et al. 2013) or simply do not evaluate success. This largely arises because a fundamental lack of understanding of the planning, design and implementation stage of rehabilitation schemes, especially as there are a number of easily accessible river rehabilitation manuals, previously mentioned, that provided detailed guidance in this area. Projects should typically proceed through three main phases associated with the project cycle (e.g. Skidmore et al. 2011):

- *Planning* : which establishes the purpose and need for restoration, puts the project in a watershed context, and articulates the specific intentions of a project;
- *Design*: which describes the details of the project and how it will be implemented and the project objectives accomplished;
- *Implementation & monitoring*: which includes the actions taken to complete the project, checking to see that the project was implemented as designed, and evaluating whether the project had the desired habitat and biological effects.

The complexity of these phases leads to a number of constraints that can lead to failure of a rehabilitation programme. For instance:

- where expectations have not been clearly defined with measurable objectives, project success is difficult to evaluate through monitoring (Bernhardt et al. 2007);
- skipping key design steps that link the analysis of root causes of habitat degradation to project design, thereby failing to fully consider the project context (Roni & Beechie 2013);
- inappropriate uses of common techniques (one size fits all) (Montgomery & Buffingtion, 1997);
- upstream processes or downstream barriers to connectivity;
- no or an inconsistent approach for sequencing or prioritizing projects (Roni et al. 2013);
- failure to get adequate support from public and private organizations;
- inadequate monitoring to determine project effectiveness (Downs & Kondolf 2002, Eden & Tunstall, 2006; FAO, 2008; Roni & Beechie 2013).

These constraints can be overcome by systematically following several, detailed logical steps that are critical for developing a successful restoration programme or project. A well designed adaptive management project planning framework for river rehabilitation will reduce the uncertainty of management actions (Roni et al. 2005) through the implementation of policies and application of a logical path that links rehabilitation goals, watershed assessment, identification of rehabilitation needs, selection and prioritisation actions, design of projects, and development of a monitoring programme (e.g. Beechie et al. 2013). A feedback loop within an adaptive management framework, typically expressed I the project cycle planning process, provides managers with the ability to account for uncertainty through evaluation of outcomes, and facilitate improved understanding of the efficacy of rehabilitation measures. This will enable all managers to adjust developments appropriate for the conditions and objectives (Bash & Ryan, 2002; Wohl et al. 2005).

The planning stage should identify the purpose and need for restoration through pre-monitoring where remedial action should focus on the underlying cause(s). More specifically pre-monitoring will evaluate watershed processes, current river health and ecological status to further: (1) identify how habitats have changed and altered biota; (2) identify the causes of habitat changes; (3) identify rehabilitation actions needed to address those causes; and (4) acknowledge social, economic and land use constraints (Beechie et al. 2008, 2009). This will enable suitable 'goals' and 'objectives' to be established for restoring the system to an acceptable state, ultimately leading to a self-sustaining river ecosystem (Cowx, 1994; Kondolf et al. 2006; England et al. 2007). Effective management requires the collaboration between disciplines (e.g. hydrologist, biologist, ecologist, geologist, economist, sociologist) and interaction with policy makers and the local, stakeholder community to distinguish between the social, economic and environmental requirements of the foreseen project (Letcher & Giupponi, 2005). Applying the ecosystem services concept in the analysis can help identifying stakeholders likely to be affected by decisions and therefore improve communication and engagement, allowing them to contribute to the decision process. Within the generic planning framework a problem also arises because the terms 'goals' and 'objectives' are often used interchangeably, although they represent different concepts. Skidmore et al. (2013) define 'goals' as statements of vision that define project intent, whereas 'objectives' are statements of specific and measurable outcomes (Roni & Beechie, 2013). Selecting objectives allows science to guide rehabilitation management and enables evaluation of the overall project effectiveness through application of objectives that test against outcomes. Establishing objectives that relate to the functional aspect of the ecosystem is central to the development and applicability of a suitable monitoring strategy (Dewberry, 1996) for successful river rehabilitation and should be one of the first steps within the framework. A useful framework for establishing objectives is the SMART (Specific, Measurable, Attainable, Relevant and Timely) approach (Doran, 1981) (Skidmore et al. 2013 *in* Roni & Beechie 2013). Objectives should work towards benefiting biotic communities whilst enhancing our understanding of how communities respond to changes in physical habitat over time, for example, taking into account the needs of individual fish species, size classes and guild structure, to recognise the 'missing' habitat and identify the habitat improvement measure needed. Once rehabilitation measures have been identified, they need to be assessed for risk and uncertainty to confirm they are environmentally, socially and economically acceptable, approaches such as WISE (wide, involvement, stakeholder, exchanges) are appropriate here. Rehabilitation measures need to be prioritised and although there has been recent huge investment in projects, there is no universally accepted approach for prioritizing rehabilitation actions and habitat protection (Johnson et al. 2003). Good planning of rehabilitation will enable prioritisation of ranking projects, habitat, or watersheds to determine their sequencing for funding and implementation (Roni et al. 2013); the restoration goal will also help determine the criteria to include in the prioritisation approach (Beechie et al. 2003; Roni et al. 2013 *in* Roni & Beechie, 2013). Once a project is implemented, post-monitoring is essential to evaluate river health and assess benefits. The framework should be transferable to individual rehabilitation projects by drawing on commonalities in objectives and techniques. An adaptive management framework allows each of the stages of project management to be easily visualised and highlights where monitoring fits in to the framework, selecting a suitable monitoring design, monitoring parameters with both spatial and temporal replication is essential for evaluation and knowledge transfer (Roni, 2005; Beechie & Roni, 2013). Following several logical steps can ensure that the approach is transparent, repeatable, and achieves its objectives. Rehabilitation goals initially defined during the assessment phase should be revisited to ensure that they include adequate detail on spatial and temporal scales to guide ranking of rehabilitation actions (Roni et al. 2013 *in* Roni & Beechie, 2013). In some instances river health and natural resource (ecological and biological elements) status may be satisfactory without any intervention through rehabilitation and therefore, objectives can be reset to sustainability. However, if the fishery performance and environmental quality of the river is unsatisfactory, the question of what is the cause of the degradation is needed to identifying the pressures responsible and their impacts. It may be possible to determine relationships between stressors and indicators of environmental degradation, but reaching a conclusion with an acceptable level of confidence is challenging in environmental research (Norris et al. 2012).

Overall, designing a channel that will function naturally to meet rehabilitation goals is a complex process, monitoring and evaluation are put in place to identify rehabilitation project success, but how do we assess what is successful? Despite the improved knowledge of ecological, economic and social aspects of river rehabilitation (Postel & Richter, 2003), there is still fundamental disagreement agreement on what represents a successful rehabilitation project (Jansson et al. 2005). Setting benchmarks and end points that are linked to clearly defined project goals is a valuable approach to help determine the measure of success within river rehabilitation (Roni & Beechie, 2013), especially when goals are clearly linked to objective success criteria to guide the process and the likelihood of achieving the end result (Bernhard et al. 2007).

2.2 *Benchmarking, endpoints and success*

Efforts to develop metrics of biological quality to support the WFD have been considerable (Hering et al. 2010), quality thresholds of ecological standards are rated by the response of ecological communities to human pressures along a five-point ecological status scale defined as 'high', 'good', 'moderate', 'poor' or 'bad' pressures but to a perceived reference of pristine, irrespective of the pressure (Irvine, 2012). However, this somewhat problematic as the judgment of restoration success can vary between stakeholders, particularly as different disciplines have different aspirations of project success (Howe & Milner-Gulland, 2012; Jones, 2012), and there is a need account for natural spatial and temporal variability in the response of ecological communities to environment change (Howarth, 2006; Hatton-Ellis, 2008; Moss, 2008). Projects labelled 'restoration' successes should not be assumed to be ecological successes; many projects such as protecting infrastructure and re-building parks that are considered economic and social successes are classed as restoration activities when no actual ecological aspects were considered in the planning,. For example, Sutcliffe Park, River Quaggy – Chinbrook Meadows and River Pool Linear Park Enhancement are all UK restoration case studies from a social perspective, to protect against flood mitigation and to be generally aesthetically pleasing to the public; they do not consider river processes or biota (RESTORE WIKI web site). Palmer et al. (2005) illustrated the most effective river restoration projects lay at the intersection of the three primary axes of success, 1) stakeholder success reflects human satisfaction with restoration outcome, 2) ecological success reflects meeting the desired status on ecosystem functioning and 3) learning success and management practices that will benefit future restoration action (Figure 3).

Figure 3. The most effective river restoration projects lie at the intersection of the three primary axes of success (from Palmer et al. 2005).

Furthermore, a review of 671 European case studies collated for REFORM WP1 Deliverable 1.3 (Wolter et al. 2013) only a small number of case studies that had reported ecological success or failure: many were either unclear in their findings, the restoration works were not monitored or no information was given in the reports (Figure 4). The reviewed identified that only 52% had been monitored and from this only 3%

recorded physio-chemical success, 8% recorded morphological success and 17% recorded biological success. This remarkably low adherence to what would seem good project management practice is possibly attributable the limited guidance for evaluating the success of restoration projects.

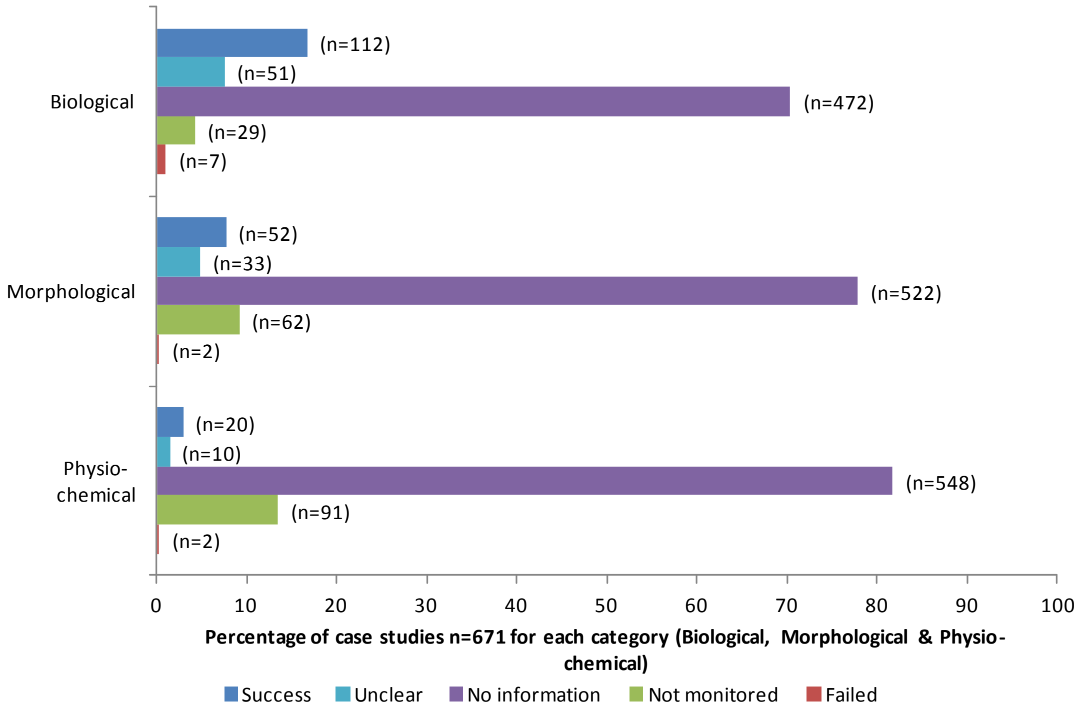

Figure 4. Success rate of 671 European case studies recorded from the REFORM WP1 database.

Designing a channel that will function naturally to meet rehabilitation goals is a complex process, and even where monitoring and evaluation are put in place to identify rehabilitation project success, it remains unclear how success is assessed? In this context it is important to consider how to determine success at local and catchment scales rather than individual projects. Setting benchmarks and end points that are linked to clearly defined project goals is considered the best approach to help determine the measure of success, especially when goals are linked to objective success criteria to guide the process and the likelihood of achieving the end result (Bernhard et al. 2007). Benchmarks and endpoints place a level of quality to rehabilitation that can be used as a standard when comparing other things against which to measure performance. They should be reviewed against reference conditions, to determine appropriate targets for restoration, rehabilitation and mitigation activities. However, river restoration, rehabilitation and mitigation require several areas of knowledge such as ecology, hydrology and engineering (Doyle et al. 1999) and goals relating to composition, structure, function and other ecological parameters, thus it is complex and considered difficult to define which measures should be used to quantify the success (Hobbs & Harris, 2001). The meaning of 'success' will change depending on the type of water body, type of project, the condition of the river health and the ecosystem services it supplies. For example, areas of HMWBs need only reach good ecological potential and therefore will have different endpoints and measures of success. It may be more achievable to reach a level of success when the goal is to restore a certain level of function/species rather than to attempt complete restoration (Lockwood & Pimm, 1999) and therefore realistic goals are essential for progress towards success (Hobbs & Harris, 2001; Hobbs, 2007). The concept of increasing habitat heterogeneity to increase biodiversity through rehabilitation has been a long-standing approach (Jungwirth et al. 1995; Kondolf & Micheli, 1995; Montgomery, 1997; Palmer et al. 1997; Kemp et al. 1999), but this is not always the smartest approach. Introducing the design of benchmarking and endpoints in to the planning stages will only strengthen rehabilitation practices as it steers away from ambiguous proposals, towards a more definite ideal of the required ecosystem in a specific segment of river. A literature review on restoration/rehabilitation identified 9504 publications that address benchmarking, endpoint or success, but critically the number of publications has double between 2002 and 2012 (Figure 5), suggesting the importance of this issue has been recognized and is starting to be addressed. However, only 663 publications mention benchmarking, endpoint or success in relation to project goals and objectives (Figure 5). It seems there are no definite criteria to define endpoints and benchmarks against which to measure performance and with no exact criteria, establishing appropriate targets for rehabilitation activities appears challenging. Although key words such as goals, success, benchmarking & endpoints were mentioned in literature, many of the papers only acknowledged the need for such criteria and do not actually address requirements.

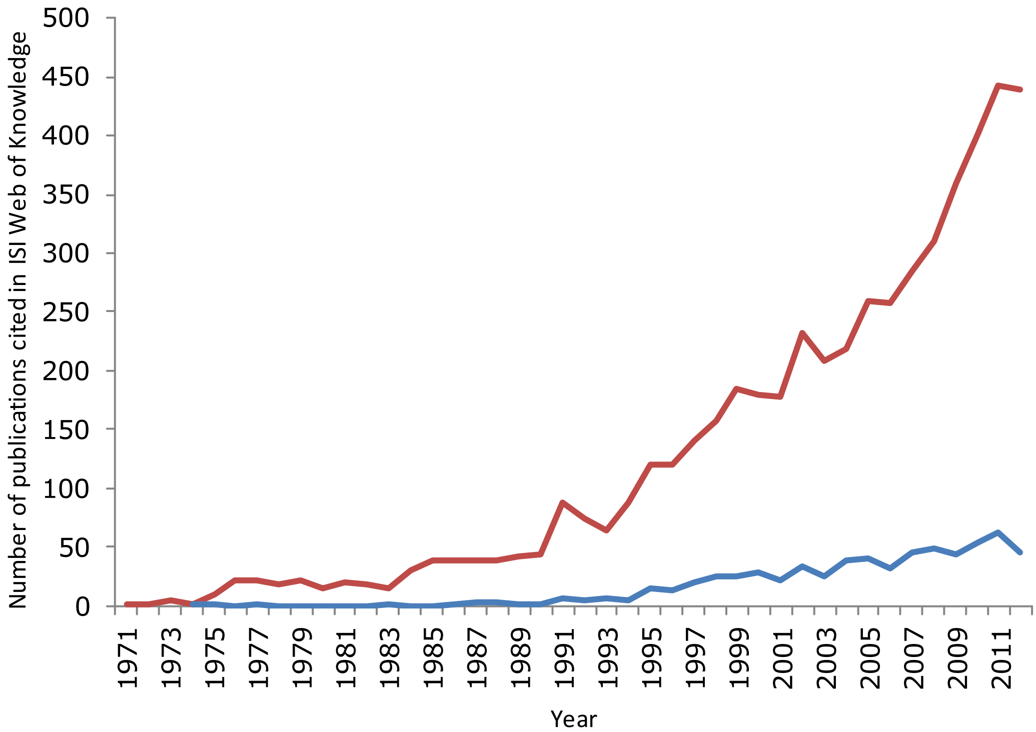

Figure 5. Number of scientific articles published annually between 1971-2013 containing the keywords — Topic=(river* OR floodplain OR stream OR riparian) AND Topic=(restor* OR rehab* OR mitig* OR conserv*) AND Topic=(endpoint* OR benchmark* OR success*) and — Topic=(river* OR floodplain OR stream OR riparian) AND Topic=(restor* OR rehab* OR mitig* OR conserv*) AND Topic=(goal* Or objective*) AND Topic=(success* OR benchmark* OR endpoint*) (Web of knowledge completed April 2013).

Benchmarking as a tool should be feasible, practical and measureable to help guide future decision support tools. Benchmarking uses representative sites otherwise known as 'reference sites' on a river that have the required ecological status and are relatively undisturbed; this is then used as a target for restoring other degraded sections of river within the same river or catchment. This approach therefore uses appropriate undisturbed sites of the same river type (Rheinhardt et al. 1999), rather than attempt to create conditions unrelated to the original ones at the site of interest and is consequently more likely to result in long-term success (Choi, 2004; Palmer et al. 2004; Suding et al. 2004; Woolsey et al. 2007). The use of reference reaches to help restoration objectives is common in North America (Wheaton et al. 2004), but less common in Europe and other parts of the world where un-impacted reference reaches are rare (Statzner et al. 2005; Comiti et al. 2009; Skidmore et al. 2013 *in* Roni & Beechie, 2013).

It is imperative that endpoints accompany benchmarking in the planning process to guarantee the prospect of measuring success because endpoints are feasible targets for river rehabilitation, especially as they do not need to be quantifiable. It is important to note that endpoints are different to benchmarks, this is because other demands on the river systems also have to be met and references can only function as a source of inspiration on which the development towards the endpoints is based (Buijse et al. 2005). Given that benchmark standards cannot always be achieved, especially on urban rivers, endpoints will therefore assist in moving restoration effort towards benchmark standards through application of the SMART approach to decide what is achievable and what is feasible. There is a need to distinguish endpoints for:

- individual measures;
- combination of measures;
- catchment water bodies;
- river basin districts.

It is important to recognize what is the minimum acceptable achievement level of restoration and what is the desirable level to have as a target end point that is still below the benchmark level, yet still aims for WFD status targets. Subsequently, what can be compromised for this desired level, will it be cost, ecosystem services or ecological aspects? Albeit, applying benchmarking to increase the accuracy and success of restoration appears in theory to be an uncomplicated method, in fact it increases the level of intricacy that rehabilitation needs to apply. This is because natural instream habitats consist of complex multidimensional arrays of morphological conditions (substrate, woody debris, hydraulic patterns) along with the complex life structures and habitat guilds of the biota (Statzner et al. 1988; Strange, 1999) and the environmental conditions (velocity, depth, temperature) and resources (food, space) on which they depend, all of which need to be incorporated in to river rehabilitation. As a result, river rehabilitation practise is prevented from moving forward as we revisit the reoccurring problem of how to revitalise such a complex systems and of course the only way to move forward is to identify project success of which benchmarking and end points will play a vital role in future watershed management. It will enable us to identify trends, successful techniques and compare actual performance with planned outcomes through the identification of tangible, attainable and scientifically sound endpoints to direct and focus efforts. The planning process (Table 3) and the definition of endpoints is necessary to develop prognostic tools that identify the geomorphological and ecological consequences of rehabilitation measures and their respective spatial and temporal scales, however challenging this may be (Buijse et al. 2005).

Table 3. Planning process to measure the success of river restoration

Process	Action
Review status of the water body and compliance with WFD GES & GEP	Identify pressures and constraints on system – local and catchment scale
Examine regional/national policy objectives and resource policy objectives – link to WFD, HD, Eel Directive, Renewable Energy Directive, Flood Directive	Identify local, national and regional policy objectives
Compare status with objectives to identify constraints	Deficit analysis
Identify issues and pressures that are constraining meeting policy objectives - Deficit analysis	Deficit analysis
Identify options for addressing issues	Identification and implementation of measures

When considering spatial and temporal scales of river systems, it is important to highlight that rivers are a continuous state, they are dynamic and forever changing, therefore it is important to make sure endpoints are understood and used in the correct manner. Part of the complexity of judging successful ecological restoration at a spatial scale is deciding when the process is 'complete' (Jansson et al. 2005). Hughes et al. (2008) have an alternative idea towards 'restoration' that differs from the need for endpoints, to the requirement of 'open-ended restoration' that would encourage natural processes dictate ecological outcomes rather than attempting to steer them to fit a pre-selected reference system. It is easy to appreciate that open-ended restoration would overcome the uncertainty of an ever changing ecosystem; however, it will not advance river rehabilitation from where it is to date. The open-ended concept is not suitable for river rehabilitation management because it will produce the same practical issues, such as how to frame the goals for the project, and how to monitor and evaluate change of which Hughes et al. (2011) later identified. Perhaps it is a good suggestion that the open-ended concept promotes the need to assess long term outcomes, especially as system shifts in environmental processes are to be expected, and this highlights the importance of long term monitoring. Monitoring against project aims and objectives is a key part of evaluating how successful rehabilitation has been, as well as identifying any problems with the techniques used. According to Bernhardt et al. (2007), the evaluation of project success must be based on an "analysis of a series of measurements appropriate to the success criteria made prior to and after project implementation". Therefore, monitoring and evaluation requires the collection, management and analysis of relevant information, of attributes of the physical and biological environment prior to and after the rehabilitation works (Avarello, 2011).

2.3 *WFD benchmarking and endpoints for the ecological status of rivers*

Water management in Europe is complex, owing to the diverse geophysical, climatic, socio-economic, and political views that exist across Member States. Adopting an integrated approach through the WFD and related water legislation can overcome this (EEA, 2012). The WFD endeavours to improve ecological functioning through rehabilitation and uses ecosystem health as the basis for decisions, defined by chemical, physical, biological and morphological factors and further characterises all water bodies according to five quality (from 1 – high status to 5 – bad status) classes. There are four Biological Quality Elements (BQE) involved in the monitoring of river health, fish, macroinvertebrates, macrophytes and phytoplankton (Schmutz et al. 2007). It is a legislative tool that aims to prevent deterioration by achieving good ecological status of rivers by 2027 and has the potential to increase the number of rehabilitation schemes undertaken across Europe (Logan & Furze, 2002; England et al. 2007), it is especially important because almost 60% of European water bodies are currently failing good ecological status (Haase et al. 2013). Importantly hydromorphology is recognized as a key element of habitat quality (Newson, 2002; Clarke et al. 2003) signifying a considerable change in river management, with emphasis placed on biological and physical associations and recognition that hydromorphology is a key factor in defining habitat quality (Harvey & Clifford, 2008). River Basin Management Plans (RBMPs) are a requirement of the WFD to reach good ecological status (GES) through the Programme of Measures (PoM) by 2027. In some cases, where a considerable amount of modification has occurred, the river channel is classified as heavily modified water bodies (HMWB) and means that a surface water body cannot reach GES and therefore has to aim for 'good ecological potential' (GEP), other water bodies such as canals are further classified as artificial also aim only for GEP. The RBMPs are to be updated every six years, and the second round of RBMPs are to be released in 2015.

Most Member States (23 of 27) have reported their RBMPs and delivered an data on status, pressures and measures to the Water Information System for Europe (WISE) WFD database. The EU Member States have via the RBMPs reported information from more than 13 000 groundwater bodies and 127 000 surface water bodies (82 % of them rivers, 15 % lakes, and 3 % coastal and transitional waters). In 2009, 42 % of all surface water bodies held good or high ecological status; in 2015, 52 % of water bodies are expected to reach good status (EEA, 2012). Although an improvement, it is still only a small improvement in ecological status and far from meeting WFD outcomes. The current status classification is now the baseline for future improvements towards WFD objectives measured (EEA, 2012). The application of hydromorphological measures across EU states indicates that improvements have been determined in nearly all RBMPs assessed (96% of RBDs) through the PoMs (EC, 2012a). '*Around two thirds of the RBMPs had measures to mitigate the negative impact of mitigation barriers. These include the removal of obstacles and the installation of fish passes. Some measures focused on re-naturalisation of aquatic habitats, such as improving physical habitats, including by the restoration of bank structures and riverbeds. Measures related to sediment management strategy were* *also relatively common. Natural water retention measures that restore natural water storage, for example by inundating flood plains and constructing retention basins, were mentioned in less than a fifth of the RBMPs. Measures to improve the water flow regime such as setting minimum flow requirements were found in around half of the RBMPs'* (Figure 6, EEA 2012).

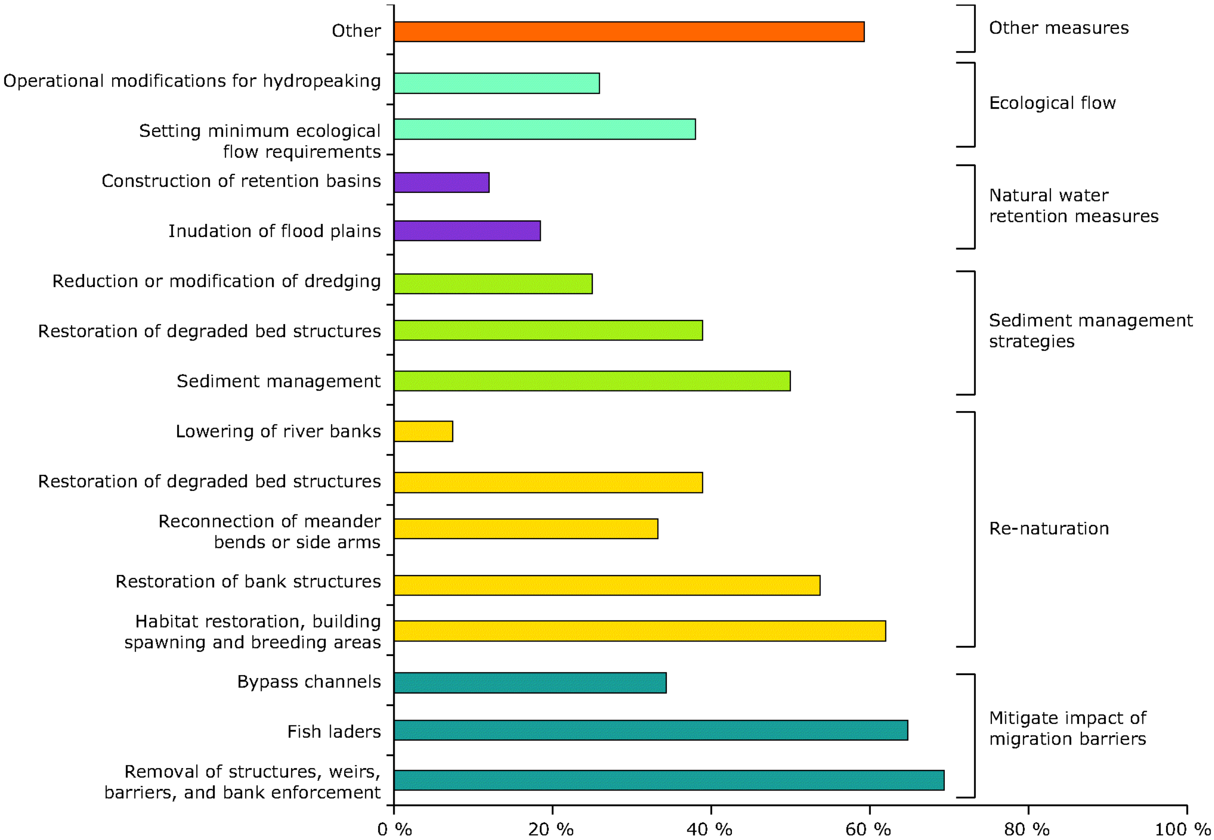

Figure 6. Occurrence of hydromorphology measures in RBMPs (% of RBMPs); the different hydromorphological measures have been divided into five groups (taken from EEA, 2012).

The difficulty with this assessment is that the improvements relate to the ecological status and do not necessarily relate to benchmarking and endpoint criteria of rehabilitation actions per se. There is thus a need to consider not only the procedures for defining benchmarking and endpoints for at the project level but also integrate the outcomes into WFD scenarios related to GES and GEP targets. Several examples of how this can be achieved were discussed in the ECOSTAT workshop on Hydromorphology of the WFD Common Implementation Strategy in Brussels (12-13 June 2012) and will be discussed later.

One other problem that needs to be overcome is ensure compliance with endpoints and benchmarking related to other EC Directives, particular Natura 2000 (Habitats and Birds Directives). It appears that the HD is merely setting endpoints that maintain the quality of Special Areas of Conservation (SACs) for habitats and species but not to expand those areas towards more natural rivers, thus benchmarking is not at relevant. Nevertheless ensuring healthy aquatic ecosystems while at the same time ensuring a balance between water and nature protection and the sustainable use of natural resources is critical. As many habitats and aquatic species are related to WFD water bodies or water types, the measures proposed under the Birds and Habitats Directives (BHDs) and the WFD may be partly the same. Therefore there is a need for coordination between the responsible authorities for nature conservation and water management; measures may offer joint benefits (EEA, 2012). At the moment, the two processes designating aquatic habitat types under Natura 2000 and the WFD water types run in parallel, and there appears not to be enough coordination between the two processes. Common WFD water types will together with the Natura 2000 aquatic habitat types provide a good basis for coordinated assessment of status, pressures and impact, and will result in co-benefits for both processes (EEA, 2012)

2.4 Programmes of measures

River Basin Management Plans (RBMPs) are a requirement of the WFD to reach sustainable catchment river restoration to meet WFD objectives through the Programme of Measures (PoM) and further supports catchment planning. RBMPs identify pressures and remedial actions at a river basin level and demonstrate what actions need to be taken to address pressures and how the actions will make a difference to the local environment. The RBMPs are to be updated every six years, the second round of RBMPs are to be released 2015. The WFD therefore aims to prevent further deterioration of our rivers and has the potential to increase the number of rehabilitation schemes undertaken across Europe, to achieve GES and to ensure it is maintained once achieved. In some cases, where a considerable amount of modification has occurred, the river channel is classified as HMWB and means that a surface water body cannot reach GES and therefore has to aim for GEP, other water bodies such as canals are further classified as artificial and also aim only for GEP.

2.4.1 **Catchment planning restoration**

The concept of returning a river to a pristine or pre-existing state by use of mitigation measures to overcome degradation is unrealistic and dated, especially due to the irreversible changes in catchment boundary conditions (e.g. impervious surface area, hydrology, vegetation cover (Findlay & Taylor, 2000)). Freshwater river ecosystems are intrinsically linked and have a natural habitat continuum between river and landscape (May, 2006). Broad-scale processes and interactions between adjoining ecosystems consist of a set of hierarchically nested physical, chemical and biological processes operating at widely varying space and timescales add further complexity (Hermoso et al. 2011). As a consequence, it is difficult to conserve a small reach of river by simply using rehabilitation actions at a local level; furthermore impacts in one place may be the result of events or management decisions elsewhere (Findlay & Taylor, 2000). Therefore, the question of ‘scale’, and its significance in the way rivers function, needs to be addressed and catchment scale approaches need to be employed. The importance of scale in river conservation and management has grown over the past 20 years, advancing from Ward’s (1989) ‘four dimensional nature of lotic ecosystems’ (Boon & Raven, 2012), right up to more recent advances in integrated catchment management (ICM) to support WFD. Unfortunately the majority of river rehabilitation project goals often only address problems on single rivers at a small scale and have limited impact on catchment-scale processes and can often be more destructive than constructive (Frissell & Nawa, 1992; Buijse et al. 2005; Eden & Tunstall, 2006). Fortunately potential benefits of implementing river rehabilitation and conservation at a catchment-scale are being increasingly recognized as an essential component of future restorative practices (Hodder et al. 2010), especially through legal frameworks such as the WFD. These aim to combine catchment scale understanding across a range of aquatic ecosystems to improve ecological status within specific river basins. Although the development of catchment scale management has started to be applied it is often constrained by inadequate funding sources and will therefore influence rehabilitation priorities leading to single, small scale actions being the most frequently employed, with no association to catchment plans at a larger scale. Small scale restoration is cheap, easy to apply and is quick to accomplish. As a consequence it becomes important to understand how to apply small scale rehabilitation to benefit at a larger scale and to integrate this approach at a catchment scale. Thus, project planning of a rehabilitation scheme should incorporate habitat unit (small scale) and reach (mid-scale), in addition to river basin (large scale) scales, when determining the scale of river degradation, selecting the type of rehabilitation action when monitoring the rivers biotic and abiotic response to rehabilitation work (Frissell & Ralph, 1998; Roni et al. 2003; Roni, 2005). Nevertheless, there are several good examples of rehabilitation projects (Steel et al. 2008; www.moriverrecovery.org; www.edenriverstrust.org.uk;www.chesapeakebay.net/restrtn.htm) that have been conducted at a catchment scale and emphasis must be drawn on the procedure of these good examples so we can learn from them for future benefit. Planning and implementing scales of river rehabilitation do not necessarily have to be the same, providing that the individual rehabilitation scheme is integrated at the whole catchment scale (Hermoso et al. 2011).

Overall there is a need for more large-scale catchment programmes where river basin wide assessment will enable prioritisation of rehabilitation sites (Buijse et al. 2005) and in some instances assessment will identify large pressures where rehabilitation at small scale, single reaches may not be an appropriate approach (Palmer et al. 2005). Catchment planning will require long term planning over a number of years adapted over time, that should be able to be accustomed to changes to ensure the best rehabilitation methods are being applied at all times.

2.5 *Individual measures*

2.5.1 Monitoring and evaluation

Monitoring is imperative to all river rehabilitation project planning frameworks as it facilitates the evaluation of overall project effectiveness by assessing results (outcomes) against objectives. It is a vital stage in adaptive management as it influences the decisions made to continue, modify or discontinue management actions (Bash & Ryan, 2002). Although the need for monitoring has been acknowledged in recent years (Roni & Beechie, 2013) the majority of river rehabilitation schemes fail to assess outcomes and effectiveness, however, there are an increasing number of scientific publications in the peer reviewed literature relating to effectiveness, evaluation, assessment and monitoring (Figure 1Figure 5). In 2000, 43% of all publications in Web of Knowledge (June 2013) referenced the terms effectiveness, evaluation, assessment or monitoring, subsequently only small progress has been made (2006 - 44%; 2012 - 50%). Similar findings were found in the USA where many projects are not monitored. For example, of 37,099 projects listed in the U.S. National River Restoration Science Synthesis database, 20% had no project goals identified, only 58% reported project costs, and just 10% indicated any measure of assessment or monitoring (Bernhardt *et al*. 2005). Further progress is needed in river rehabilitation science and management through the implementation of monitoring and evaluation (Wohl et al. 2005; Tompkins & Kondolf, 2007; Woolsey *et al*. 2007). The application of monitoring and evaluation should be promoted within river rehabilitation project planning as it will assist the EU Water Framework Directive's aim to ensure rivers reach good ecological status or potential by the year 2015.

Current scientific understanding of river rehabilitation is generally poor (Vaughan et al. 2009), many uncertainties still arise and there is still limited understanding of how river systems and catchments respond to rehabilitation (Szaro et al. 1998; Downs & Kondolf, 2002; Gillilan et al. 2005; Jansson et al. 2005). Although there are an increasing number of scientific publications in the peer reviewed literature relating to effectiveness, evaluation, assessment and monitoring, many past and recent papers have also highlighted a lack of information on the success of rehabilitation projects and consequently, there are many calls for further research through monitoring and evaluation to improve knowledge in this area (Tarzwell, 1937; Reeves et al. 1991; Brookes & Shields, 1996; Edgar et al. 2001; Ward et al. 2001; Downs & Kondolf, 2002; Roni et al. 2002; Bernhardt et al. 2005; Roni et al. 2008). While there is a steady increase of restoration projects each year, the absence of adequate monitoring and evaluation is most frequently a consequence of lack of resources than unwillingness and this constrains the ability to assess the effectiveness of rehabilitation techniques (Eden & Tunstall, 2006; FAO, 2008). Furthermore, the key problem to our paucity is poor project design and implementation consequential to the outcome of restoration being intangible and difficult to quantify. There is little knowledge or guidance on how to design and implement monitoring programmes for rehabilitation projects (Roni, 2005), even though monitoring and evaluation is a necessary process that should be included in all river project planning frameworks because it determines the effectiveness of rehabilitation actions, thus supporting the WFD (Wolter, 2010). Without such analysis it is difficult to assess to what extent the restoration is successful (Possingham, 2012). Presently, there are many single, small-scale efforts to measure rehabilitation impacts but these differ in their goals, are not integrated with one another and measure different factors, at different temporal and spatial scales, with different techniques (Roni et al. 2002). Further to this quandary is the potentially long timeframe needed to detect response, in addition to the inadequate funding to support monitoring, evaluation and reporting (Bruce-Burgess, 2001; Roni, 2005; Howe & Milner-Gulland, 2012).

The importance of monitoring and evaluation is clearly recognised and although awareness of the value of monitoring is growing, putting it in to practise is still challenging. The number of biological and multi-species metrics that can be used to measure and monitor aquatic ecosystem health has grown rapidly (Karr, 1981 & 1991; Welcomme et al. 2006) and although they are vital contributing factors to successful monitoring, singularly they can be insufficient in the assessment of river rehabilitation (Beechie et al. 2009). Selecting monitoring parameters should depend on the goals and objectives, definition of scale and selection of study design (FAO, 2008). Fish and invertebrates are the two most common biological parameters used to monitor and evaluate instream rehabilitation (Roni et al. 2005), use of these biotic monitoring techniques combined with physical habitat assessment can strengthen a rehabilitation scheme (England et al. 2007). A variety of monitoring techniques are available for detecting environmental impacts of rehabilitation project whose data collection methods differ spatially and temporally. These monitoring assessment techniques are Before/After (BA) contrasts at a single site, Before/After and Control/Impact (BACI) sampling sites and repeated BACI and post-treatment design (Ellis & Schneider, 1997). Monitoring using a BA design is intended to focus monitor at the impact/treated site before and after rehabilitation (Green, 1979), therefore it only measures the site of impact so it is generally replicated in time rather than space (Morrisey, 1993; Roni, 2005). A BACI design consists of sampling before and after at the impacted site and also at a control site. This was first proposed by Green (1979) and further developed by Stewart-Oaten et al. (1986). The addition of a control(s) is intended to account for environmental variability and temporal trends found in both the control and treatment areas and therefore increase the ability to differentiate treatment effects from natural (Smith et al. 1993; Roni et al. 2005a). An impact is therefore determined as an effect over and above that which can be attributed to temporal and spatial influences (Sedgwick, 2006). Post-treatment designs have frequently been used for monitoring of many river rehabilitation projects where the collection of pre-data has not been an option. Insufficient or no prior data from the impacted site may limit the scope of the design and reduce the efficiency of the analysis. In general, post-treatment designs tend to apply spatial replication more than temporal replication and therefore, data from the impacted site can be compared with a control/reference site, enabling a BACI design to still be generated but with a more limited capacity to detect temporal variation (Sedgwick, 2006).

The REFORM WP1 database identified 878 EU and non-EU ‘restoration’ case studies of which only 62% carried out some form of monitoring. Of the projects that were monitored a number applied BA, CI, BACI & post-treatment designs for morphological, physio-chemical and biological assessment, but biological project assessment was applied most frequently (Figure 7). Although it is advised to use these monitoring assessments to measure project success, it is still vital that the outcomes from these monitoring designs are still used with caution and in combination with project goals and professional expertise (Conquest, 2000). Restrictions in design criteria can also cause complications in monitoring assessment that could prevent the outcome of meaningful evidence to identify the basis of the impact (Sedgwick, 2006). An example of this can also be taken from the REFORM WP1 database; all biologically assessed projects that were only monitored after restorative actions were recorded as successful. However, persons with knowledge of river monitoring will recognise that it is difficult to identify project success or failure when there is no pre-monitoring or control sites to compare with post-restoration conditions (Figure 9). It is therefore likely that these projects have been categorised as successful because of poor monitoring design and/or a lack of expert judgment, and procedures to determine how many years, locations or samples are required to isolate the impact from natural variability that can occur at a temporal or spatial scale are required (Green, 1989; Fairweather, 1991; Faith et al. 1991; Osenberg et al. 1992; Cooper & Barmuta, 1993; Osenberg et al. 1994; Zar, 1999; Roni, 2005).

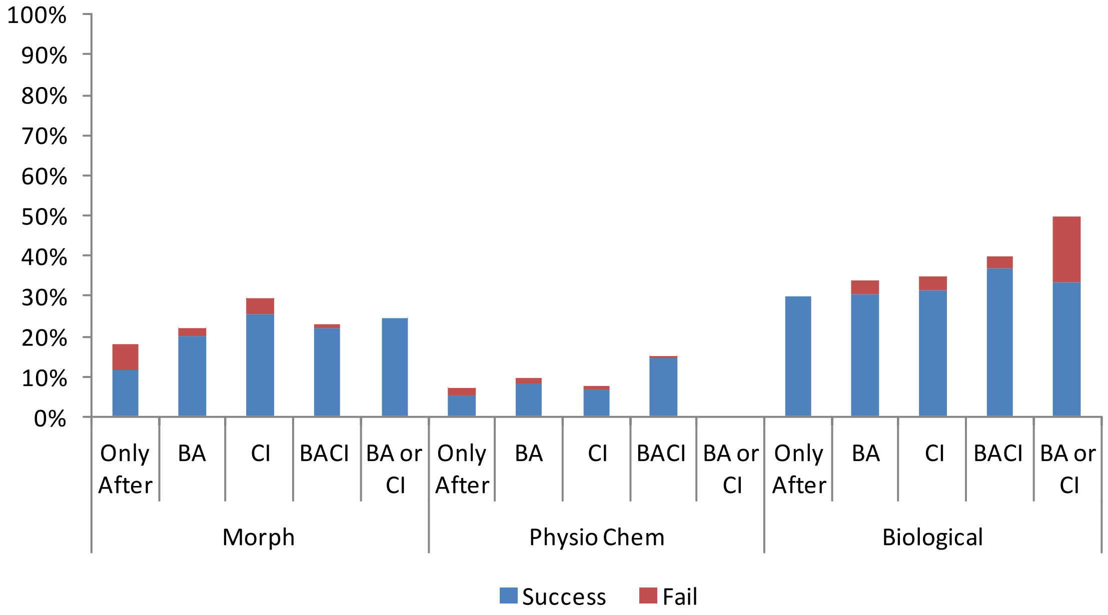

Figure 7. Monitoring methods and project success for 878 EU and non-EU restoration case studies.

Rehabilitation projects use a variety of techniques on a variety of different rivers making comparison of different approaches and strategies difficult (Roni et al. 2008). Nevertheless, it is essential that each rehabilitation project is monitored to ensure it has reached its aims and objectives to restore and create habitat for specific species, to ensure rehabilitation processes actually do benefit fish populations and to ensure that good status is maintained once achieved (Kershner, 1997; England et al. 2007). There is the necessity to produce meaningful results to inform on future projects and encourage decision makers to include these stages into their project planning framework. Palmer & Allan (2006) suggested new regulations need to be put in place to make project monitoring and evaluation (including data sharing) a funded mandate rather than an optional expense. It seems it will be the only way to increase our scientific understanding of river restoration practise, to appreciate how river process and aquatic biota respond to restoration and to progress from this current state of uncertainty. However, it is a challenging prospect for all projects to include detailed monitoring, thus to encourage future development in this area it is recommended that a select number of projects are considered for long term monitoring (both pre and post) and preferably those at a catchment scale as this is the direction future rehabilitation activities should be heading. This approach is also supported by Buijse et al. (2005) and Palmer & Allan (2006). Conversely, Bernhardt et al. (2007) establish that only one of more than 300 interviewees mentioned that a scientific paper significantly informed the design and implementation of a project. It is also apparent that scientific research is unlikely to make its way quickly into ‘restoration’ practice (Shields et al. 2003). This demonstrates the importance of continued monitoring and evaluation for all projects, even if at a smaller level of detail, after all ‘one size does not fit all’ and only gaining information on a few studies may not be transferable to all studies. It is therefore essential that a sufficient amount of information is gathered from all projects and disseminated not only through scientific literature but through reports, websites (e.g. REFORM [http://wiki.reformrivers.eu/index.php/Main_Page] and RESTORE [http://www.restorerivers.eu/] WIKIs) and stakeholder workshops. Furthermore, monitoring and analysis should not be too complicated; it needs to be practical and easily applied to common management practises. If individual rehabilitation projects prove effective at reaching their ecological goals, the probability of additional funding for monitoring will be higher (Bernhardt et al. 2007).

There are a number of challenges and uncertainties to account for when attempting to understand the intricacies of how ecosystem networks respond to river rehabilitation. Monitoring and evaluation of rehabilitation schemes is a necessary process that should be included in all project planning frameworks because it determines the effectiveness of actions, and thus supports WFD requirements (Wolter, 2010). Challenges and uncertainties can be overcome by increasing the efficiency of monitoring and evaluation through an adaptive management framework. Effective monitoring should follow a strategic listing of questions, such as what when and how should we monitor to identify the appropriate procedure/protocol for each individual rehabilitation projects. Appling SMART objectives can define measurable parameters with target values enabling a monitoring protocol to evaluate project success (Skidmore et al. 2013 *in* Roni & Beechie, 2013). Without well-designed monitoring and evaluation, adaptive management of rehabilitation ecology is implausible (Downs et al. 2002).

The timeframe over which monitoring programmes are implemented should capture the natural range of behaviour of the river to show the timeframe over which geomorphological adjustments occur (Brierley et al. 2010). However, it is difficult to foresee the recovery time-scale for any rehabilitation project, especially those based around geomorphological modifications. When physical structures are installed in river channels to improve fish habitat, the adjustment process that occurs over time can sometimes be more harmful than good (Rosgen, 1994). Ecological recovery time from this type of habitat modification depends on hydromorphological characteristics of the river (Brookes, 1996; Sear et al. 1998) and how this further affects ecological processes within the river; for this reason long-term monitoring is needed to enhance understanding (England et al. 2007). Few ecosystems have been studied comprehensively in terms of their abiotic parameters, species composition, community structure, functional attributes and responses to natural disturbance (Clewell & Rigour, 1997). Recognising when monitoring should take place is vital to increase the accuracy and understanding of the success level of each rehabilitation project. Both pre and post monitoring is essential within a river rehabilitation project planning framework. Pre-monitoring includes the collection of baseline data to assess the status of river health and fisheries health, and assist in the identification of river rehabilitation objectives (Kondolf & Downs, 1996). Baseline data (or pre-monitoring data) can be used within river rehabilitation assessment to compare the status of habitat and fisheries of the river between pre and post monitoring of the rehabilitation works. Evaluating multiple control sites across a spatial scale will allow the level of success of rehabilitation projects to be measured by taking in to account patch dynamics (Clegwell & Rigour, 1997) to give a comprehensive review of the biota local to that river. Post-monitoring is an essential phase that is needed to assess the success of rehabilitation works, and long-term, post-monitoring will provide a more valuable data source for evaluation purposes; however, it is not always easy to know the length of monitoring needed but it should cover at least 2 generations of the longest living species (Kondolf & Micheli, 1995).

The scale of monitoring should be decided in association with the target species or communities present determining their scale of response to physical change requires distinguishing between habitat, reach, or sector and network scale effects, and for fish in particular, their different life stages will need to be considered (FAO, 2008). Regular, long-term monitoring will account for natural variability in species population dynamics as illustrated by Figure 8. The dots represent the occurrence of regular sampling of the metric in question, whilst the red line shows the variability between each measured metric over time. If sampling were to be sporadic, for example, to only sample the times demonstrated by the red dots (show a decline in the measured metric) or the green dots (show an increase in the measured metric), thus a contradictory perspective would be gained. So, if fish were to be the metric collected over time, sampling that occurred only at the time represented by the red dots would show a decrease in fish numbers over time, however, sampling that occurred only at the time represented by the green dots would show an increase in fish numbers. If sampling was to occur more regularly, for example, at the time of both green and red dots, a more accurate observation could be made and in the case of Figure 8, the metric measured would be considered stable. Overall, Figure 8 is an exaggerated example to demonstrate that infrequent monitoring can give false results, but can be overcome with frequent monitoring that will capture the variability within the data and will give a more accurate portrayal. A number of unmanageable factors (e.g. weather, predation, disease) are known to affect populations even when the habitat can support a larger population (Block et al. 2001). These factors can influence natural fluctuations within populations that only frequent monitoring can

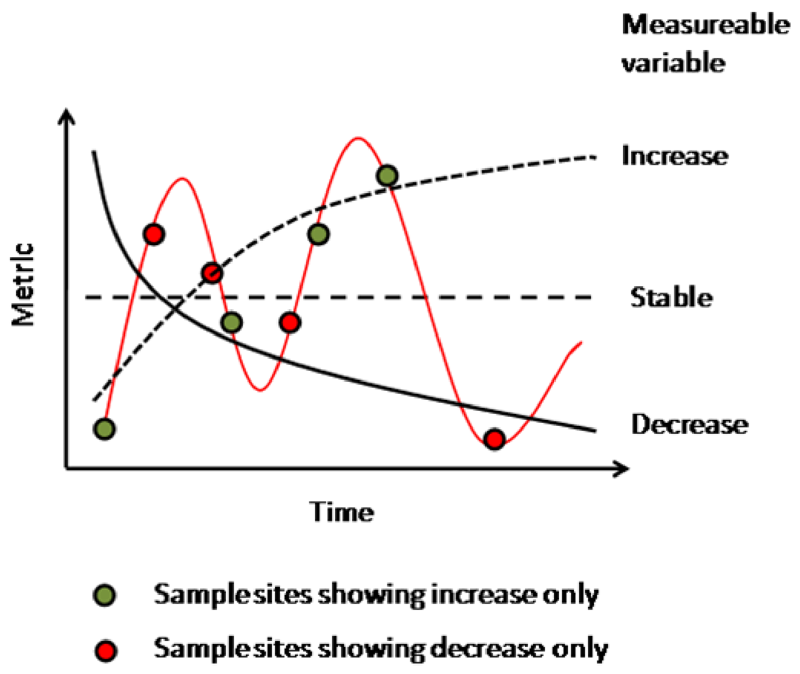

Figure 8. Conceptual graph demonstrating the importance of long term, regular monitoring.

identify. Therefore, the timeframe and frequency over which monitoring is completed is fundamental when it comes to overcoming the complex interactions within an ecosystem and understanding the lag time associated with rehabilitation activities (Beechie et al. 2000, 2005, 2009). Long-term monitoring of rehabilitation works is essential to ensure that the population has time to adjust to time-dependent changes (Block et al. 2001) so accurate evaluation of the rehabilitation scheme can be made, although short-term monitoring will not necessarily capture these time-dependant changes it is still necessary.

Both spatial and temporal monitoring is required when monitoring rehabilitation schemes. Ecosystems exhibit natural fluctuations from patch dynamics that differs between sites (Clewell & Rigour, 1997) and hence, a single control site does not necessarily represent the habitat across the whole river, and therefore, cannot accurately assess the efficiency of a rehabilitation scheme. Successful monitoring requires multiple control sites and frequent sampling of variables to overcome patch dynamics and to identify trends, thus improving understanding of the natural variability that occurs within a river ecosystem. Control sites provide a basis of comparison between the rehabilitated area and the conditions before rehabilitation, accounting for natural variability and helping to differentiate between any ecological changes associated with seasonality or temporal population dynamics, and are essential for river rehabilitation monitoring (White & Walker, 1997; Roni, 2005; England et al. 2007). Nevertheless, on the whole most rehabilitation projects do not include these fundamental requirements in their experimental design (Minns et al. 1996). The National Research Council (NRC, 1992) stated that '*one of the most effective ways to establish rehabilitation goals is to evaluate the success of stream rehabilitation by comparing biological communities in a disturbed reach to communities in a set of relatively undisturbed reference streams of the same order in the same eco-region*.' Reference/benchmark and control sections should be selected with caution to ensure the geology (including gradient), hydrology, biology and scale of habitat modification are comparable with the rehabilitated reach (Roni, 2005; Wyzga et al. 2009). Pairing a control or reference site to an impacted site within the same reach will significantly account for variability, albeit worth noting these paired sites will not be totally independent of each other because there may be upstream-downstream effects and fish movements (Roni et al. 2005). Within a stream, control reaches generally should be located upstream from treatment reaches (Roni et al. 2005), but there are always limitations when using control or references sites to assess the success of river rehabilitation as sites may not be accessible or may not be present (Clewell & Rieger, 1997). In extreme cases a similar near-by river could provide a more comparable reach but the risk of including the effect of other variables is increased (Sedgwick, 2006).

3. Review of river restoration case studies to assess measures of success

3.1 Introduction

River restoration projects are becoming increasingly popular and have been playing an important role in bringing an ecological component to a range of water management activities. Nevertheless, despite rapid increases in river restoration funding and projects throughout Europe, little is known about the effectiveness of this effort (Rumps et al. 2007; Avarello, 2011). Using information from various LIFE and Interreg projects and a number of 'good' case studies (e.g. Rhone, Kissimmee River – Florida), has enabled a metadata analysis of benchmarking techniques and strategic endpoints (focusing on ecological indicators sensitive to the functional response of rivers) that are consistent with WFD objectives that can serve to evaluate the outcomes of restoration measures. This analysis will discuss quantifiable indicators of end-points in project proposals against realised endpoints. Such bench-marking would consist of a comparative analysis of the SMARTness (i.e. specific, measurable, attainable, realistic and time-limited) of endpoint criteria (both qualitative and quantitative) for assessing restoration projects from the local to basin scale. This will assist in establishing a protocol (Section 4) to set realistic quantifiable endpoints for restoration projects that are socially acceptable, ecologically appropriate and economically feasible.

3.2 Case studies

The assessment of 'good' examples to advance river and watershed restoration guidelines necessary to improve river restoration success is an ideal with many restrictions. Most restoration projects neglect the key steps of the design and implementation stages, many also overlook monitoring and evaluation which further obstructs the ability to identify project success, especially if sufficient goals have not been set. It is therefore difficult to find a large number of suitable examples, as an alternative a few select projects, deemed successful, are presented for best-practise protocols and features distinct from other projects.

3.2.1 LIFE and INTERREG projects

LIFE & INTERREG are European funding programmes aimed at assisting the implementation of EU Directives. LIFE Nature and LIFE Environment are both the main strands of the European Union's funding programme to preserve the environment (European Commission Environment – LIFE Programme, 2011). They were established to support the implementation of EU water policy. LIFE Environment focuses more on issues such as river habitats and species conservation, river basin management while LIFE Nature supports especially projects that contribute to the implementation of the EU Birds and Habitats Directives through the development of the NATURA 2000 network. Assuming that national and regional borders should not be a barrier to the balanced development and integration, the European Union has initiated the INTERREG programme to stimulate cooperation between regions within the EU (Interact, 2011). The programme, funded under the European Regional Development Fund (ERDF) is made up of three strands: INTERREG A focusing on cross-border cooperation, INTERREG B intending on the development of transnational cooperation and INTERREG C foreseeing interregional cooperation. Therefore, the INTERREG network consists of several sub INTERREG programmes that finance independently projects undertaken in their area. With regards to the European Union water policy, INTERREG aims to assist project managers, authorities in implementing the WFD, the flood directive or also by promoting species or habitat action plans that set management priorities for NATURA 2000 areas across Europe.

The European Union has developed an online database compiling all the implemented LIFE projects, but there is no single database for INTERREG projects available at present. Averello (2011) carried out an intensive online search of 253 LIFE & INTERREG projects and found:

- Projects do not necessarily implement river restoration in the same perspective. While INTERREG project objectives are more or less equally distributed among objectives such as flood management and species enhancement, LIFE projects implement restoration measures mainly to improve river and floodplain habitats or species enhancement.
- Although most projects were implemented within the frame of a wider approach such as a national conservation strategy, river basin management plan (e.g. LIFE Skjern project & CASS project), 'restoration' success was rather difficult to evaluate, even with well developed ecological monitoring, because most projects did not establish measurable success criteria.

An additional 27 LIFE & INTERREG projects have since been added to Avarello's (2011) study making a total of 280 projects analysed for global objectives. Unfortunately very little change in the original conclusions were found. INTERREG project objectives are more equally distributed among the main objectives of flood management, integrated river basin management, river and floodplain restoration and water quality improvement, while the most common reasons to undertake river restoration measures in LIFE projects were for river and floodplain restoration (67%) and then species conservation and management (30%) (Table 4).

Table 4. Global objectives of LIFE & INTERREG funded river restoration projects

Global objective	INTERREG		LIFE	
	n	%	N	%
Flood management	20	24	2	1
Integrated River Basin Management	26	31	1	1
River and floodplain restoration	21	25	132	67
Species conservation and management	14	16	59	30
Water quality improvement	4	5	2	1

Information was also investigated focusing on the specific ecological goals of both LIFE predominant objectives mentioned above. Results (Table 5) showed that 42% of the river and floodplain restoration projects implement a large range of measures aimed at improving multiple ecosystem components. In addition, 20% of projects carried out river restoration measures aimed at improvement of floodplains/off-channel/lateral connectivity habitats and 15% were for riparian zone improvement. Regarding species conservation and management objectives, the projects mainly aimed at fish species enhancement (56%) and mollusc enhancement (16%).

Table 5. Specific goals of river and floodplain restoration species and conservation and management global objectives (LIFE projects)

Objective: River & floodplain restoration		**Objective: Species conservation and management**	
Specific goals	**n**	**Specific goals**	**n**
Lateral connectivity improvement	27	Bird species enhancement	4
Flow dynamics improvement	7	Crayfish species enhancement	1
In-channel & substrate improvement	6	Fish species enhancement	43
Longitudinal connectivity improvement	8	Invasive species management	3
Network development	5	Mammal species enhancement	6
Multiple	57	Mollusc species enhancement	12
Riparian zone improvement	20	Multiple	8
River bed depth/width variation improvement	1		
Sediment flow quantity improvement	2		
Water flow quantity improvement	4		

Those LIFE & INTERREG projects with main or secondary objectives to improve river habitats and/or enhance species, were assessed to evaluate project success amongst similar projects.

- Project motives play a key role while undertaking a river restoration project. Among the ten assessed projects, two aimed to improve flood management in a sustainable way by implementing alternatives for flood risk management measures such as the restoration of former and existing floodplains. However, since the main aim was to counteract flooding, the ecological perspective was not as developed as the flood management approach thus preventing pre-restoration ecological state evaluation, post-restoration monitoring;

- Application of specific ecological goals and evaluation of ecological state of the ecosystem before and after restoration. However, projects that did not implement such monitoring were constrained by 2 factors: timing or funding (e.g. although the AVON project did carry a pre restoration ecosystem evaluation, timing made it tricky to collect long-term pre-data, as they got the LIFE money 6 months before the official project start. In the case of the LIFE project implemented along the Lippe River, the project board could not receive any funding for project success monitoring either from the European Union or from the German state and therefore could not include success monitoring in the project proposal);

- Moreover, project managers brought up the difficulty of setting meaningful biological targets when the monitoring only last for 2 years in the frame of LIFE or INTERREG funded projects. (e.g. due to the complex life cycle of the freshwater mussel, it would take 5-10 years (at least) before it is possible to assess the real conservation impact of the implemented actions according to the project manager of the LIFE project 'Freshwater Pearl Mussel and its habitats in Sweden').

3.2.2 Review of Benchmark and Endpoint Summary Reporting for French ONEMA Stream Restoration Projects

ONEMA (French National Office of Water and Aquatic Environments) directs many of the river restoration projects that may contribute to meeting the requirement of good ecological status (or good ecological potential) for French rivers as required by the European Water Framework Directive (WFD). A volume has been published, *La restauration des cours d'eau : retour d'expériences sur l'hydromorphologie* (Towards the restoration of watercourses and aquatic environments), summarizing more than 80 examples of river hydromorphology restoration projects (http://www.onema.fr/IMG/Hydromorphologie/recueil_hydro.pdf).

This section reviews project summaries for 84 French stream restoration projects to determine if the four parameters of reference condition benchmarks, success evaluation endpoints, monitoring, and European policy drivers were considered in the conception, design, implementation, and evaluation of the projects. Only the information included in the project summaries on the ONEMA website was considered. Where European policy drivers were mentioned, more information was gathered from the Natura 2000 Viewer (European Union, 1995-2009, http://natura2000.eea.europa.eu). It cannot be assumed that the project summary information includes all the information pertinent to the project.

The review results were examined by percent of inclusion of the four parameters for the all the projects and for each of the nine project types. The degree of parameter inclusion could not be considered given the type of information available and the diversity of descriptions. Where possible, information was identified by whether it was qualitative or quantitative, biological or physical, collected pre-project implementation or post-project implementation, or explicitly not considered.

Project summary descriptions

The ONEMA project summaries are available on-line at http://www.onema.fr/Hydromorphologie,510 and include the following information:

1. Title
2. Operation
    a. Category
        i. preservation and management
        ii. restoration
    b. Type of operation
        i. obstacle removals
        ii. elimination or disconnection of ponds from stream channels
        iii. reconnecting orphaned parts of hydraulic systems

iv. bedload transport
v. reconnecting the floodplain
vi. remeandering and other modifications to bed geometry
vii. returning streams to original channels
viii. daylighting

c. Type of environmental system
i. canal
ii. headwater stream
iii. lowland stream
iv. intermediate zone stream
v. pond, lake, lagoon, manmade reservoir
vi. wetland, peat bog
vii. alluvial valley

d. Global objectives (water, biodiversity, climate: depending on type of operation)
i. hydromorphologic
ii. ecologic
iii. other added values

e. Project dates
f. Length of stream effected

3. Restored stream section information
    a. Name
    b. Distance from source
    c. Average channel width
    d. Average bed slope
    e. Average flow
4. Location
    a. Country
    b. Catchment
    c. Region(s)
    d. Department
    e. Municipality
5. National regulatory context and European directives context
6. Objectives of the project manager (site specific)
    i. hydromorphologic
    ii. ecologic
    iii. other added values
7. Landscape and the pressures
8. Intervention opportunities
    a. possible techniques
    b. related issues
        i. complementary measures
        ii. issues to watch out for
        iii. scientific and technical implementation references
9. Construction planning, design, and implementation
10. Permitting
11. Post-project management
12. Costs and partners
    a. pre-project study

  b. acquisitions
  c. construction
  d. stakeholder affairs
  e. total project costs
  f. financial partners and percent of financing
  g. technical partners
13. Monitoring
14. Results and future planning
15. Project recognition and dissemination

Project summary parameters review

ONEMA Project Type

- obstacle removals : 39
- remeandering and other modifications to bed geometry: 12
- disconnection of ponds from stream channels: 8
- reconnecting orphaned parts of hydraulic systems: 3
- bedload transport : 4
- reconnecting the floodplain : 3
- channel geometry changes : 5
- returning streams to original talwegs : 6
- daylighting : 4

Quantitative/Qualitative Reference Condition Benchmarks (existing site data, historical, model)

Only those reference condition benchmarks that were clearly stated or where the site(s) source for the reference conditions was clearly identified were used. Reference condition benchmarks should be a measurable target within the same river or catchment for restoring degraded sections of a river. These benchmarks should be identified before project implementation and a study at the project site should be completed prior to project design and implementation to identify the deviation of the project site condition from the reference condition. Quantitative benchmarks should come from existing reference condition sites, historical data, and/or predictive models. Historic records, if from authenticated sources, may be qualitative or quantitative. Information in the project summaries was categorized by type of reference condition benchmark (historic site conditions, existing site conditions, predictive model results) and whether quantitative or qualitative. Project summaries often indicated that the project reach has the potential to support a particular ecological function (ex. salmon fishery), but this was not considered as a reference condition benchmark unless data from an existing reference site, historic site or predictive model were used.

Presumably, engineering design calculations were used in large projects requiring construction or environmental permits, but these were not considered as predictive models; nor were they usually referenced in the project summary. It is possible that reference condition benchmarks and success evaluation endpoints were missed in this review because the authors of the summaries did not include information identifiable as benchmarks and/or endpoints and, that in reality, benchmarks and endpoints were used.

Pre/Post Implementation Biological Endpoints

Even when reference condition benchmarks are used, it is not always possible to achieve these conditions. Acceptable endpoints (measureable target levels) should be identified before project design and implementation in order to determine if the project is successful. Unlike benchmarks, success endpoints may be identified in hindsight after implementation of the project, though this is less desirable. For the ONEMA projects, post-implementation endpoint identification resulted from some kind of monitoring. Information in the project summaries was categorized by whether the biological endpoints were determined before project implementation or identified as a result of post-implementation hindsight. General, unmeasurable, biological project goals/objectives were not considered as endpoints per se. In some cases, only hydromorphologic endpoints (HYMO) were identified without any reference to biology.

Pre/Post Implementation Monitoring (Time Frame)

Pre-project monitoring may be used to determine the deviation of the site conditions from the reference conditions and, in some cases, results may be used for design engineering purposes. Post-project monitoring determines whether endpoints were met and the project was successful. In cases where endpoints are not identified before project implementation, post-project monitoring may identify acceptable endpoints in hindsight. Monitoring information in the project summaries was categorized by whether it occurred pre- or post-implementation. For pre- and post-monitoring, the types of monitoring are divided into biological or physical (HYMO or water quality). If the monitoring took place after implementation, it was also noted if there was a monitoring time-frame or schedule. In some cases, monitoring also took place during implementation.

European Policy Drivers

The project summaries were reviewed to determine if river ecological status was considered either directly or indirectly as part of a European policy driver (program). Ideally, the exact ecological status of the stream would be known and sites with less than good ecological status would be targeted. The use of European policy drivers was determined from the Natura 2000 Viewer http://natura2000.eea.europa.eu, which includes Natura 2000, LIFE, and the Common Database on Designated Areas (CDDA) sites, or from INPN (Inventaire National du Patrimoine Naturel), MNHN (Muséum National d'Histoire Naturelle), Recherche de données Natura 2000 http://inpn.mnhn.fr/site/natura2000/recherche. A link is provided below to the MNHN site profile, where available. REFORM Forecaster Wiki was also consulted to determine if the project was included in this European, project summary database. In some cases, a project site was been identified as not meeting some component of the WFD general criteria for good ecological status.

Results

Table 6 presents the results of the review for the 84 ONEMA projects. In total 9.5% of the 84 project summaries identified considered existing site data for reference condition benchmarks as a part of the project planning and design. Only 2.4% of the projects identified using qualitative benchmarks and 7.1% identified using quantitative benchmarks.

Table 6: Overview of information in 84 ONEMA Restoration reviews. Abbreviations: WQ: water quality; NA: not applicable; Q: flows; HYMO: hydromorphologic, channel geometry, sediment transport, flow; Pre: Pre-implementation ; Post: post-implementation ; RC : reference condition site data

Total Number of Projects: 84	**%**
Quantitative/Qualitative Reference Condition Benchmarks	
Existing Site Data :	9.5
Qualitative	2.4
Quantitative	7.1
Historic:	13.1
Qualitative	8.3
Quantitative	4.8
Predictive Model:	0.0
None given:	77.4
Pre/Post Implementation Biological Endpoints	
Biologic: Pre-implementation	0.0
Post-implementation	71.4
With HYMO	58.3
HYMO only:	19.0
None:	10.7
Pre/Post Implementation Monitoring (Time Frame)	
Pre-implementation	66.7
Biological/Physical	34.5
Biological only	14.3
Physical only	13.1
Unknown	2.4
Post-implementation	77.4
Biological/Physical	42.9
Biological only	19.0
Physical only	13.1
Unknown	2.4
Post-implementation with time-frame	54.8
During implementation work	7.14
No monitoring	11.9
European Policy Drivers	
European Drivers:	44
Natura 2000:	29.8
Birds Directive	9.5
Habitats Directive	22.6
Unknown directive	6.0
Forecaster:	20
Water Framework Directive "objectives":	3.6
LIFE:	8.3
CDDA:	10.7

More than half the projects (56%) have the goal of restoring ecological continuity by removing the connection between stream channels and impounded water and are included in two type groupings: obstacle removals (46%) and disconnection of ponds from stream channels (10%). three types related to lateral and vertical reconnection represent 8.4% of the projects, reconnecting orphaned parts of hydraulic systems (4%), reconnecting the floodplain (4%), and bedload transport (5%). three types are related to improving channel geometry and represent 27% of the projects and include returning streams to original thalwegs (7%), channel geometry changes (6%), and remeandering and other modifications to bed geometry (14%). the last type, daylighting, represents 5% of the projects.

The following outlines the major review findings for all the projects.
Table 7 presents the numbers and percentage by project type for each of the four parameters reviewed.

Reference Condition Benchmarks:

- The summaries for more than three quarters of the sites (77%) did not give any reference condition benchmarks and only 12% used quantitative benchmarks.
- Historic reference condition benchmarks (13.1%) were the type most commonly used and no benchmarks came from predictive models.

Biological Endpoints:

- Biological endpoints were exclusively identified in hindsight after the project was implemented and results could be seen or measured.
- No project appeared to identify success evaluation endpoints prior to project implementation.
- Post-implementation, 71.4% of the projects did identify at least one success (or failure) biological endpoint.
- Post-implementation, 58.3% of the projects also included at least one hydromorphological endpoint.
- Only 10.7% of the projects failed to identify any success endpoint. In many of these cases, the project was only recently completed.

Pre/Post Implementation Monitoring, with Time Frame:

- Monitoring has been conducted with 66.7% of the projects undertaking pre-project implementation monitoring of at least one quality element variable and 77.4% undertaking post-implementation monitoring of at least one quality element variable.
- Both biological and physical quality elements were followed during pre-implementation (34.5%) and post-implementation (43.9%) monitoring.
- Only 11.9% of the projects did no monitoring.
- Time frames (or schedules) were given for 54.8% of the project monitoring programmes.

European Policy Drivers:

- Some reference to a European policy driver was made in 44% of project summaries.
- Nearly 30% were part a Natura 2000 directive, particularly the Habitats Directive.
- Twenty percent of the projects are included in the REFORM Forecaster Wiki.
- More than half did not mention any connection to a European programme.

Table 7: Proportion of ONEMA projects with reference to benchmarking, endpoint, monitoring and policy drivers.

ONEMA Project Type (#)	Quantitative/ Qualitative Reference Condition Benchmarks	Pre/Post Implementation Biological Endpoints	Pre/Post Implementation Monitoring (Time Frame)	European Policy Drivers
Obstacle removals (39)	Existing Site Data : 0 Historic: 8 (20.5%) Qualitative 6 (15%) Quantitative 2 (5%) Predictive Model: 0 None given: 31 (79.5%)	Biological: Pre-implementation 0 Post-implementation 25 (64%) With HYMO 22 (56%) HYMO only: 8 (20.5%) None: 6 (15%)	Pre-implementation 26 (67%): Biological/Physical 10 (26%) Biological only 6 (15%) Physical only 8 (20.5%) Unknown 2 (5%) Post-implementation 30 (77%) Biological/Physical 15 (38.5%) Biological only 6 (15%) Physical only 8 (20.5%) Unknown 1 (3%) Post-implementation with time-frame 20 (51%) During implementation 6 (15%) No monitoring 4 (10%)	European Drivers: 14 (40%) Natura 2000: 8 (20.5%) Birds Directive 1 (3%) Habitats Directive 6 (15%) Unknown directive 1 (3%) Forecaster: 14 (36%) Water Framework Directive "objectives": 3 (8%) LIFE: 0 CDDA: 1 (3%)
Remeandering and other modifications to bed geometry (12)	Existing Site Data: 1(8%) Qualitative 1 (8%) Historic: 2 (17%) Qualitative 1 (8%) Quantitative 1 (8%) Predictive Model: 0 None given: 9 (75%)	Biological: Pre-implementation 0 Post-implementation 10 (83%) With HYMO 10 (83%) HYMO only: 2 (17%) None: 0	Pre-implementation 8 (67%): Biological/Physical 7 (58%) Biological only 1 (8%) Physical only 0 Unknown 0 Post-implementation 12 (100%) Biological/Physical 9 (75%) Biological only 3 (25%) Physical only 0 Unknown 0 Post-implementation with time-frame 9 (75%) During implementation work 0 No monitoring 0	European Drivers: 10 (83%) Natura 2000: 6 (50%) Birds Directive 4 (33%) Habitats Directive 5 (42%) Unknown directive 1 (8%) Forecaster: 10 (83%) Water Framework Directive "objectives": 0 LIFE: 4(33%) CDDA: 4(33%)

ONEMA Project Type (#)	Quantitative/ Qualitative Reference Condition Benchmarks	Pre/Post Implementation Biological Endpoints	Pre/Post Implementation Monitoring (Time Frame)	European Policy Drivers
Disconnection of ponds from stream channels (8)	Existing Site Data : 0 Historic: 1 (12.5%) Qualitative 0 Quantitative 1 (12.5%) Predictive Model: 0 None given: 7 (87.5%)	Biological: Pre-implementation 0 Post-implementation 6 (75%) With HYMO 2 (25%) HYMO only: 1 (12.5%) None: 1 (12.5%)	Pre-implementation 5 (62.5%): Biological/Physical 3 (37.5%) Biological only 2 (25%) Physical only 0 Unknown 0 Post-implementation 7 (87.5%) Biological/Physical 2 (25%) Biological only 3 (37.5) Physical only 1 (12.5%) Unknown 1 (12.5%) Post-implementation with time-frame 4 (50%) During implementation work 0 No monitoring 1 (12.5%)	European Drivers: 5 (62%) Natura 2000: 4 (50%) Birds Directive 1 (12.5%) Habitats Directive 3 (37.5%) Unknown directive 1 (12.5%) Forecaster: 3 (37.5%) Water Framework Directive "objectives": 0 LIFE: 1 (12.5%) CDDA: 3 (37.5%)
Reconnecting orphaned parts of hydraulic systems (3)	Existing Site Data : 0 Historic: 0 Predictive Model: 0 None given: 3 (100%)	Biological: Pre-implementation 0 Post-implementation 2 (67%) With HYMO 2 (67%) HYMO only: 1 (33%) None: 0	Pre-implementation 2 (67%): Biological/Physical 1 (33%) Biological only 1 (33%) Physical only 0 Unknown 0 Post-implementation 2 (67%) Biological/Physical 2 (67%) Biological only 0 Physical only 0 Unknown 0 Post-implementation with time-frame 2 (67%) During implementation work 0 No monitoring 1 (33%)	European Drivers: 3 (100%) Natura 2000: 3 (100%) Habitats Directive 2 (67%) Unknown directive 1 (33%) Forecaster: 1 (33%) Water Framework Directive "objectives": 0 LIFE: 2 (67%) CDDA: 2 (67%)

ONEMA Project Type (#)	Quantitative/ Qualitative Reference Condition Benchmarks	Pre/Post Implementation Biological Endpoints	Pre/Post Implementation Monitoring (Time Frame)	European Policy Drivers
Bedload transport (4)	Existing Site Data : 0 Historic: 0 Predictive Model: 0 None given: 4 (100%)	Biological: Pre-implementation 0 Post-implementation 2 (50%) With HYMO 2 (50%) HYMO only: 2 (50%) None: 0	Pre-implementation 3 (75%): Biological/Physical 2 (50%) Biological only 1 (25%) Physical only 0 Unknown 0 Post-implementation 2 (50%) Biological/Physical 1 (25%) Biological only 1 (25%) Physical only 0 Unknown 0 Post-implementation with time-frame 2 (50%) During implementation work 0 No monitoring 1 (25%)	European Drivers: 1 (25%) Natura 2000: 1 (25%) Unknown directive 1 (25%) Forecaster: 0 Water Framework Directive "objectives": 0 LIFE: 0 CDDA: 0
Reconnecting the floodplain (3)	Existing Site Data : 0 Historic: 0 Predictive Model: 0 None given: 3 (100%)	Biological: Pre-implementation 0 Post-implementation 2 (67%) With HYMO 0 HYMO only: 1 (33%) None: 0	Pre-implementation 3 (100%): Biological/Physical 0 Biological only 0 Physical only 2 (67%) Unknown 0 Post-implementation 1 (33%) Biological/Physical 1 (33%) Biological only 0 Physical only 0 Unknown 0 Post-implementation with time-frame 1 (33%) During implementation work 0 No monitoring 1 (33%)	European Drivers: 0 Natura 2000: 0 Forecaster: 0 Water Framework Directive "objectives": 0 LIFE: 0 CDDA: 0

ONEMA Project Type (#)	Quantitative/ Qualitative Reference Condition Benchmarks	Pre/Post Implementation Biological Endpoints	Pre/Post Implementation Monitoring (Time Frame)	European Policy Drivers
Channel geometry changes (5)	Existing Site Data : 1 (20%) Qualitative 1 (20%) Historic: 0 Predictive Model: 0 None given: 4 (80%)	Biological: Pre-implementation 0 Post-implementation 4 (80%) With HYMO 4 (80%) HYMO only: 0 None: 1 (20%)	Pre-implementation 5 (100%): Biological/Physical 3 (60%) Biological only 0 Physical only 1 (20%) Unknown 1 (20%) Post-implementation 3 (60%) Biological/Physical 1 (20%) Biological only 1 (20%) Physical only 1 (20%) Unknown 0 Post-implementation with time-frame 2 (40%) During implementation work 0 No monitoring 0	European Drivers: 0 Natura 2000: 0 Forecaster: 0 Water Framework Directive "objectives": 0 LIFE: 0 CDDA: 0
Returning streams to original thalwegs (6)	Existing Site Data : 6 (100%) Quantitative 6 (100%) Historic: 0 Predictive Model: 0 None given: 0	Biological: Pre-implementation 0 Post-implementation 6 (100%) With HYMO 6 (100%) HYMO only: 0 None: 0	Pre-implementation 3 (50%): Biological/Physical 2 (33%) Biological only 1 (17%) Physical only 0 Unknown 0 Post-implementation 5 (83%) Biological/Physical 4 (67%) Biological only 0 Physical only 1 (17%) Unknown 0 Post-implementation with time-frame 4 (67%) During implementation work 0 No monitoring 1 (17%)	European Drivers: 4 (67%) Natura 2000: 3 (50%) Birds Directive 2 (33%) Habitats Directive 3 (50%) Forecaster: 1 (18%) Water Framework Directive "objectives": 0 LIFE: 0 CDDA: 1 (17%)

ONEMA Project Type (#)	Quantitative/ Qualitative Reference Condition Benchmarks	Pre/Post Implementation Biological Endpoints	Pre/Post Implementation Monitoring (Time Frame)	European Policy Drivers
Daylighting (4)	Existing Site Data : 0 Historic: 0 Predictive Model: 0 None given: 4 (100%)	Biological: Pre-implementation 0 Post-implementation 3 (75%) With HYMO 1 (25%) HYMO only: 1 (25%) None: 1 (25%)	Pre-implementation 1 (25%): Biological/Physical 1 (25%) Biological only 0 Physical only 0 Unknown 0 Post-implementation 3 (75%) Biological/Physical 1 (25%) Biological only 2 (50%) Physical only 0 Unknown 0 Post-implementation with time-frame 2 (50%) During implementation work 0 No monitoring 1 (25%)	European Drivers: 0 Natura 2000: 0 Forecaster: 0 Water Framework Directive "objectives": 0 LIFE: 0 CDDA: 0

The following outlines the major review findings for the projects by project type.

Reference Condition Benchmarks:

- For eight out of nine project types, a very high percentage (77-100%) made no reference to benchmarks.
- Only projects Returning streams to original thalwegs (100%) mentioned reference condition benchmarks.

Biological Endpoints:

- The percent range for eight project types identifying post-implementation endpoints in hindsight was 64-83%.
- One hundred percent of the projects Returning streams to original thalwegs used post-implementation endpoints.
- Five out of the nine project types identified some kind of endpoint for every project.

Pre/Post Implementation Monitoring, with Time Frame:

- Only two out of nine project types used some kind of monitoring: Remeandering and other modifications to bed geometry and Channel geometry changes.
- A range of 33-75% of the projects included monitoring time frames across all nine types.
- Six out of nine of the project types included some pre-implementation biological monitoring.
- Five out of nine of the project types included some post-implementation biological monitoring.

European Policy Drivers:

- Three of the nine project types made no reference to a European policy driver.
- Only one project types, Obstacle removals, referred to the Water Framework Directive, and then in only 3 (7.7%) of the projects.

Dicussion

Reference Condition Benchmarks:

The lack of use of reference condition benchmarks may be attributable to many causes, some related to comprehension issues and some to limitations.

Comprehension issues may include:

- Confusion about the definition of a reference condition
- Confusion over the value of reference conditions to a project
- Confusion about the multiplicity of reference condition types applicable to project spatial and temporal scale
- Conflicting data on the success of using reference conditions in project design
- Confusion over the multiplicity of planning documents and regulations at the local, national, and European levels
- Conflict between river management, engineering, construction implementation, and scientific research mindsets

Limitations may include:

- Lack of reference condition reaches (particularly for larger rivers)

- Lack of reference condition study data (reference sites may not be adequately studied and/or monitored)
- Lack of access to existing data
- Lack of project partner funding for the necessary pre- and post-implementation studies
- Lack of project partner technical expertise for effective analysis and application of the data
- Lack of project space and time, which may lead partners to dismiss the consideration of reference conditions

Many of the ONEMA restoration projects are small and include objectives that are social rather than ecological. While this would not necessarily preclude the consideration of reference condition benchmarks, lack of funding, space, time, and technical expertise may incline partners to pursue site specific actions that are inexpensive, easily permitted, quickly implemented, and easy to see and understand.

Biological Endpoints:
Biological success endpoints were largely identified in hindsight. However, it is clear from many of the summaries that general biological objectives existed prior to project implementation. For example, the objectives of improving fish habitat or ecological continuity were frequently given, but measurable endpoints were not given. The utility of measurable endpoints for success evaluation lies in the availability and analysis of pre-implementation and post-implementation data. If these data do not exist, it is not possible to evaluate success scientifically. Biological success was frequently defined by the presence after implementation of something considered desirable (e.g. trout, ducks, riparian vegetation, diverse flow facets) or the disappearance of something undesirable (e.g. odours, algae, warm water species, fine sediments). A number of projects mentioned only social endpoints (e.g. improved access, aesthetics, recreation).

As with benchmarks, it is possible that the use of measurable, evaluation success endpoints is not well understood. Ecological objectives are often given in the project summaries, but they are never measurable. The connection between establishing endpoints and conducting pre- and post-implementation monitoring programmes is clear, but the lack of effective monitoring programmes has limited endpoint consideration to hindsight only. Interestingly, most of the projects were written up as significant successes. In some cases, a failure was acknowledged for one or more project expectations and, in one case, the project was deemed a total failure.

Pre/Post Implementation Monitoring (Time Frame):
Monitoring is often a component of stream restoration that is not done. The ONEMA projects tended to include monitoring, though post-implementation monitoring was often more extensive with more quality element variables and greater frequency than pre-implementation monitoring. Some of the monitoring programs were limited to visual or photographic surveys and most did not have any regular schedule for future monitoring. Funding for data collection and technical expertise for data analysis are often lacking and the time and expertise required for data collection can be daunting. Only a few project summaries mentioned data collection or analysis protocols and none indicated where the

monitoring data could be found. Many of the projects without or with limited monitoring programs identified this lack as a serious defect in the project.

European Policy Drivers:
The impacts of European policy drivers on the choice, design, implementation, and monitoring were not given in the project summaries, and European directives are only given in a reference list. The only area where the connection is clear is if funding was provided by a European programme. Even if European policy drivers are not mentioned, many projects clearly indicated their connection to national, regional, municipal or catchment policy drivers, which were not considered in this review.

Conclusion
The concepts of reference condition benchmarks and success evaluation endpoints need to be more highly developed and promulgated in a way that is useful to river managers, project partnerships, and stakeholder groups. It may help to link project funding and permitting to the use of reference condition benchmarks and success evaluation endpoints.

To make the use of benchmarks and endpoints effective, well-funded and scientifically designed and implemented monitoring programmes are needed. Stream restoration projects are often expensive to design and implement; poorly designed and implemented projects are a waste of funds that could be spent on good monitoring programmes that would result in more, successful restoration projects.

European policy drivers must include intelligent monitoring programs, methods for data management and dissemination, protocols for data analysis, and publication of results in formats that are useable by river managers.

3.2.3 Thur River Case Study– Switzerland

Source: Woolsey et al. 2005 & 2007

The river Thur, is 127 km in length and flows from the mountains, originating from Mount Säntis, Canton of St. Gallen to the River Rhine, downstream of Andelfingen. The main pressures on the system are:

- Disturbed bedload regime
- Lack of river dynamics
- Insufficient connectivity, both longitudinal and lateral
- Fluctuating water quality

In 2002, river widening took place at Schäffäuli, Switzerland as a main measure to improve flood protection and enhance river dynamics and ecological value. The river width was increased from 50m to 100m over a length of 1500 m. Furthermore, the area is used for recreational purpose by the public. Expected outcomes were:

- Lateral connectivity

- As a result, bedload deposition may increase, resulting in stabilisation of the river bed and development of gravel bars and sand banks (Formann, Schober & Habersack, 2004; Peter, Kienast & Woolsey, 2005)
- Given the geomorphic setting of the Thur River, the channel should also start to become braided and islands should be formed (Schweizer, 2006).
- Habitat conditions similar to those existing before the first river regulation should develop (Schmid, 1879).
- Variability of depth and current velocity are expected to increase, creating characteristic floodplain habitats and causing an associated surge in species richness (Arscott et al. 2005; Rohde et al. 2006).

Figure 9: Before and after views of Thur River restoration scheme

In view of these expectations and the general project goals, restoration objectives were selected to evaluate success of the river widening near Schäffäuli:

- Provision of high recreational value
- Morphological and hydraulic variability
- Lateral connectivity
- Vertical connectivity
- Near-natural abundance and diversity of fauna

Indicators for evaluating these restoration objectives were selected based on their relevancy to more than one of the five restoration objectives that assessed objectives directly (although this was not always possible), required low-effort (with two exceptions) and were suitable for evaluation within 2 years following completion of restoration:

- Number of visitors
- Public accessibility for recreation
- Fish species abundance and dominance
- Diversity of ecological guilds of fish
- Variability If measured wetted width
- Clogging of hyporheic sediment
- Shoreline length

A pre-restoration survey was not possible because restoration had been completed 2-years previously. Therefore, two river sections at Weinfelden-Bürglen and Frauenfeld similar to that of the former un-restored Schäffäuli section served as control substitutes.

Results: Overall success categories determined for each project objective were based on standardised indicator values averaged for each objective and the evaluation matrix. Results show that the Schäffäuli project was very successful in achieving the objective 'provision of high recreational value'. The objectives 'lateral connectivity' and 'vertical connectivity' were also achieved, although improvements were less pronounced. No change was observed in 'morphological and hydraulic variability', and 'near-natural abundance and diversity of fauna' even declined.

Application of indicators to assess rehabilitation success *Source: Woolsey et al. 2005 & 2007*

Indicators are used as tools to assess, quantitatively, if and to what extent the project objectives were achieved. The choice of indicators is dependent on the project objectives and the measure to be implemented. Woolsey et al. (2005) produced a table (Appendix 2) of 49 indicators, grouped by 17 indicator categories, for different measures. The information in Appendix 2 is based on scientific literature and expert opinion. It is important that project objectives are clearly defined from the beginning and then a suitable, project-specific set of indicators from Appendix 2 can be selected according to the following guidelines (Woolsey *et al*. 2007):

1. For each project objective one or, preferably, more indicators are selected. Indicators that pertain to more than one objective are generally recommended to keep the list of required measurements short and assessment costs low.
2. Direct indicators are generally preferred over indirect indicators, because direct indication of an influence is likely to provide more accurate information.
3. If financial or time constraints are important, as is often the case (Holl & Cairns, 1996), selection can be limited to indicators that require low effort.
4. Indicators must be surveyed at an appropriate time in terms of both the number of years elapsed after restoration and of the interannual patterns defined by factors such as season or flood history.

Indicator values are determined in various measurement dimensions and so need to be standardised before calculating an overall dimensionless evaluation score between 0 and 1. The benchmark condition is assigned the value 1, often corresponds to the undisturbed state before large scale pressures occurred (near natural conditions are impractical in Europe). Measured indicator values are standardised according to an indicator-specific equation or a semi-quantitative or qualitative classification scheme. Overall project evaluation consists of assessing to what extent individual project objectives were met. This is achieved by averaging all standardised indicator values relating to a given project objective before and after restoration and comparing the resulting values in five success categories (Table 8).

Discussion
Woolsey et al. (2007) suggested a set of complementary indicators for each objective is required to increase confidence in the evaluation results. While four indicators were used to evaluate the objective 'morphological and hydraulic variability', only one or two indicators were used to evaluate the four remaining objectives. Applying a

complementary set of indicators for the individual objectives would enable a more subtle assessment of the project success and, in addition, help to identify potential deficits and gaps in the design of the restoration project.

Table 8: Proposed matrix to evaluate restoration success in five categories by comparison of standardised indicator values before and after restoration measures are taken (Woolsey et al. 2007).

	Indicator value before restoration										
Indicator value after restoration	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
0.0	0	-	-	-	-	-	-	-	-	-	-
0.1	+	0	-	-	-	-	-	-	-	-	-
0.2	+	+	0	-	-	-	-	-	-	-	-
0.3	+	+	+	0	-	-	-	-	-	-	-
0.4	+	+	+	+	0	-	-	-	-	-	-
0.5	++	++	+	+	+	0	-	-	-	-	-
0.6	++	++	++	+	+	+	0	-	-	-	-
0.7	++	++	++	++	++	+	+	0	-	-	-
0.8	+++	+++	++	++	++	++	+	+	0	-	-
0.9	+++	+++	+++	+++	+++	++	++	++	++	0	-
1.0	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	0

Symbol for success category: -, deterioration, failure; 0, no change, failure; +, slight improvement, small success; ++, medium improvement, medium success; +++; strong improvement, large success.

According to the presented evaluation strategy the Thur River restoration project near Schäffäuli was considered successful only with regard to the objectives 'provision of high recreational value', 'lateral connectivity' and 'vertical connectivity'. Although it is not surprising that the restoration was more successful in addressing certain objectives more than others, the differences between the categories of success for the five evaluated objectives seem rather large. However, evaluations of the two objectives for which no successes were registered were partly or wholly based on the two fish indicators. As discussed above, these indicators are influenced by factors that were not taken into account in the present evaluation. The use of fish was therefore insufficient to provide an accurate assessment of project success. In contrast, 'morphological and hydraulic variability' may have been sufficiently characterised by the two indicators 'variability of measured wetted width' and 'clogging of hyporheic sediments'. An evaluation based on these two indicators would have resulted in a 'small success'. This example further highlights the need for complementary sets of indicators.

3.2.4 Rhône River – France

Sources: Henry & Amoros, 1995; Henry et al. 1995; Henry & Amoros, 1996; Henry et al. 2002; Amoros, 2000, 2001; Amoros et al. 2005; Amoros et al. 2005.

Background

At the end of the 19th Century a 15 km (2 km wide) stretch of the River Rhöne, characterised by a braiding pattern was impacted by the construction of a submersible embankment to improve navigation. The longitudinal embankments were reinforced by perpendicular ones that crossed the side arms and therefore at high flow the river could overflow into the side arms. These embankments had two major consequences.

1) Formed obstacles that slowed down river overflowing and thereby increased alluvial deposition within the side arms, resulting in terrestrialization;
2) Impeded any lateral erosion found in pristine river systems.

In addition, a hydroelectric project completed in 1966 bypassed the former main river and reduced discharge to a minimum flow. A decrease in base-flow discharge of the main river resulted in a lower water table in the alluvial aquifer that, in addition to the siltation increase from the end of the 19th century, led to the disappearance of almost all the floodplain waterbodies. A further 19 hydroelectric projects impacted on the River Rhöne, especially as all, bar one, bypassed the former main river and reduced discharge to a minimum flow (varying from 1% to 30% of the base flow discharge (Roux et al 1989)).

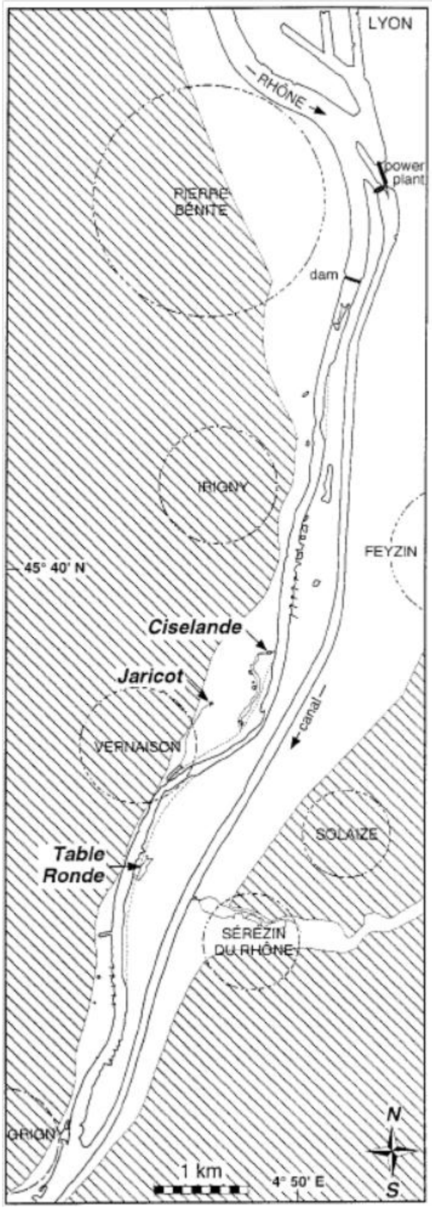

Figure 10 Location of the former side arms to be restored in the Rhône River (source: Amoros 2001)

Project goals and objectives

The preservation of a side-channel needs ecological restoration to compensate for both natural processes (succession and alluvial deposition) and human impacts (embankment and hydroelectric equipment). In this framework, the increase on biodiversity corresponding to previous successional stages, through the increase in habitat diversity between and within ecosystems, has been used as a guiding principal to define targets in the rehabilitation experiments carried out on the Rhône River, France. Two major mechanisms that rule and sustain habitat diversity have been incorporated in the design of rehabilitation projects in order to increase the long-term success (Henry & Amoros 1995; Ward et al. 1999):

1. Flood pulsing and resulting disturbance dynamics increase habitat diversity, can compensate for competitive exclusion and thereby enhance biodiversity and set back ecological succession;
2. Ground water supply also enhances habitat diversity and resulting biodiversity.

Rehabilitation measure

Three terrestrialized side arms were restored on a section of the River Rhöne, 3 km downstream from the Saöne River confluence (Table 9). Jaricot and Ciselande were designed to be flood scoured; Jaricot had an additional supply of groundwater, the other being connected to the river at both ends. Table-Ronde cannot be scoured by floods because of upstream construction and was therefore supplied by river backflow through a downstream connection.

Table 9: Details of the connections of three terrestrialized side arms, River Rhöne.

	Jaricot	**Ciselande**	**Table-Ronde**
Connect groundwater			
Upstream connection to river			
Downstream connection to river			
Flood scouring			

Rehabilitation measures:

- Bed excavation and sediment removal.
- Self-recolonization of the aquatic ecosystem (expected in upstream sectors of the Rhöne River as well as on its tributaries).

Indicators for evaluating restoration

Monitoring across 5 years was completed for:

1. Water physio-chemistry assess the differences in water origins;
2. Sediment rates were used to assess the sustainability of rehabilitation operations (In this study predicted sedimentation rates were calculated from present connections of old side-channels);
3. Number of plant species was used to assess the effects of self-colonization and the differences in resulting biodiversity.

Brief overview of Results

1) *Water physio chemistry*

Hillslope ground water was characterized by higher electric conductivity and higher contents in hydro-genocarbonates, sulfates and nitrates. The rehabilitation side channels Ciselande (bi-connected) and Table- Ronde (downstream connected) appeared similar to the river, whereas Jaricot (downstream connected, close to hill slope) was similar to river water and hill slope groundwater alike.

2) *Sediment dynamics*

The three side-channels have recorded a significantly different sediment rate since rehabilitation. The highest rate was measured in the backwater of Table-Ronde (D50=7.25 cm.yr^{-1}) and the lowest in Ciselande, the bi-connected channel (D50=1 cm/yr). Jaricot, which is supplied by groundwater and connected upstream during floods, recorded intermediate values of sedimentation (D50=3.25 cm/yr).

The spatial pattern of the sedimentation after each flood also differs from one channel to the other. In the downstream Table-Ronde, the sedimentation rate decreases clearly (3-4 times) from the downstream entrance to the upstream dead end; whereas on Jaricot, there is no significant difference along the channel.

3) Aquatic vegetation dynamics

The number of plant species occurring only in a single side-channel, were the highest in Jaricot in the first 3 years after the rehabilitation works then decreased but remained rather high since it constituted 28.6% of the total number of species occurring in this side-channel in 2003. In Ciselande, that number constituted 34.8% of the total species number in 2003. Those numbers were the lowest in Table-Ronde as well as in the non-rehabilitated site.

Discussion

The three side channels differ in sedimentation rate in relation to their hydrological connectivity. The backwater of Table-Ronde traps the sediments which are supplied by the River Rhöne during the high water levels and flood and underwent a downstream-upstream gradient. It is expected that an alluvial plug will develop in the coming years (according to the observed sediment rate). Ciselande (permanently bi-connected) underwent the lowest sedimentation and is expected that this channel will maintain running water sections without sedimentation over a long period of time (more than 100 years according to the observations of other side channels with similar characteristics). Jaricot recorded intermediate sedimentation rate because of its length reducing the effects of backflow, and the hydraulic conditions occurring during the floods, the upstream overbank flow allowing scouring of sediment previously deposited. However, the sedimentation rate is expected to be much lower than those observed, because the flood that occurred has a low occurrence frequency and thereby should have been efficient to scour away the sediments deposited. From observation, the side channel cannot self-maintain its geometry during the scouring events and will evolve to terrestrial stages within the 24 to 40 years.

Jaricot and Table-Ronde have undergone a much higher sedimentation than expected. This can be explained by the fact that the predicted rates were calculated from long-term measurements whereas the observed rates were recorded during a short and particular hydrological period where two decadal floods occurred.

The results indicate that the differences in water supply instigated a clear difference in aquatic vegetation composition between Jaricot and Ciselande. The vegetation dynamics demonstrate the role of connectivity in the colonization rate of the rehabilitated side channel since the two water bodies that were up-stream-connected during the floods (Jaricot and Ciselande) exhibited a higher colonization rate than Table-Ronde that was only downstream connected.

Conclusion
The expected differences in habitat conditions, resulting from both the groundwater supply and flood scouring were observed during the presented post-rehabilitation survey carried out over the 5 years. The differences in aquatic vegetation appearing early between Ciselande and Jaricot remained till 2003, five years after rehabilitation works. The relative slow colonization of the Table-Ronde may continue and competitive exclusion may result in a change if the floristic composition of this side-channel in the near future. Sedimentation rates also differ between the three channels and their values exceeded the predictions. Future changes are expected such as the formation of an alluvial plug at the downstream end of the Table-Ronde, decreasing its connectivity. Jaricot will slowly but continuously aggraded by which the physical habitat conditions could become progressively similar to those of Table-Ronde on a long-term scale except the channel consequently.

3.2.5 Kissimmee River - Florida

Source: Anderson et al. 2005

Background
The Kissimmee River is a shallow, low-gradient river in south-central Florida, USA. In its original state the river meandered for approximately 166 km between Lakes Kissimmee and Okeechobee through the 1942-ha Lower Kissimmee Basin . Hurricanes in the 1920s and 1940s caused widespread flooding with loss of life and property damage. The Central and Southern Florida Flood Control Project was created in 1954 to provide flood protection for surrounding communities and agricultural interests. Between 1962 and 1971, a number of modifications were made to the Kissimmee River, including excavation of a central canal and installation of six water control structures that subdivided the canal into five impoundments (Figure 1).

The hydromorphological impacts on the river included:
- conversion of a meandering river to a canal
- no lateral connectivity with the floodplain
- loss of 7 951 hectares of wetland and dramatic losses of associated animal populations
- significant degradation of water quality
- loss of seasonal flow variability
- loss of seasonal water storage

Restoration
Grass-roots pressure for restoration started to mount in the early 1970s before the flood control alterations were completed (Figure 11). The U.S. Congress passed the Water Resources Development Act of 1992, which authorized the ecosystem restoration of the Kissimmee River (Kissimmee River Restoration Project - KRRP) and changes to several lakes in the upper basin of the watershed to support the river restoration (Headwaters Revitalization Project) (Figure 12).

The Kissimmee River Restoration Project is one of the largest river restorations in the world. The project is restoring approximately 104 square kilometres of floodplain wetlands and will reconnect over 69 kilometres of meandering river channel, while maintaining the same level of flood control as the channelized system. Construction components of the project are being completed over a projected 13-year period and will cost an estimated $578 million (in Fiscal Year 2004 dollars). Over 40,500 hectares of land have been acquired.

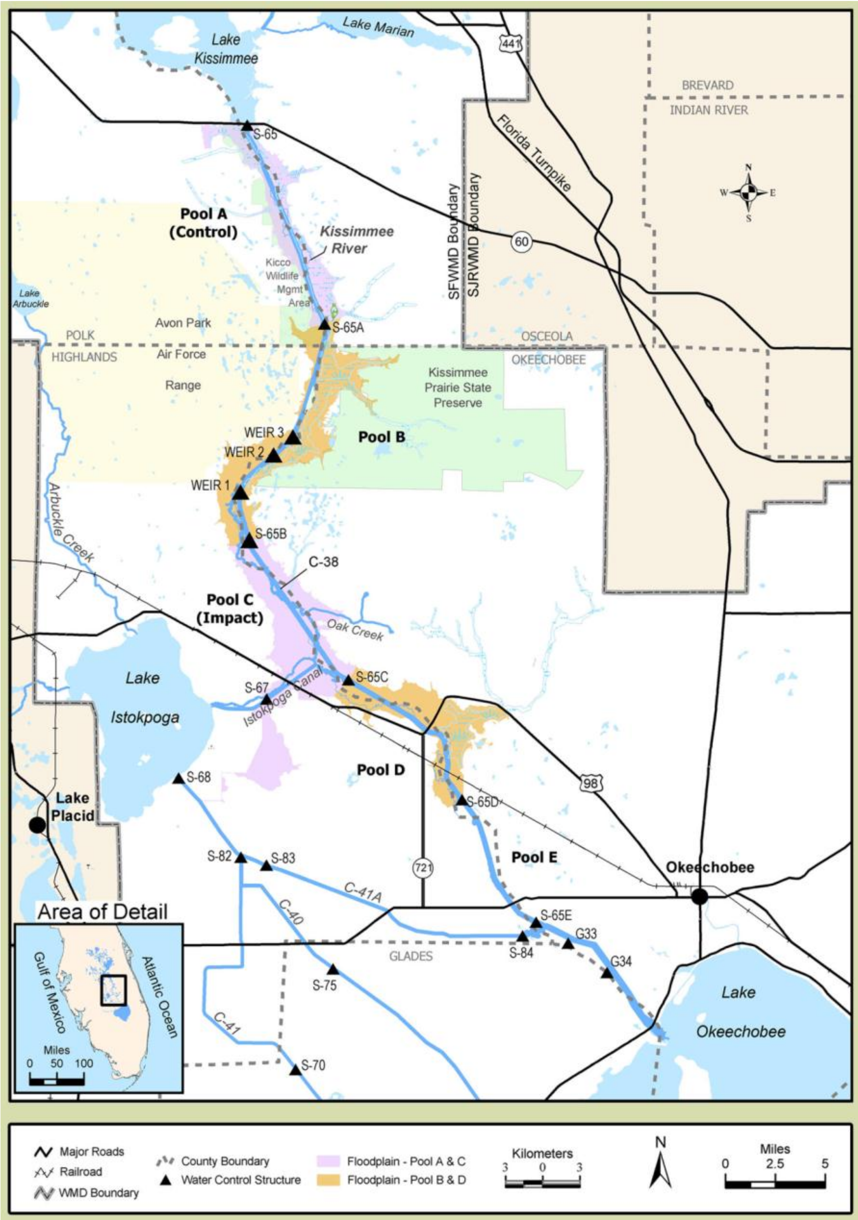

Figure 11: Map of Kissimmee River flood control alterations

The project is noteworthy not only for its size and scope, but for its uncommon goal of re-establishing the ecology of the river and floodplain. While many restoration projects attempt to reconstruct critical habitat features for individual species, the KRRP is one of the few in the world to attempt reestablishment of the integrity of an entire ecosystem. Reestablishment of ecological integrity means that the river and floodplain ecosystem's restored physical and chemical components will help drive recovery of the plant and animal communities (over 300 species of fish and wildlife) associated with the river and floodplain prior to the Central and Southern Florida Flood Control Project.

Figure 12: Photographs of the Kissimmee River prior to channelization and after channelization

Expectations
Due to the geographic size and ecological complexity of the KRRP, a very organized planning outline was developed to take the project from goals identification through to expectations, followed by implementation, evaluation, and future planning (Figure 13).

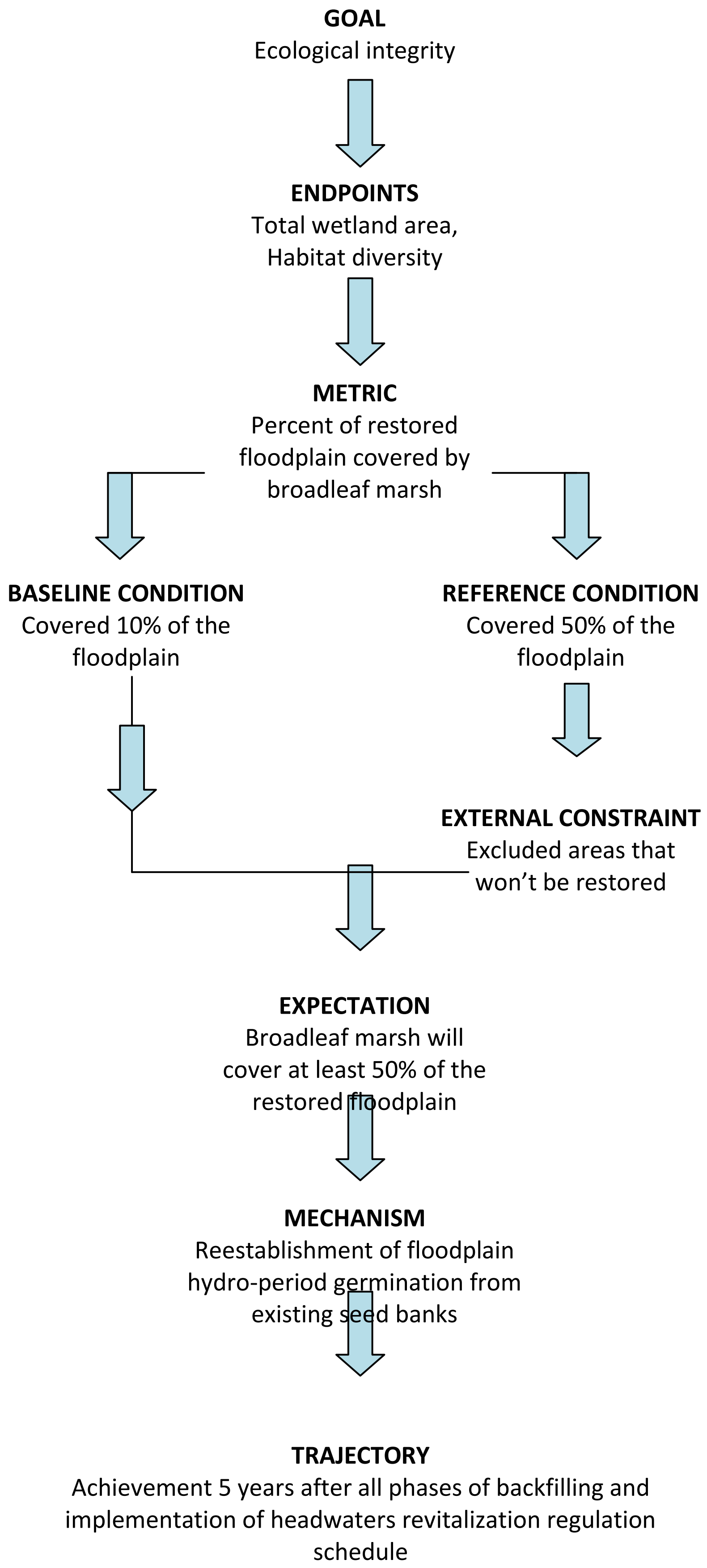
GOAL
Ecological integrity
ENDPOINTS
Total wetland area,
Habitat diversity
METRIC
Percent of restored
floodplain covered by
broadleaf marsh
BASELINE CONDITION
Covered 10% of the
floodplain
REFERENCE CONDITION
Covered 50% of the
floodplain
EXTERNAL CONSTRAINT
Excluded areas that
won't be restored
EXPECTATION
Broadleaf marsh will
cover at least 50% of the
restored floodplain
MECHANISM
Reestablishment of floodplain
hydro-period germination from
existing seed banks
TRAJECTORY
Achievement 5 years after all phases of backfilling and
implementation of headwaters revitalization regulation
schedule

Figure 13: Project flow chart (examples in parentheses).

The process of developing expectations began with the goal of re-establishing ecological integrity. For purposes of developing restoration expectations, the time period before the Central and Southern Florida Flood Control Project represents ecological integrity in the Kissimmee Basin. The next step involved expressing the ecological integrity goal as a set of key characteristics of the system called endpoints. Each endpoint was represented by one or more metrics. For each metric, studies were conducted to collect data on remnant river channels or on the floodplain to establish the baseline condition. Reference conditions used to estimate pre-channelization conditions were identified from pre-existing data for each metric, and reference condition estimates were adjusted to account for constraints that are outside the influence of the restoration project. The summary statement of an expectation was expressed as the difference between the baseline condition and the reference condition, adjusted for anticipated external constraints. For each expectation, a mechanism was proposed that outlined conceptually how the restoration project would cause the expectation to be achieved. Finally, a trajectory or appropriate time frame was identified for achieving the responses.

The following are the 25 expectations, the first 7 of which are hydromorphologic (after Anderson et al. 2005)

Hydrology geomorphology, and water quality responses

1. Continuous River Channel Flow
2. Annual Distribution and Year-to-Year Variability of Monthly Mean Flows
3. Stage Hydrograph Characteristics
4. Stage Recession Rates
5. River Channel Velocities
6. River Channel Bed Deposits
7. Sand Deposition and Point Bar Formation Inside River Channel Bends
8. Dissolved Oxygen Concentrations in the River Channel
9. Turbidity and Suspended Solids Concentrations in the River Channel

River channel and floodplain plant communities responses

10. Width of Littoral Vegetation Beds Relative to Channel Pattern
11. Plant Community Structure in the River Channels
12. Areal Coverage of Floodplain Wetlands
13. Areal Coverage of Broadleaf Marsh
14. Areal Coverage of Wet Prairie

Invertebrate and amphibian and reptile community responses

15. River Channel Macroinvertebrate Drift Composition
16. Increased Relative Density, Biomass, and Production of Passive Filtering-Collectors on River Channel Snags
17. Aquatic Invertebrate Community Structure in Broadleaf Marshes
18. Aquatic Invertebrate Community Structure in River Channel Benthic Habitats
19. Number of Amphibians and Reptiles Using the Floodplain
20. Use of Floodplain for Amphibian Reproduction and Larval Development

Fish and bird community responses

21. Densities of Small Fishes within Floodplain Marshes
22. River Channel Fish Community Structure
23. Guild Composition, Age Classes, and Relative Abundance of Fishes Using
24. Density of Long-Legged Wading Birds on the Floodplain
25. Winter Abundance of Waterfowl on the Floodplain

The geomorphology study focused on attributes of the river channel that are likely to respond directly to reestablishment of flow and that influence habitat quality for plants and animals using the river channel. These attributes included point bars and the accumulation of organic matter on the river bottom. Pre-channelization aerial photography revealed active formation of point bars on almost every meander bend, while aerial photography of the channelized system showed that none of the meanders in the study area had active point bars and that relict point bars were overgrown with vegetation. Sediment samples from remnant river channels showed that organic deposits were thicker and covered a larger portion of the channel than in the reference condition based on remnant channels with partially restored flow. These organic deposits altered the river channel by reducing average channel depth, increasing the width/depth ratio, and reducing channel cross-sectional area.

Expectations for hydromorphology were broken into two groups, hydrology and geomorphology, as follows:

Expectations for Hydrology

1. The number of days that discharge is equal to 0 cfs in a water year will be zero for the restored channel of the Kissimmee River.
2. Intra-annual monthly mean flows will reflect historic seasonal patterns and have interannual variability (coefficient of variation) 1.0.
3. River channel stage will exceed the average ground elevation for 180 d per water year and stages will fluctuate by 3.75 feet.
4. An annual prolonged recession event will be re-established with an average duration 173 days and with peak stages in the wet season receding to a low stage in the dry season at a rate that will not exceed 1.0 ft (30 cm) per 30 days.
5. Mean velocities within the main river channel will range from 0.8 to 1.8 ft/s (0.2 to 0.6 m/s) a minimum of 85% of the year.

Expectations for Geomorphology

6. In restored river channels, mean thickness of substrate-overlying river bed deposits will decrease by 65%, percent of samples without substrate-overlying river bed deposits will increase by 165%, and the thickness of substrate-overlying river bed deposits at the thalweg (deepest point in the channel) will decrease by 70%.
7. Point bars will form on the inside bends of river channel meanders with an arc angle 70°.

An example of how expectations were formulated and measured is provided Box 1for Expectation 7 above on *sand deposition and point bar formation inside river channel bends.*

BOX 1: EXPECTATION 7 IN FURTHER DETAIL

SAND DEPOSITION AND POINT BAR FORMATION INSIDE RIVER CHANNEL BENDS

Expectation
Point bars will form on the inside bends of river channel meanders with an arc angle >70°.

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Date June 29, 1999; revised April 3, 2001

Relevant Endpoints
- Ecological Integrity/Restoration/Physical Integrity - River Channel Substrate
- Ecological Integrity/Restoration/Physical Integrity - Hydrogeomorphic Processes
- Ecological Integrity/Restoration /System Functional Integrity - Habitat Quality
- Ecological Integrity/Restoration /System Functional Integrity - Habitat Diversity

Metrics
Number of meanders with point bars

Baseline Conditions
Aerial photographs taken since channelization indicate that active point bars (i.e., sand deposition found on the inside bend of meanders) are not visible in remnant river channels (Anderson et al. 2005). Point bars that were present in the pre-channelized system have been colonized by vegetation, and elimination of flow has precluded development of new bars. Cross sectional profiles show a remnant sloping riverbed along inner portions of meanders remains, but submerged portions of these relic point bars are covered with organic deposits or aquatic vegetation.

Reference Conditions
Point bars were likely an important habitat feature in the historic Kissimmee River. Point bars provided topographic diversity and a range of flow velocities useful to many species (Bain et al. 1988, Lobb and Orth 1991, Sheldon and Meffe 1995), and likely provided spawning habitat for pit nesters (e.g., centrarchids) (L. Glenn, personal communication), refuge and foraging habitat for small fish, and habitat for shore birds and foraging wading birds. Point bars are typical of rivers with sinuous, low-gradient, meandering channels, sandy substrates, and well-developed floodplains in broad drainage basins (Leopold 1994, Rosgen 1994, 1996). We quantified the occurrence of point bars using historical aerial photographs during extreme low water levels (38.64 NGVD at Fort Kissimmee) in June 1956. Point bars occurred on the inside of 329 of 330 river meanders with an arc angle >70°. We used an arc angle of 70° (Rosgen 1996) to distinguish meander bends from minor curvature of the channel. Largest point bars occurred on curves downstream of long, straight river runs.

Point bars formed on inside curves of meanders after flow was partially restored to remnant river channels in Pool B (Toth 1993). After the Test Fill Plug was constructed in

1994 (Koebel et al. 1999), point bars in the adjacent remnant river channel increased in area and height, particularly after high flows in winter 1998.

Mechanism for Achieving Expectation
Point bar formation is a result of sediment transport and deposition and has a well-documented relationship to river suspended sediment size and flow velocities (Knighton 1998). Restoration of point bars will be dependent on the discharge volume and duration of flow. Reestablishment of historical flow regimes (e.g., bankfull discharge of 40–50 m3/s) is expected to reestablish active point bar formation on inside curves of meanders in remnant river channels.

Adjustments for External Constraints
None

Means of Evaluation
Point bar formation will be monitored annually for five years after reestablishment of flow through the river channel. The formation or reappearance of point bars will be tracked and georeferenced with GPS along 80 meanders with an arc angle >70º within Pool C and lower Pool B. This area will be affected by restored flow from the first phase of the restoration project.

Time Course
Based on sediment transport and deposition in Pool B during the Kissimmee River Demonstration Project of 1985–1988 and after the Test Fill Plug construction in 1994, point bar formation will occur following bankful discharge events. Reestablishment of pre-channelization point bar distribution will occur within three to five years, depending on the magnitude and duration of bankfull discharge.

Evaluation
The KRRP's success is being evaluated through the Kissimmee River Restoration Evaluation Program (KRREP). Evaluation of restoration success was recognized as a crucial aspect of the project. The ecosystem restoration evaluation program evaluates ecosystem processes and the diversity, density and production of key communities (e.g., vascular plants, fish, and water and wading birds). Changes in principal habitat components include hydrologic characteristics, water quality and nutrient cycling, and river channel and floodplain geomorphic parameters along the river channel. The evaluation program includes many components focusing on four major categories of monitoring, of which 3 are hydromorphologic.

1. ***Ecological***: Ecological monitoring is intended to measure changes in attributes that would indicate the attainment of the ecological integrity goal. These attributes include water quality, vegetation, habitat, fish and wildlife, endangered species, and ecosystem functions such as energy flow and nutrient cycling.
2. ***Hydraulics***: Monitoring of water levels, velocities, and flows is needed to evaluate five specific hydrologic criteria for the restoration project and to aid in the interpretation of the results of other monitoring studies.
3. ***Sedimentation***: The restored river channel will consist of segments of remnant river channel reconnected across the backfilled canal. Monitoring is needed to determine if

the managed flow regime results in erosion and deposition in the reconstructed river channel, leading to excessive sedimentation.

4. ***Stability of the restored river channel:*** Similar to sedimentation, monitoring of cross-sections is needed to determine if the reconstructed river channel remains stable under the managed flow regime.

Benchmarking and the KRRP

The Kissimmee River Restoration Evaluation Program is an excellent example of river restoration project benchmarking and endpoint development. The Kissimmee River Restoration Evaluation Program (KRREP) is based on extensive long-term monitoring and effectively connects results and future planning back to the benchmarks and endpoints. However, the terminology used in the KRRP and KRREP is not the same, but a translation can be made, as follows.

KRRP and KRREP	Quantitative/qualitative	WP 5.1	Quantitative/qualitative
objective	qualitative	endpoint	qualitative
benchmark	either	reference condition	quantitative
endpoint	either	expectation	quantitative

The KRRP and KRREP use quantitative data only for benchmarks and endpoints, while WP 5.1 permits qualitative assessments. Most projects expected to use the benchmarking tools in WP 5.1 are much smaller in geographic and financial scope and will sometimes need to use qualitative assessments to identify project objectives, determine reference conditions, develop acceptable endpoints, and evaluate project results.

Regardless of the differences in scope and terminology, the KRRP's underlying planning organization, attention to detail, standardized presentation of expectations and monitoring results, and the feedback loop to future planning are all elements useful for the planning of any river restoration project.

3.2.6 Environmental flows

Virtually all lentic ecosystems are controlled by the hydrological regime (Junk et al. 1989; Bunn & Arthington, 2002; Poff & Zimmerman, 2010). The changing quantity of water flowing in a river provides habitat and influences water quality, temperature, nutrient cycling, oxygen availability and the geomorphic processes that shape river channels and floodplains (Poff et al. 1997; Richter et al. 1997). Natural riverine landscapes ("riverscapes") are characterised by floodplain, natural flow regime, high hydraulic connectivity, a successional landscape mosaic with high habitat heterogeneity and complex land-water coupling and exchange (Fausch et al. 2002). The shape and size of river channels, the distribution of pool-riffle habitats and the stability of the substrate are all largely determined by the interaction between the flow regime and local geology and landform (Bunn & Arthington, 2002). The natural flow regime is thus a critical factor in determining both physical habitat structure and diversity in rivers; these are important factors in influencing ecological functioning and biological community structures in rivers, where changes in physical habitat structures are reflected by changes in biological communities.

Unfortunately, in many locations, water demand often exceeds availability, and in many cases exploitation of water resources has led to significant degradation of freshwater biodiversity. Water resource management needs to be an integrated part of the RBMP. In more arid river basins, such as in the Mediterranean, drought management plans are already partly integrated into RBM planning. However, the recent assessment of both the water scarcity and drought policy and the climate change adaptation and vulnerability policies show that there are considerable improvements needed in the future management of water resources in Europe. The European Commission 'Blueprint to safeguard Europe's waters' and EEA's report 'European waters — current status and future challenges (Synthesis)' (EEA, 2012) kicks-off the discussion of the future management of European water resources (EEA, 2012). In this context, ecological flows are an important element for achieving good hydromorphological status. Ecological flows reflect the volumes and flow regimes that are required for the ecosystem and all relevant functionalities (EEA, 2012).

As such the concept of ecological or environmental flows to ensure good ecological functioning is a specific requirement of restoration success and can be considered an environmental objective and potentially a defined endpoint. Methods for determining environmental flows differ in input information requirements, types of ecosystems they are designed for, time which is needed for their application, and in the level of confidence in the final estimates. The methods range from purely hydrological methods, which derive environmentally acceptable flows from flow data and use limited ecological information or eco-hydrological hypotheses (e.g. Richter et al. 1997; Hughes & Münster, 2000), to multidisciplinary, comprehensive methods that involve expert panel discussions and collection of significant amounts of geo-morphological and ecological data (e.g. Arthington et al. 1998, 2006; King & Louw, 1998). Dammed rivers often have highly regulated flow regimes and rehabilitation requires changes to dam operations to provide more natural environmental flows. In hydropeaking systems with flows that vary on a diel basis relative to hydropower demand, regulators often prescribe the range of acceptable flows as well as the rate at which flows can be changed (i.e. ramping rates; Smokorowski et al. 2011) in an attempt to minimise stranding (Nagrodski et al. 2012). In some instances where flows have been modified to yield low and stable flows, the use of strategically-timed pulse flows can be used to stimulate upstream movement of migratory fish (Hasler et al. 2012). Ultimately, however, there is a need to understand how eco-hydromorphic processes generate observed patterns, and in turn how patterns influence processes. Thus, there is a need for indicators that can be used measure the efficacy of setting environmental flows for achieving GES and GEP.

3.3 Conclusions

There is paucity in information from restoration projects that measure success and this is mainly attributable to a lack of understanding of how to measure success. This section has drawn upon what are considered 'good' examples of river restoration where ideal project frameworks have been utilised to identify key features for project success. They identified the importance of background knowledge on the status of river in question and the pressures that act upon it, in addition to identifying problems and constraints to restoration. Pre-monitoring and identification of reference sites enabled benchmarks and endpoints to be set, further enabling the formulation of clear and realistic objectives to related to achievable endpoints. The case studies provide good examples where success was defined in a pre-restoration phase and guided subsequent monitoring. Measurable performance indicators were used to determine the extent to which the objectives have been achieved through the monitoring design and evaluation stage. Woolsey et al. (2005 & 2007) recommended '*performance indicators should and must be measured in various ecosystem compartments or elements and at various spatial and temporal scales because they give complementary information at different spatial and temporal scales*'. The more project objectives that record measurable improvements, the more successful the project and for that reason, indicators need to be quantified to identify change. To develop the appropriate objectives and performance indicators to measure the success or failure of a restoration project requires collaboration between different scientific disciplines, engineers and stakeholders. This was proven to be a vital step in the Kissimmee, Thur and Rhöne projects. The key features and processes to evaluate restoration success from the different case studies are used as the basis for development of the project framework tool in Section 4.

4. Planning protocol

Despite considerable investment, restoration projects have, in general, infrequently been evaluated for their success or conducted in a manner that allows such evaluation. Whilst the reasons for this are complex, lack of comprehensive and well formulated planning, implementation and appraisal techniques are probably a root cause. The project approach methodologies used in aid-financed development offer tools for planning, implementing and appraising restoration projects (Gittinger, 1982; Anon, 1982). The aims of restoration activities in Europe are influenced by a plethora of EU Directives and national government policies. The aims and objectives provide a framework into which projects must fit in order that remediation actions can proceed in a rational way. For example, the WFD objectives of GES and GEP embody the strategy used to implement restoration actions.

The institutional context in which river restoration has taken place has evolved over the last 30 years and is subject to rapid change, but in Europe more particularly since the promulgation of the WFD in 2000. The environment where river restoration takes place is the location of intense competition between water users, thus by definition, development in these conditions is complex, dynamic and regularly frustrating. This is especially so for the protection and improvement in aquatic biodiversity, which has lagged behind other water users in several ways, notably in the creation of a legislative framework to govern development. River engineering for flood control and navigation and water pollution control by contrast, have developed rapidly from a legislative base initiated in the late 19th Century and gradually strengthened through to the present. Today, in the EU, the way forward for inland aquatic biodiversity conservation and recovery must be through the establishment of a coherent policy which establishes the goals of restoration in the context of other water users.

To support this direction, this section develops tools to help prepare river restoration plans from an integrated perspective accounting for both living aquatic resources-related components and well as externalities acting on the biota. This approach, which has its roots in catchment management and coastal zone management, provides a more holistic view of restoration management and overcomes one of the major problems faced by managers, isolation of the sector from other sector developments in freshwater ecosystems. Such an approach must be interactive and engage all stakeholders to enable wider issues beyond those related to a single activity, such as biodiversity conservation, to be taken into account during the process of taking decisions about that activity and its likely effect upon the environment and other activities, or conversely the likely effect of other activities on biodiversity.

In view of the high degree of inter-dependence between activities, to develop the project approach it is necessary to explore the wide range of uses and issues (problems and conflicts with and between user groups) within the system itself and then define management decisions that account for these interactions. The planning process adopts a formulaic approach to account for the needs and aspirations of the various stakeholders and also the impact of their activities on ecosystem functioning and services. Such a strategy is outlined in Figure 14. The procedure is process driven in its development and

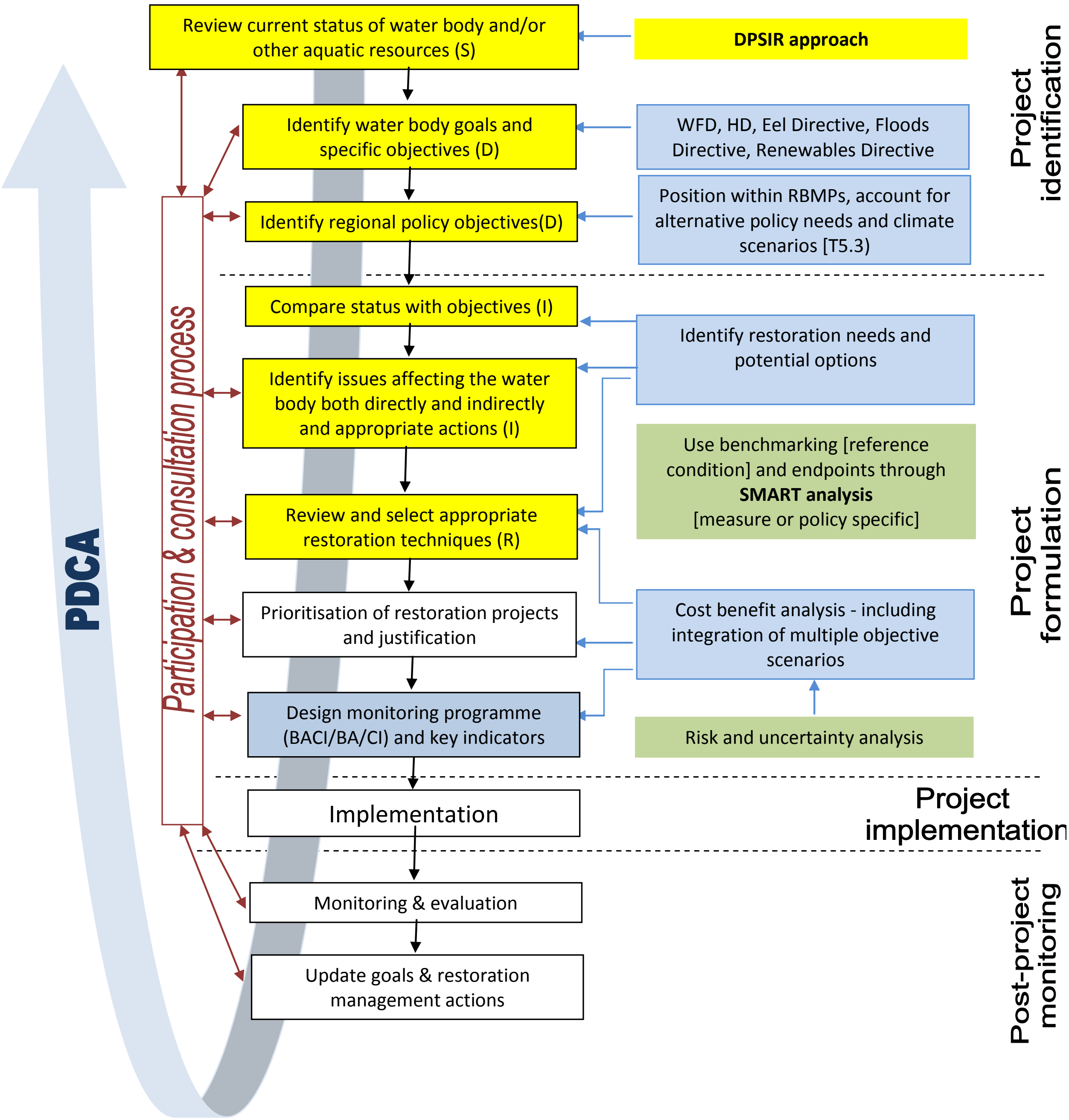

Figure 14. Proposed planning protocol for restoration projects - yellow coloured boxes represent steps in the DPSIR approach to management intervention.

makes use of various project planning tools (e.g. PCDA, DPSIR, conflict resolution, Environmental Impact Assessment and Logical Framework, SMART and participation ladders) to:

- diagnose problems and produce a strategy for their remediation;
- provide knowledge of the technical policy and background to conflicts of multiple use of resources;

- develop a plan based on comparison of status of the target ecosystem with objectives as defined by the institutional, regional, national policy;
- ultimately develop an action plan with actions and targets, whilst recognising the need for an integrated approach to management of resources to minimise conflicts and optimise use.

The approach specifically does not just deal with technical issues targeting ecosystem functioning and services, and their effectiveness or limitations. It works within a regional policy framework and attempts to address societal and prevailing ideas and values and accounts for institutional frameworks, i.e. fit within the regulations and legislation. It is developed for resources and environmental entities whose physical boundaries are based on logical and sensible limits. Because the needs and aspirations of all resource users are integrated into the framework, there is the capacity to minimise conflicts and optimise use.

Key to establishing a restoration plan is defining boundaries of the management area. In a river system this can be the whole river system but must include the associate catchment, accounting for all its land uses. In larger river systems, the river can be divided into zones based on natural features, such as an instream lake or confluence of two major rivers. Geographical Information System platforms can be used effectively to map the boundaries of the management area. When the river is broken into zones, care must be taken to account for upstream or downstream factors that could affect the ecosystem functioning and delivery of services in the management zone, e.g. polluting effluent discharged upstream may have considerable impacts further downstream within the management area. Similarly, a downstream dam may prevent migratory fish accessing spawning or feeding areas further upstream.

4.1 The project approach

A project may be defined (Gittinger, 1982) as an activity upon which resources (costs) are expended to create capital assets that will produce benefits (related to ecosystem services delivery) over an extended period of time: and which logically lends itself to planning, financing and implementing as a unit. The project approach to development is characterised by a number of phases (PCDA – plan, check, do and act) that are linked, and relate overall to national policies and sector plans (

Figure 14). The phases are themselves characterised by certain features which are summarised in Table 10, but more specifically can be aligned with the DPSIR approach (Drivers, Pressures, State, Impact, Response). The strategy is concerned with identifying projects that have a high priority within the sector and appear suitable for development. The emphasis is on developing projects in a rational way supported by economic and sectoral analyses to gain an understanding of the potential of a particular action. It is then possible to identify projects that fit into and support a coherent restoration strategy and that meet both WFD and cross-sectoral objectives.

Table 10. Overview of steps in the planning protocol outlined in Figure 14

Step	Stage of protocol	Possible methodological approach	Potential selection population	Resulting selection population	Step product	Explanation	Example
Project Identification							
1	Review current status of water body and/or other aquatic resources	DPSIR (current *state*)	All water bodies	All water bodies w/ HYMO issues and status < good	List of all water bodies w/ HYMO issues and status < good	The WFD and other European directives stipulate that all rivers be assessed. The list of those that do not meet the minimum status requirement of "good" will be reviewed for potential HYMO rehabilitation project sites.	Ex. A water body may have a lower than "good" status because of poor water quality due to high nutrient loads (QE). If the source of nutrients is erosion of legacy bank sediments in incised channels, there may exist HYMO rehabilitation potential. If the cause is over-application of fertilizers or failing wastewater treatment, then there is no HYMO rehabilitation potential and the water body can be dropped from the potential site list.
2 (3)	Identify regional policy objectives	DPSIR (*drivers*)	Water bodies with RBMP or other plans	All Step 1 water bodies with HYMO issues and status < good, preferably with relevant RBMP	List of all water bodies w/ HYMO issues and status < good, including those with a RBMP or other plan.	RBMPs are required for all river basins. The list created in Step 1 should be reviewed against the RBMP to see how rehabilitation might be connected to other projects and future planning. The RBMP may have already identified certain rivers, river reaches or river types as priorities for rehabilitation. Issues of ownership, politics, finances, cultural resources, etc. may eliminate some sites from the potential projects list.	Ex. Rehabilitation potential is also dependent on river basin management. Erosion of legacy bank sediments in a reach may be controlled by reducing storm water runoff and rehabilitating the reach channel and floodplain. However, if long-term basin planning includes removing an upstream dam in the future, it may be wise to start with the upstream dam removal and consider the channel rehabilitation later, as a subsequent dam removal may make a prior reach rehabilitation unnecessary or cause a future failure.

Step	Stage of protocol	Possible methodological approach	Potential selection population	Resulting selection population	Step product	Explanation	Example
3 (2)	Identify water body goals and specific objectives	DPSIR (reference *state*)	Reference conditions benchmarks (BM) water bodies	Reference conditions BM water bodies for comparison to water bodies selected in Step 2	List of water bodies and their characteristics that can provide reference conditions BMs	Identify one or more reference rivers/reaches and the key quality elements (QE) and HYMO processes that will serve as reference condition benchmarks. These rivers/reaches will be used in Step 4 to assess potential rehabilitation sites, to identify causative issues affecting the impaired water body and the effective actions to rehabilitate in Steps 5a, 5b, to provide the monitoring framework and/or serve as a monitoring control in Step 8.	Ex. The "high" status water quality BM reference condition for the nutrient QE is a lower nutrient concentration than the existing condition. The HYMO BM is minimal bank erosion and a channel with a floodplain that is active on average 3 times a year.
Project formulation							
4	Compare water body status with objectives	DPSIR (*impacts*)	Step 2 potential water body sites	Water bodies with QE deficits determined by comparing Step 3 reference sites with Step 2 potential rehabilitation sites	Analysis QE deficits for Step 2 water bodies	Analyse the QE deficits resulting in the status < good. A HYMO processes deficit analysis should be completed using the BM reference conditions for the relevant QEs.	Ex. QE deficit: The nutrient concentration is too high for "good" status. HYMO process deficits: The existing incised channel overflows only in the 25+ year recurrence event and bank erosion is significant, w/d ratio too low.
5a (5)	Identify issues affecting the water body both directly and indirectly	DPSIR (*pressures*)	Cause and effect issues of HYMO degradation resulting in QE deficits	HYMO degradation cause and effect issues for QE deficits identified in Step 4	List of causes and effects for the QE deficits for the Step 2 water bodies	Examine both basin hydrology and in-stream hydraulics for causes and effects of HYMO process degradation and identify which causes must be addressed to achieve "good" status. Be sure to include potential human activity changes (land uses), without which a rehabilitation project will fail or with which will not be needed. Issues of time and spatial scales must be addressed at this point.	Ex. Hydrology: Percent basin impervious surface area is high leading to large flow and minimal sediment delivery regimes with high erosion potential. Hydraulics: Streambed incised to bedrock causing bank erosion and failure. Water quality: Stored nutrients released from eroding bank sediments.
5b	Identify	DPSIR	HYMO process	Appropriate HYMO	List of types of	Achieving the reference BM	Ex. Increase basin infiltration

Step	Stage of protocol	Possible methodological approach	Potential selection population	Resulting selection population	Step product	Explanation	Example
(5)	appropriate HYMO process rehabilitation actions	(*responses*)	rehabilitation actions	process rehabilitation actions to address Step 5a HYMO QE causes relevant to the achievable EPs for Step 4 sites	HYMO rehabilitation actions to achieve each acceptable EP	conditions may be possible, but probably is not. After determining causes and effects (Step 4), identify what processes must be addressed and what endpoints (EP) are acceptable for achieving "good" status. Select the set of hydrologic and hydraulic processes to be considered for rehabilitation actions to achieve these EPs. Spatial scale issues should be addressed.	capacity to reduce storm runoff flow, reconfigure channel geometry erosion and deposition competence to dynamic equilibrium and the floodplain to flood on average 3 times per year. The watershed is partially built-out so infiltration zone sites are somewhat limited. There is room to reconstruct a floodplain.
6	Review and select appropriate HYMO rehabilitation techniques	SMART (*specific)*	HYMO rehabilitation techniques to meet EP	Appropriate HYMO rehabilitation techniques relevant to Step 5b HYMO process actions	Report on specific implementable techniques	For each HYMO action there is a plurality of implementation techniques, each with a specific design and engineering effort, cost, operation and maintenance requirements, spatial and temporal requirements, and efficiency.	Ex. Disconnect impervious surfaces with infiltration zones using a combination of hard and soft techniques. Reconfigure channel and FP geometry and resistance for the equilibrium flow and sediment transport regimes. Watershed open space limitations may require some retrofitting of built areas.
7	Prioritisation of rehabilitation projects and justification	SMART (*attainable*)	Recent rehabilitation project costs for the relevant techniques	Cost effective technique(s) for each project site	Analysis of cost effective technique(s) and costs for each project site	Cost-benefit analysis – including integration of multiple objective scenarios. Highly engineered techniques tend to be very costly and may require costly operation and maintenance efforts. Success monitoring may require high tech installations and expertise. The costs (damage, legal, replacement, etc.) of failure may also be high (e.g. flooding).	Ex. Soils are appropriate for infiltration zones and existing, upland open space should be used. If there is insufficient open space, creation of wetlands in a constructed floodplain might be considered, which may address 2 or more of the deficits. Open space preservation and reforestation schemes should be preferred and engineered infiltration systems should be avoided where possible.
8	Design monitoring programme (BACI/BA/CI) and key indicators	SMART (*measurable*)	Existing and new monitoring protocols for the key indicators	Key indicators to be monitored and monitoring protocol	Programme of key indicators and monitoring protocol for each rehabilitation site	The monitoring program must be designed prior to implementation of the rehabilitation project. Data from controls or reference sites may be needed for engineering design and "before" monitoring must begin at	Ex. A "before" monitoring programme should include piezometric and percolation studies of potential infiltration sites. In addition, a complete geomorphologic study is needed of the stream and

Step	Stage of protocol	Possible methodological approach	Potential selection population	Resulting selection population	Step product	Explanation	Example
						least 1 year before changes are made. Depending on the type of changes proposed, a considerably longer "before" monitoring programme may be required. Time and spatial scales of monitoring should be carefully considered. Any change in the watershed or channel is a disturbance and the response time and space will vary.	riparian areas. If sediment transport and stream flow data are needed, the studies should start several years before implementation. If a reference reach is being used for channel design purposes, the geomorphologic study of the reference channel must be done in advance of any engineering design, cost determination, or permitting. Reduction in nutrient concentrations may be quick and monitored only for several years at the immediate site. Stability of the reconfigured channel may need to be monitored over several decades depending on flood recurrence. Results of channel monitoring may result in renewed nutrient concentration monitoring.
Project implementation							
9	Implementation		Selected rehabilitation sites and watersheds	Rehabilitated sites and watersheds	Completed rehabilitation project	Most rehabilitation projects have several parts, some of which should be implemented consecutively and some simultaneously. The temporal scales of disturbance and recovery must be considered.	Ex. Infiltration zones should be implemented first as they may have an effect on stream flow, sediment supply, flood periodicity, and erosion rates. Reduction in bank erosion may sufficiently reduce nutrient load (EP) so that channel geometry reconfiguration is not needed to address the nutrient concentration QE deficit, though it may be desirable for other reasons.
Post-project actions							

Step	Stage of protocol	Possible methodological approach	Potential selection population	Resulting selection population	Step product	Explanation	Example
10	Monitoring	SMART (*relevant, time-bound*)	Rehabilitated site(s) and appropriate parts of the watershed	Monitoring results	Periodic monitoring results reports	Key indicators are all monitored at appropriate temporal and spatial scales.	Ex. The "after" monitoring programme included real-time water quality (nutrient, turbidity, etc.) and flow monitoring, monthly bank erosion rate monitoring, and an annual channel geometry survey. Nutrient concentration was reduced, but the acceptable EP was not reached. The expected flow reduction did not occur.
11	Evaluation	SMARTER (*evaluate*)	Monitoring results	Successes and failures of rehabilitation project	Report and proposed corrections	Most projects experience a mix of success and failure. Sometimes corrections are easily identified. Monitoring and subsequent evaluation should be conducted.	Ex. The infiltration zones were studied to determine if they were functioning as designed. Some plantings had failed and some zones were undersized. Corrections were proposed.
12	Update goals and restoration management actions	SMARTER (*re-evaluate*)	Evaluation results	Immediate corrections and future monitoring, evaluation, and rehabilitation.	Revised rehabilitation goals and management actions	Updating goals and revising management actions are iterative processes and periodicity will depend on HYMO processes, monitoring results, changing patterns of human activity, etc.	Ex. Repair and expansion of the infiltration zones will be completed immediately. Monitoring will continue for another 2 years. If the EP is not reached, reconfiguration of channel geometry and floodplain will be considered.

4.1.1 **Project identification**

Project identification is the stage at which the initial restoration project proposal is conceived and formulated. The identification phase may be divided into two fundamental aspects. In the first the restoration project concept is considered in relation to:

- the overall status of the aquatic ecosystem functioning and the ecological status or potential; and
- the regional or national policy and WFD priorities (see - http://www.restorerivers.eu/Publications/tabid/2624/mod/11083/articleType/ArticleView/articleId/3052/Default.aspx).

The first step provides an understanding of the current status of the ecosystem functioning and ecosystem services in the management zone to establish the baseline against which to develop any restoration project (equivalent to the DPSIR State assessment). The basic information required includes, but is not exclusive to:

- background geography and landscape topography, political domains, climate and general infrastructural development;
- habitat modification and geomorphological alteration;
- hydrology, including modifications to flow regulation, abstraction and other water uses;
- flood defence;
- fisheries, recreation and conservation;
- water quality;
- land use/navigation and mineral extraction;
- urban, agricultural and industrial development.

All possible information should be collated and analysed to provide a comprehensive picture of the ecological status and resource use patterns. Key to this evaluation is assessment of the interrelationships between human activities and environmental factors that drive the ecosystem functioning and provision of services. Particular environmental characteristics to be examined include hydrology and limnology, and modifications thereof, water quality, land use changes, habitat degradation and other impacts of resources user. In addition to assessment of the aquatic resources, equal attention should focus on socio-economic and institutional framework. These influence the way the resources are exploited and managed, the role in society and thus performance of provisioning services in regional economies. The capacity of the institutional arrangements to manage and enforce legislation is fundamental to implementing restoration actions developed within a plan. Similarly, knowledge of the socioeconomic status and pressures are critical to developing a sustainable restoration plan and associated actions. Finally, it is critical that full consultation with stakeholders and those likely to be affected by the restoration scheme should be instigated at this stage and the needs and aspirations of all included in the decision making procedure.

These factors set the proposed restoration project in the context of policy issues. In the second aspect of the identification phase the relevant policy issues are considered, notably:

- the overall justification for the project (perspectives, development objectives)
- the likely target groups and impact beneficiaries, as well as those who might be adversely affected;
- the key factors influencing the likely success and failure of the project.

Restoration objectives should be clearly defined adopting a river basin-wide approach, and have been developed from high priority WFD and national policy objectives (equivalent to the DPSIR Drivers assessment). This intrinsically moves the existing approach from being issue-driven towards an emphasis on forward planning. Typical WFD policy objectives include:

- Achievement of GES or GEP
- Conservation & efficient exploitation of resources;
- Contribution to species conservation objectives;
- Creation of regional employment and maximising social benefits;
- Regional development (regional and multi-lateral cooperation);
- Establishment of the legal and administrative framework for regulation;
- Assessment of environmental, economic and social impacts;
- Maximising ecosystem health.

The third aspect concentrates on the techniques used to measure the viability of the restoration project as it evolves through the phases of the project approach. One of the most commonly used techniques to structure the process described above is the logical framework approach (Anon, 1982; Table 11). The technique (summarised in Appendix 4) is useful in setting out the design of the restoration project in a clear and logical way so that any weaknesses that exist can be brought to the attention of the planners. The identified deficiencies may then be remedied at an early stage, or if insuperable, the restoration project may be discounted. The logical framework technique emphasises the value of choosing measurable indicators or endpoints which can be assessed throughout the life of the project, and also instructs the planners to assess carefully the risks and assumptions upon which the project is based.

Table 11: Form of the Logical Framework Approach (source: Anon. 1982)

PROJECT STRUCTURE	Measureable indicators	Means of verification	External factors / assumptions
Goal: sectoral objectives			
Purpose: specific objective			
Outputs			
Activities	Inputs		

Indicators or endpoints (see section 4.1.2.1 for detailed explanation) are used to determine the extent to which the objectives have been achieved and can be measured at different times, notably in the monitoring of project performance, appraisal and evaluation phases. Where possible, the endpoints should define the target groups, quantities, quality, time and location. The section of the project devoted to the risks and conditions of the logical framework is concerned with establishing realistic parameters of the environment in which the development project is to function and the likelihood of the project meeting its objectives (see Section 4.1.2.2).

Table 11 illustrates a project framework format that might be adopted at the outset of a restoration project (see Appendix 4 for further details). Starting with the aim of the project, a series of objectives, outputs and inputs are developed down the first column at the left-hand side of the page. The second column addresses the indicators (endpoints) that have been determined at the outset of the project and how they can be verified as the project is developed further through the various phases of the project approach. The final column assesses the risks and assumptions which underpin the elements described in the first two columns. As the restoration project develops so the logical framework will be modified to take account of new information likely to affect the project elements.

An example of the use of the Logical Project Framework is given in Table 12. In this theoretical example, a familiar theme associated with fisheries is embodied in the overall remediation aim. A certain stretch of river is deemed to have deteriorated in productivity and species diversity, and as a consequence is failing WFD objectives. The underlying causes are barriers to migration and sedimentation of spawning and nursery habitats in the headwaters. These concerns are transmitted to the river basin management authority, who is asked to implement a remediation programme. This situation is typical of the scenarios experienced under WFD compliance. If the aims and objectives of the logical framework are considered (Table 12), the recommended course of action is frequently fish passage easement (improving fish passage facilities at barriers). However, the chances of success are limited if the original aim of recovery of migratory fish stocks is to be pursued because the recruitment bottleneck associated with degraded spawning and nursery habits is not addressed. Thus to commit scarce resources to this project aim will probably result in only short term and easily dissipated benefits. In essence this action would very likely not contribute to any lasting improvement of the 'quality' of the river fishery and improvement in WFD status. In the assumptions\risks (Table 12) attention is drawn to the perceived nature of the problem and the question of the value of fish easement as a corrective measure. At this stage the project planners would probably reject this option or re-examine the restoration measures from a different perspective.

As a result, the project should be re-orientated to address the problem of the perceived poor quality of the spawning and nursery habitat in the river (Table 12). In this example the river basin management authority would be advised to follow a course of action which is circumspect, may involve a lesser commitment of scarce resources (at least in the early stages of implementation) and may contribute to a better understanding of the river ecology by all those concerned. The reorientation described in Table 12 with refinement and quantification of the indicators, would be appropriate to take the project on to the formulation/preparation phase.

4.1.1 Project formulation

The identified project now comes under a more intensive scrutiny by the project planning team. Earlier estimates, and qualitative indicators laid down in the implementation phase will be refined and examined in detail. The technical, financial, economic, institutional, social and environmental criteria should all be revised, especially in the light of the requirements of detailed budgeting and monitoring which hitherto will not have been investigated. In the project identification phase the project planners should be concerned with the suitability and feasibility of the project, in the formulation phase the emphasis shifts to the acceptability of the project and the desired outcomes.

The assessment should also focus on those aspects of the project which appear uncertain and merit special attention. The logical framework will be expanded and upgraded to describe not only the objectives, principal issues, and definition of project components, but also the detailed costings, proposals for organisation and management arrangements, and economic and financial assessments. At this stage base-line survey work to substantiate the technical components of the project should be undertaken. In short, the project preparation/formulation is usually considered to include all those activities which preclude a final decision to invest in the restoration project.

The formulation of restoration projects naturally falls out of comparison of the status of the aquatic ecosystem and the overall regional and national policy objectives. With respect to meeting WFD objects of GES and GEP, the current ecological status of the aquatic system as whole is compared against the environmental aspirations and targets (end points – see section 4.1.2.1). This will highlight the dichotomy between current status and functioning of the ecosystem and aspirations for the water body, and thus draw out the aspects of the water body that will need to be maintained, improved and developed, and identify the issues and constraints to achieving the target. Typical areas to review include:

- natural resources as strategic assets;
- focus on the natural resources of current and/or potential economic importance;
- sustainable development;
- extent to which effective natural resources management is currently being achieved and examine future proposal in the light of technical and institutional capabilities;
- present broad management options as the basis for restoration strategies;
- identify externalities that impact on the ecological status and responses to these externalities;
- identify economic and functional linkages between restoration actions and between other sectors (e.g. hydropower and navigation);
- identify potential for combining inputs to optimise resources or increase benefits;
- conflicts between interest groups;
- identify actual and perceived conflicts and ways to alleviating them;
- assess effectiveness of authorities and make proposals for improvement;
- legislative framework;

- assess how legal framework adds or detracts from successful economic performance;
- monitoring and enforcement of management regulations;
- review social issues in relation to restoration objectives;
- human resource capabilities;
- capacity of research institutions and institutional framework for dissemination of information;
- identify existing skills and aptitudes can be developed to generate increased benefits;
- examine record of introducing new technology and management ideas;

At this stage a problem tree analysis is undertaken to review the cause effect of key issues (Figure 15). This identifies substantial and direct causes and effects of the focal problems. It is critical that existing issues are identified as well as future issues that will arise because of knowledge of planned development, e.g. a new hydropower dam being constructed. A problem/issue is not the absence of a solution (e.g. no land available for reinstating the natural water course) but an existing negative state (e.g. obstructions to fish migration). Conflicts between user groups will potentially be highlighted. Throughout the analysis there is a need for comprehensive local consultation with between stakeholders to understand their needs, motives and drivers. An example of a problem analysis is shown in Figure 16 with reference to channelization and disconnection of the floodplain.

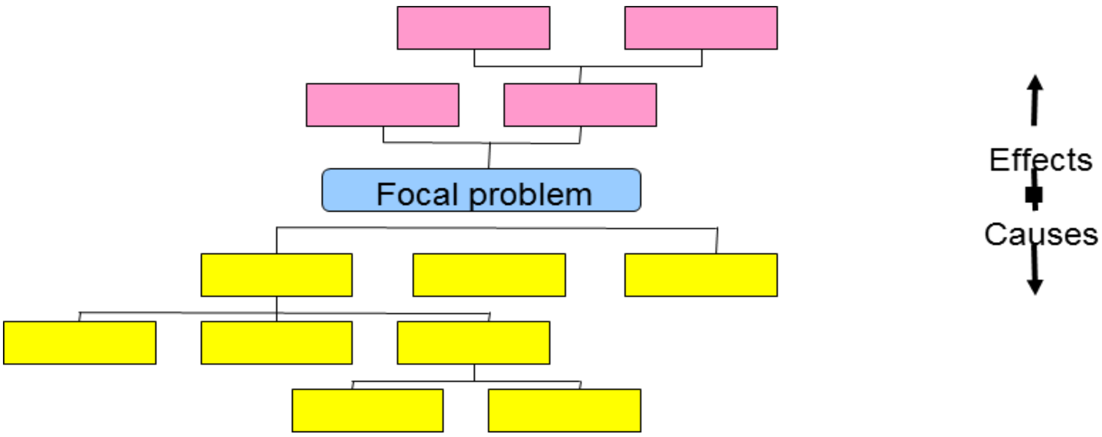

Figure 15: Structure of problem analysis tree

It is critical at this stage to set SMART objectives for the proposed restoration action. This should encompass establishing target conditions based on an understanding of what is technically feasible, socially acceptable and economically viable. The procedures of setting benchmarks and endpoints are critical to defining the outcomes of this stage, i.e. setting project objectives.

Table 12: Theoretical example of logical framework approach addressing the impact of barriers to migration and sedimentation of spawning and nursery habitats in the headwaters on fisheries.

Goal / Action	Indicators of success	Means of verification	Assumptions/risks
Problem statement			
A stretch of river is deemed to have deteriorated in productivity and species diversity, and as a consequence is failing WFD objectives. In addition anglers are complaining about reduction in catches. The underlying causes are deemed barriers to migration and sedimentation of spawning and nursery habitats in the headwaters.			
Strategic goal: Sustainable natural recruitment of migratory salmonid fish stocks in River X			
Project Title: Improve longitudinal connectivity of migratory salmonids to headwater spawning areas			
i. Assess the status of current fish populations and determine whether the sports fishery has declined compared to previous years ii. Assess migration barriers and prioritise barriers for improvement of fish passage iii. Design and construct appropriate fish passage facilities	• Fish catches maintained in accordance with long-term annual average and improved against recent catches. • Improvement in fish biomass and species composition of the river fishery to desired EQS • % improvement in sport fishery performance • Detailed analysis of the barriers and prioritization matrix with cost benefit appraisal • Fish passes constructed and proven efficient using biotelemetry tools • Upstream migration of salmonids to spawning areas facilitated	• Procedures for accurate monitoring, research and reporting in place and comprehensive annual reports of monitoring and research in fishery • Assessment of the fish biomass and species composition of the river fishery • Monitoring of sport fishing performance • Monitoring of time series data describing fish population (cycles of) abundance • Monitoring of changes in habitat quality, fish population sizes, introductions, climate, over the period of the work and at least 2 life cycles • Monitoring of size\composition of anglers catches over the period • Monitoring habitat quality over time	• That historical records are available and contribute a non ambiguous body of information to the study • That barriers to migration can be identified and that remedial action is feasible given resource constraints and heritage value of barriers • That remedial action does not impact on other resource users, e.g. hydropower. That good quality time series data are available to be evaluated and assessed • That the resources are available to carry out the action • That the managers of various data sources collaborate with the study • That the data sources indicate unambiguously which factors (if any) are the cause of the problem
Project Title: Improve habitat quality in headwater spawning and nursery areas			
i. Generation of clear picture of current status of fish populations in headwaters ii. Identify causes of sedimentation and assess impact on habitat iii. Identification\implementation of restoration management actions to address problems	• Construction of in-channel features, improved riparian vegetation, fencing, to mitigate sedimentation delivery and erosion issues. • Engagement with local stakeholders to address sources of problems • Improvements in biomass and	• Procedures for accurate monitoring, research and reporting in place and comprehensive annual reports of monitoring and research in fishery • Assessment of the fish biomass and species composition of the river fishery	• That the river can be effectively sampled • That the methods of population assessment are appropriate and the results reliable • That the resources are available to carry out the action • That the land use managers and farmers

Goal / Action	Indicators of success	Means of verification	Assumptions/risks
	species diversity of biota and fish stocks to desired EQSs • Evidence of natural recruitment of fish populations	• Monitoring of time series data describing fish population (cycles of) abundance • Monitoring of changes in habitat quality, fish population sizes, introductions, climate, over the period of the work and at least 2 life cycles • Monitoring habitat quality over time	comply with proposed project.
Inputs			
• Ecological assessment of the status of the biota to confirm degradation of stocks • Analysis of supporting environmental data over an extended period of time • Assessment of the barriers to migration to prioritize for implementing fish passage improve programme • Fish pass designs and costs for targeted barriers • Habitat improvement measures to address sedimentation issues • Organised angler opinion survey • Assessment of all other sources of coverage relating to the river fishery over recent history, e.g. historical records, press reports, personal views. • Post project monitoring and appraisal costs • Appropriate resources and funds to support restoration activities			

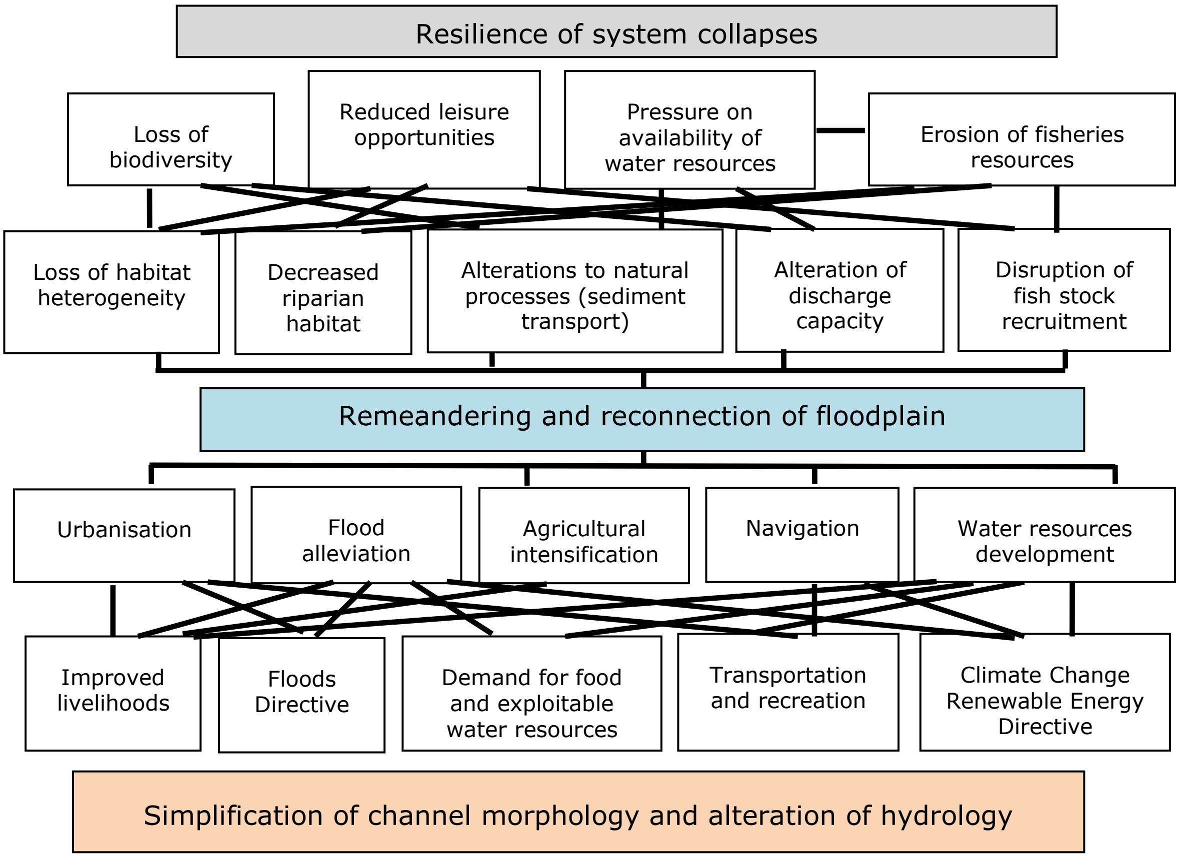

Figure 16: Example of problem analysis related to channelization and disconnection of the floodplain.

4.1.2.1 Setting benchmarks and endpoints

Establishing benchmark conditions against which to target restoration measures is a fundamental step in all restoration project planning but it is seldom adopted. Setting benchmarks draws on the assessment of catchment status and identifying restoration needs before selecting appropriate restoration actions to address those needs, identifying a prioritization strategy and prioritizing actions (see REFORM WP6), and developing a monitoring and evaluation programme. In addition to these steps, a basic understanding of the social dimension of watershed restoration is needed. This overview takes place within the context of the River Basin Management Plans, but this diagnosis to identify the causes and bottlenecks of degradation is usually inadequately specified and insufficiently quantified in most restoration plans and thus do not necessarily help plan the most effective ways for improvement. Goals and objectives need to be set at multiple stages of the restoration process, and there are multiple steps within each stage, but the initial step is to identify endpoints and benchmarks against which to measure performance. This needs be reviewed against reference conditions, to determine appropriate targets for restoration, rehabilitation and mitigation activities. Acquiring reference information can also contribute to a larger goal - determining the conditions under which restored ecosystems are likely to be self-sustaining and therefore likely to have low recurring costs of management. Even when self-sustaining behaviour is not possible (e.g. for an area that is too small for a natural disturbance regime to be reinstated) or not even desirable (e.g. for historic communities that require management against natural successional change), reference information helps determine a site-specific set of feasible restoration goals and forecast the need for management that will replace or counteract natural processes. However, this step is often missing from most restoration planning (see section 3.2), although excellent examples exist on which to base the process, e.g. Kissimmee River Restoration (Section 3.2.5; Anderson et al. 2005). Part of the problem is that in most industrialised countries, natural reference points no longer exist and complete restoration to pristine state is not possible. As an alternative, a 'guiding image' can be developed based on historical data and theoretical models (Jungwirth et al. 2002; Jansson et al. 2005; Palmer et al. 2005). Definition of such a 'guiding image', which describes the restoration potential of a river under the given circumstances and constraints, is an important step in the restoration planning process. Using, realistic, maximally attainable, near-natural reference conditions as a benchmark is more appropriate and measurable.

In the Kissimmee example, the managers have defined their expectations based on nine abiotic responses for hydrology, geomorphology, and water quality, five related to changes in plant communities in the river channel and floodplain, six related to invertebrate and amphibian and reptile communities and five expectations to describe anticipated changes in fish and bird communities (see Section 3.2.5). Twelve elements of information (Table 13) are required for each of these expectations that provide criteria against which to evaluate the outcomes of the restoration programme.

Table 13: Elements of information are required to assess expectations of restoration measures

Title	identifies the expectation.
Expectation	states the success criterion that will be evaluated to determine restoration success and concisely describes the anticipated change including values for quantitative metrics.
Author	identifies the person(s) responsible for creating the expectation and who should be contacted to answer any questions.
Date	identifies when an expectation was developed.
Relevant Endpoints	identifies characteristics of concern that reflect the restoration goal.
Metric	identifies the attributes that will be measured to evaluate the expected change.
Baseline Condition	characterizes the state of the metric for the disturbed (pre-restoration) system.
Reference Condition	describes the state or value of the metric if the system had not been disturbed (i.e., an ecosystem with ecological integrity).
Mechanism for Achieving Expectation	explains how the restoration will cause the system to change, so that the metric achieves the expected value.
Adjustment for External Constraints	explains any adjustments to the reference condition because of constraints external to the restoration project.
Means of Evaluation	describes how the expectation will be evaluated including the sampling design (sampling sites, control sites, sampling methods, replication, and frequency), the calculation of metrics, and the evaluation of the expectation (statistical test, comparison to a threshold).
Time Course	estimates the time required to achieve an expectation.

Using this example, the process of benchmarking can be broke down into a number of steps:

- "Reference condition": Deriving reference criteria – need to establish reference conditions of specific river types or river styles as defined by WP2. This may not be the pristine state but should describe the state or value of a defined ecological attribute if the system had not been disturbed by the specific pressure of pressures. It may well be defined by nearby undisturbed (by said pressure[s]) reaches of rivers that is achieving GES or GEP, i.e. an ecosystem with ecological integrity commensurate with what meeting societal aspirations.

- "Expectation": Transfer reference conditions to end points for target systems – different for each river style including temporal and spatial dimensions. This will require comparison of status against objectives for restoration that are appropriate to accommodate variability in river style/types (WP2). Establishing endpoints identifies characteristics of concern that reflect the overall restoration goal.
- "Baseline condition": Undertake deficit analysis (to identify what hydromorphological limitations and processes are constraining the recovery of the biota) and explore the potential for restoration to establish 'endpoint' target conditions.
- Once the end points have been established these restoration targets need integration into wider catchment-based activities to deliver win-win scenarios (e.g. flood mitigation, hydropower, agriculture, navigation) and take due account of the cost and benefits, specifically in relation to ecosystem services delivery, to ascertain the most effective measures to meet specific objective.

This mechanism of identifying endpoints and benchmarks to measure performance against clearly defined goals and procedures should ensure effective use of resources and increase the probability of restoration success (but see Schiemer, Baumgartner & Tockner, 1999; Buijse et al., 2005). (Woolsey et al 2007). It is recognised that the Kissimmee is a complex 350 million USD project but the underlying principles are easily adopted and downscaled for the size of project being proposed. If we continue to ignore the process of setting well-defined measureable targets then restoration sciences will continue to be based on expert judgement and fail to deliver desired outcomes.

The situation with regards benchmarking and setting endpoints for heavily modified water bodies poses different challenges. This is because the reference point for ecological potential is the maximum ecological quality that could be achieved without a significant adverse impact on the designated activities (e.g. water storage for drinking water supply) or wider environment interests that are reliant on the hydromorphological alterations (CIS-ECOSTAT, 2012). A few countries now have well developed and implemented methods for assessing ecological potential. However, a majority of countries appear less well advanced. In some cases, methods have been developed but either not yet implemented or only partially implemented. For others, the methods are still being developed or refined (CIS-ECOSTAT, 2012).

One difference between the well-developed methods for assessing GEP is that some quantify the expected biological effect of mitigation whereas others do not, describing it only in qualitative terms. This means that classification using the latter methods cannot be based on assessments against numeric biological class limits. Instead, it is based on whether or not the required mitigation (e.g. for hydromorphological conditions) is in place. However, irrespective of whether a quantitative or qualitative biological target is specified, the ambition of all of the methods is to do what can be done for ecology without significant adverse impacts. Accurately predicting the biological effects of mitigation in quantitative terms can pose significant scientific challenges. Nevertheless practitioners should work towards estimating the biological effects of mitigation in quantitative terms and use these as indicators or successful restoration actions (CIS-ECOSTAT, 2012).

It may be easier to define successful restoration when the goal is to restore some degree of function and/or some of the species than when the goal is to achieve an ecological classification target. This is particularly so because available information suggests that restoration can improve habitat heterogeneity but only minor improvements of the biota are found (Palmer et al. 2010). This suggests that restored habitat heterogeneity may not be the primary factor controlling biological diversity and ecosystem functioning (Haase et al. 2013).

4.1.2.2 Setting project objectives

From the review of issues and deficit analysis, it should be possible to identify development options and future restoration projects. This is most easily achieved using an objectives tree analysis (Figure 17). Here the problem tree (**Error! Reference source not found.**Figure 16) is transformed into a tree of objectives (options to resolve the problem). For example, for the problem "If cause A, then effect B" the option would be "Means X to achieve end Y". The aim is to reformulate all elements in the problem tree into positive desirable conditions. It is crucial to review any resulting means-ends relationships to assure validity and completeness of the objective tree and delete options that are unrealistic. This process is designed to help the project manager think about the key aspects of the river restoration project and what the project is setting out to achieve, and to recognise the inherent complexity. Key questions to consider include:

1. Is the main aim of the project to improve the physical processes of the river or to increase biological diversity in defined areas?
2. If the focus is to increase river forms and processes, what will be the benefit for the ecology (specific fauna and flora and, where appropriate, part(s) of life cycle(s))?
3. If the focus is to increase ecological (habitat) diversity for a range of fauna and/or flora, which parts of the life cycle are being aimed to restore for and what physical river features are expected to develop to support this goal?
4. Are the objectives SMART:
   - Clear (Specific)?
   - Quantifiable (Measurable)?
   - Achievable, Realistic and Time-bound?
5. Have quantitative or qualitative indicators been established that provide a simple and reliable means to measure achievement, reveal the changes connected to an intervention, or help assess the performance of an organization against the stated target. Such performance indicators are used to assess and measure the progress related to an expected result or an aspect of it and to identify to what extent beneficiaries/target groups have been reached and such be defined in the logical project framework (Table 11).

In the context of bullet 5, an indicator is 'a characteristic of the environment which, when measured, quantifies the magnitude of stress, habitat characteristics, degree of exposure to the stressor, or degree of ecological response to the exposure' (Hunsaker & Carpenter, 1990) and 'provides information on the system's condition' (Lorenz et al., 1997). Indicators serve as tools to assess, in a quantitative way, the condition of a river in the light of the restoration goal. Indicators should be clear (precise and unambiguous); relevant (appropriate to the subject at hand); economic (available at a reasonable cost); adequate (provide a sufficient basis to assess performance) and measurable (amenable to independent validations) (Kusek & Rist, 2004). To be useful as management instruments, indicators should be associated with specific 'benchmarks' (achievable targets or measures to assess performance, ideally accompanied by baseline data describing the situation before the intervention and the means of verification). When defining indicators according to these criteria, various indicator characteristics need to be considered. They include ecological and social relevance, ease of measurement and interpretation, and cost-effectiveness (Cairns et al., 1993; Angermeier & Karr, 1994; Holl & Cairns, 1996; Lorenz et al., 1997; Woolsey et al 2007).

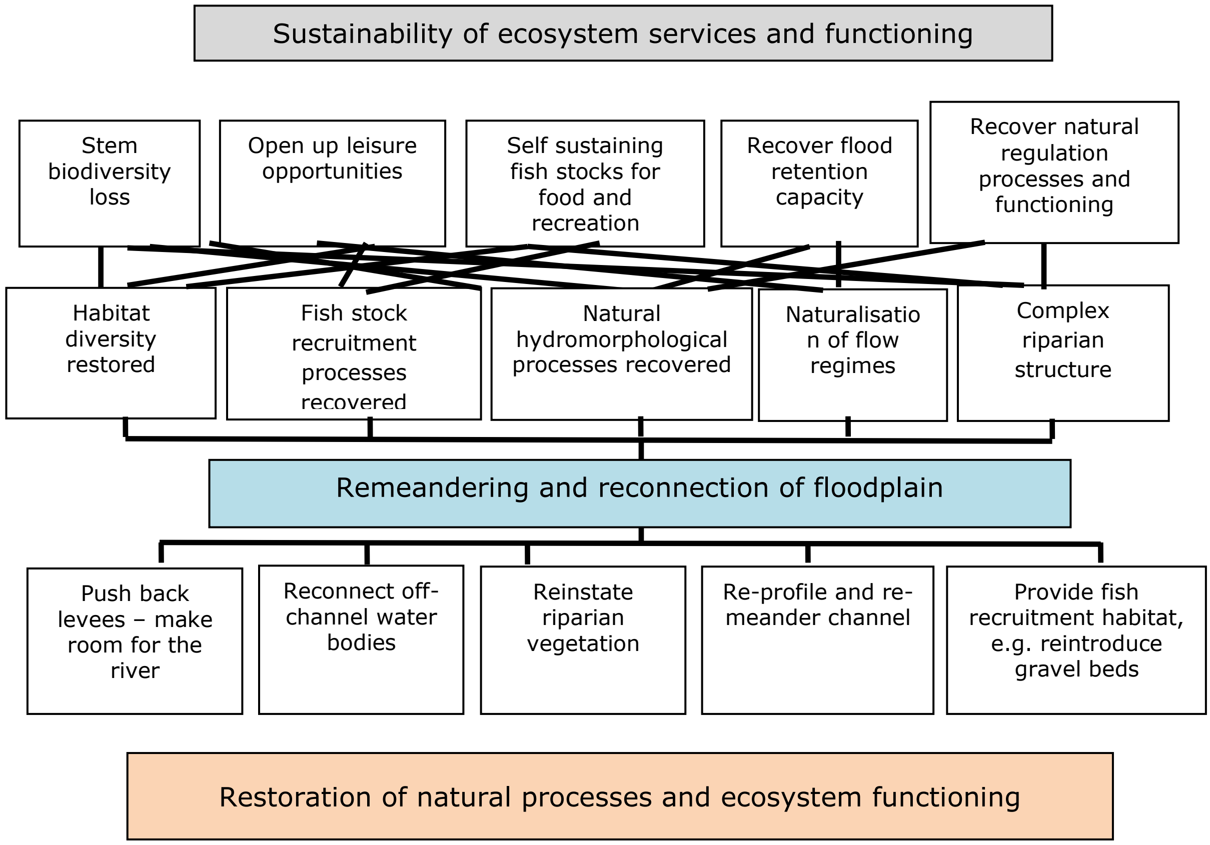

Figure 17: Example of objectives tree analysis related to channelization and disconnection of the floodplain.

The outputs can then be used to construct a matrix table that defines the issue (cause and effect) and reviews the potential options for resolving the issue, the best restoration measure to achieve the desired goal (Table 14). Since there is likely to be more than one option (measure) or a combination of measures to resolve an issue, the advantages and disadvantages of each should be considered and their inter-linkages explored. In addition this analysis should include the feasibility of achieving the outcome of the stated option both from a technical as well as a financial perspective, but also to identify win-win scenarios. If necessary, an alternatives solution may need to be sought. During this phase it is essential that the boundaries of the resource area in question are well defined. Simple delimitation into catchments or zones of a river is not necessarily adequate. In many situations activities taking place up or downstream, or land use in the adjacent catchment may have an influence on the management zone in question. Consequently, the plans should be formulated on local issues but take a wider perspective at the catchment and regional/national level. This analysis can be used in an attempt to resolve the problems by aggregating the relevant aspects into a multi-functional and multi-use plan. Critical in formulating options is identifying institutions and stakeholders responsible for implementing any action arising from the options analysis.

Table 14: Structure of table to undertake options analysis

Issues (Cause and effect)	Options	Advantages	Disadvantages	Responsibility

A summary of the main potential measures available to respond to the main pressures found on river system is provided on the REFORM WIKI (http://wiki.reformrivers.eu/index.php/Main_Page) but also in Excel spreadsheet to accompany this report (available at REFORM website reports). This spreadsheet provides summary information to aid decision-making about the most appropriate measures to achieve the defined endpoints, but the reader is referred to more details descriptions of measures on the REFORM WIKI (http://wiki.reformrivers.eu/index.php/Category:Measures).

As part of the appraisal of a prospective restoration project, there is a requirement for consultation through the planning and implementation phases to ensure all stakeholders have a say in the development and engage with the project. As part of this consultation, an evaluation of the current and future conflicts, both real and perceived, between the project activities and outcomes and other user groups should also be made. This can be achieved using matrix analyses such as those used in environmental impact assessments. Two types of matrices can be developed. The first looks at direct impact between the user groups (Figure 18 for a hypothetical example). Two evaluations are made: the numerator is the magnitude of the likely interaction on a scale of 1 (minimal) to 10 (extreme), and the denominator the extent (spatial and temporal) of the interaction on a scale of 1 (local) to 5 (catchment wide). All values are negative unless prefixed by a + sign to indicate that positive benefits probably accrue. From this assessment it can be seen that navigation and flood management probably have the greatest impact on other activities, whilst hydropower development and navigation are the activities that are most greatly impacted.

The second matrix defines the impact of each activity on various aspects of a particular service, e.g. the fisheries (Figure 19 for a hypothetical example). The same assessment technique of numerator and denominator is used as previously. As can be seen the hydropower have the greatest impact on all aspects of the fish and fisheries, whereas the impact of pollution control and habitat restoration is positive, followed by the water supply reservoir. It should also be noted that all impacts are not local and may be related to both down and upstream interventions.

	Impacted activity					
Impacting activity	Habitat restoration	Hydropower development	Pollution control	Navigation	Flood management	Total
Habitat restoration		8/2	5/2	7/3	+8/3	12/4
Hydropower development	8/3		1/1	6/2	4/2	19/8
Pollution control	+8/3	0/0		2/4	3/2	+3/4
Navigation	5/3	8/1	5/3		7/4	23/11
Flood management	7/3	3/2	3/2	7/3		20/10
Total	18/9	19/5	14/8	22/12	6/5	

Figure 18: Hypothetical example to show interaction of various water users. Values all negative unless preceded by a '+' sign. (see text for further explanation)

	Impacted or affected features of recreational fisheries				
Impacting activity	Fish migration	Fish recruitment	Exploitable stocks	Fishing experience	Total
Habitat restoration	+5/2	+8/2	+5/3	+5/2	+23/9
Hydropower development	8/4	5/2	3/2	5/2	21/10
Pollution control	+8/4	+8/3	+6/3	+8/2	+30/12
Navigation	3/2	7/3	2/1	5/2	17/8
Flood management	5/2	5/2	3/2	5/1	18/7

Figure 19: Hypothetical example to show impact of various water users on recreational fisheries. Values all negative unless preceeded by a '+' sign. (see text for further explanation)

To assist in the resolution of conflicts it will be necessary to identify a lead organisation to chair the discussion and drive uptake of the management plan. If problems arise in identifying such a lead organisation an independent trust should be considered to undertake this function. If possible the lead organisation should be from one of the local user groups or agencies who assist in regulating the use of the aquatic resources. This local development of management is essential to the overall success of the activity as it immediately removes the distrust often associated with politically appointed agencies.

It should also be noted that many factors will influence the decision on design options for river restoration schemes (Table 15). Bear in mind that any designs are site-specific and depend on local circumstances.

Table 15: Important considerations prior to, and during construction

Topic	**Description**
Adjacent land use	The river restoration scheme may be just part of a larger development area that will have detailed development proposals or a master plan. Therefore 'looking' upstream and downstream and the surrounding area will influence your design. All elements of master planning, including water access and transport routes, wider wildlife corridors, and sustainable drainage systems, should be considered in parallel with the river and waterside design options.
Land drainage	Consider how any existing land drainage strategy will interact with the river works. For example, discharge rainwater through ditches linking into the river may create a variety of habitats. Bad drainage design can lead to many problems. For example, poorly designed outfalls can lead to local erosion damage, possibly increasing flood risk or damaging habitats.
Flood risk management	The features of the flood risk management system that need to be considered include (in some countries you may need to undertake a flood risk assessment as part of any works): • Land-based loadings (e.g., soil, water, buildings, vehicles, etc.). • Current flow, waves, boat and propeller wash, and risk of illegal mooring. • Anticipated future river uses. • Durations of all forces, especially peak forces. • Frequency and duration of inundation of the area of waterside under consideration . • Ground conditions and geology. • Gradients of any maximum slopes necessary in the space available and stability of substrates at those gradients. • The strength and durability of individual components and the elements included in the design. • Water chemistry and factors affecting growth of plants such as wetted area. • The overall desired lifespan of the design. • Monitoring and maintenance. The proposal needs to set out clearly, both in terms of what you propose to construct and how.
Existing green space	Natural colonisation should always be promoted in the design as this will create locally appropriate communities. Wetlands are an important natural resource, storing and filtering water, capturing carbon, providing food and fuel, and supporting a wealth of uniquely adapted wildlife. Working with natural processes will improve local conditions for valued flora and fauna. However, planting may be needed when: • there appears to be limited scope for such natural colonisation, such as a lack of a seed bank that can reach the site naturally; • early vegetation establishment is required for slope stability (seek advice from a geomorphologist); Timing of the planting and pre-establishment of species of the correct genetic strain is an important consideration (seek advice from an ecologist to ensure that plants are of appropriate species and, wherever possible, of local origin). Plants also need to be selected at the correct size, planted at the correct level, and in appropriate groupings to ensure maximum chance of establishment. Some invasive species may be particularly problematic: this risk needs to be assessed and if necessary protection measures put in place.

Topic	Description
Archaeology and heritage	It is important to check whether the project affect any features of archaeological or heritage importance. Wetlands can contain a unique record of our past through their well-preserved organic archaeological remains.
Management and communication during the project	This is a crucial element to the success of all river restoration projects. It can manifest itself in many ways from stakeholders' expectations, appropriate communication between project designer and contractor, early considerations of necessary consents, through to no/limited site attendance from the project designer. If not managed efficiently, such elements can result in project delays and the inability to secure funding.

4.1.2.3 Cost benefit analysis

Recent trends in river management have erred towards rehabilitation to improve the aquatic environment for biodiversity and allow for sustainable exploitation of the resources (Arlinghaus et al. 2002). The costs of these rehabilitation projects vary from a few Euros to many millions depending on the scale and intensity of rehabilitation taking place. In terms of simple improvements in the ecological status and functioning of the ecosystem, or increased species diversity, it is unlikely that these schemes are economically justifiable. This is an argument that can be used to marginalise the amount of activity in this direction. In addition there is growing conflict between land drainage and flood prevention works, and well as hydropower development, and the environmental lobby, the former of which argue against rehabilitation because of increased flood risk. Nonetheless, the WFD indicates that all rivers must be returned to good ecological status or achieve best ecological potential by the year 2027. Currently, the expertise does not exist to make judgements and plan towards this scenario because an integrated approach to the rehabilitation of rivers which takes on board the ecological, physical, sociological and economic dimensions is limited. This is particularly important because it is likely cost arguments will be used to circumvent measures to restore rivers to their full potential because they will not represent good value for money (Cowx, *et al*., 2004).

Rivers, however, are of high socio-economic and socio-cultural importance and provide "a myriad of benefits to society" (Figure 1; Figure 20; Table 2; Vermaat et al. 2013). Unfortunately the benefits generated by rivers are difficult to quantify and evaluate but this is fundamental to undertake cost benefit analysis of the most appropriate measures for achieving the best outcomes in terms of WFD delivery.

Numerous methodologies have been developed to undertake cost benefit analyses that are applicable to help decide on the most appropriate measures to meet a desired outcome. It is not proposed to discuss these here but refer the reader to REFORM deliverables associated with WP 1 and 5 (D1.4, D5.2) and suffice to say that part of the planning procedure should include cost benefit analysis of the proposed actions to maximise of the benefits accrued. It is imperative that synergies between measures are explored and the measures that deliver the greatest environmental outcomes, both directly and indirectly are prioritised. Prioritising which barriers on which to construct fish passage facilities falls under this scenario and Nunn et al. (2012) developed a tool based on ease of construction, gain in suitable habitat and cost to help prioritise which barriers to build passes.

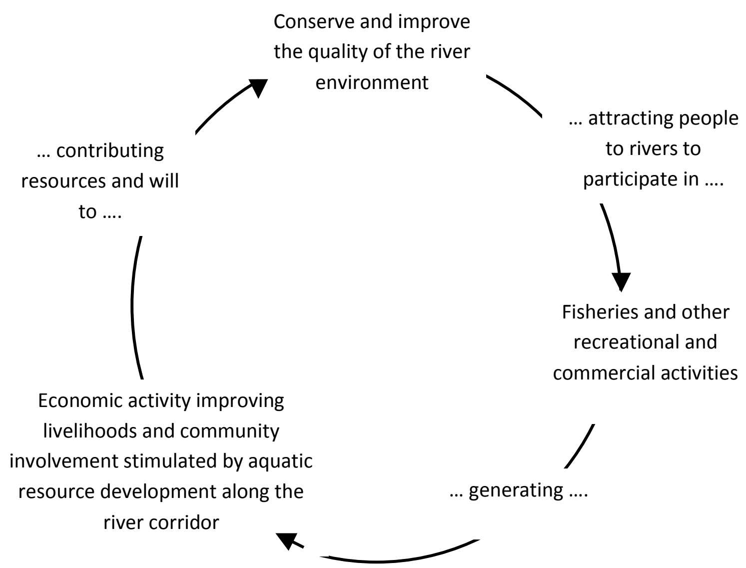

Figure 20: Cycle illustrating the importance of maintaining and improving ecosystem functioning and supporting livelihoods.

4.1.2.4 Risks and uncertainty

Before any proposal for a restoration scheme is approved, a thorough assessment of the risks associated with the exercise must be undertaken. This aspect will not be dealt with in detail because it is the subject of a separate report (REFORM D5.4) but two aspects of risk should be considered.

Risks associated with failure implement the project per se because of issues over design, management logistics, financial constraints, and externalities acting on the project arena (Table 16). Fortunately, complete 'show stoppers' are uncommon, inexperience in the designing of viable restoration projects is often the root cause. Good project planning and management and including contingency plans, will help minimise these risks of failures. Spending more time at the design stage will reduce uncertainty when implementing schemes, especially with new concepts. Site visits are essential to reveal issues that may not have been identified from a desk-based assessment.

Inexperienced staff with limited supervision or design engineers with inadequate hands-on experience is a recurring theme. Planning the project will help to identify which restoration measures may be most suitable given the type of catchment. For example, measures suitable for a low-energy, urban watercourse are likely very different from a high-energy, upland gravel-bed river. A number of manuals referring to the applicability of specific restoration measures are available on the RESTORE (http://www.restorerivers.eu/Publications/tabid/2624/Default.aspx) and REFORM (http://wiki.reformrivers.eu/index.php/Main_Page) websites.

Table 16: Important questions to consider at the design stage. Reproduced from Mant et al. (2008) "River Restoration: Managing the Uncertainty in Restoring Physical Habitat", p172.

Key issue/question	**Implication for project**
Is the contract to be based on tender rates and measured quantities or target costs?	If target cost to be used the contractor may need to be reimbursed and paid a bonus if completing within time, but measured quantities and rates could result in an unfinished job
How is the project to be managed?	There needs to be one project manager who should be employed prior to the project. This will ensure that communication links are good between the design and construction team. Project management is pivotal to the success of a project.
Who is responsible for any delays?	In a river restoration project, delays will be inevitable due to environmental uncertainty. This must not be overlooked and appropriate agreements should be outlined in the tender document.
What financial contingency is there for issues?	There will always be small issues to address in any project. Where new techniques are being applied this may rise and hence it is sensible for the client to retain some money after project completion. This may be as much 5% of total cost but will depend on the complexity and size of the project.
Have the design team and site supervisor roles been agreed?	Consider the value of design and build contract or ensure that the contractor has the opportunity to become involved in the design at an early opportunity. Working together may make the project easier; improve understanding and possibly even outline cheaper and easier to build options.
Will a method statement be drawn up by the contractor?	This is essential to ensure that the contractor's method of working will comply with specification and in a safe manner.
Is any of the work to be sub-contracted/ have any holidays been taken into account?	Ensure that replacement personnel to cover absence and holiday have been agreed with the main contractor and this is known to the project team.
How are the contractors to be paid (stage or completion)?	This may help to decide how the contingency fund is managed.

The key reasons for project failure are

- Government and donor policies are not followed
- Existing policies and other sector development inadequate
- Ambitious targets and over optimistic time scales
- Schedule too tight
- Underestimate of costs
- Poor organisation and institutional structure
- Weak coordination between components
- Inappropriate and poorly trained technical assistance
- Laws and regulations
- Procurement difficulties
- Project too big

Risks associated with project not achieving the expected ecological outcomes or endpoints. This aspect arises because of uncertainties in the ecological responses to the restoration measures implemented and can be evaluated using classical risk assessment protocols used in Environmental Impact Statements developed in numerous countries (e.g. UK DoE 1995, US ANS Task Force 1996, EPPO 2000, NZ MAF 2002), although more targeted risk assessment procedures are being developed as part of REFORM (WP 5.4).

Risk assessment procedures are used to determine the likelihood that an event may occur and what the consequences of such an event will be. The risk of an unpredicted outcome of the restoration measure that impacts on other sectors can also be defined under this procedure. A risk management framework operates by establishing the context (i.e. proposed restoration event); identifying the risks on the existing situation or other stakeholder and their recourse use (consequence and likelihood); assessing the risks; and treating the risks. A measure of risk is typically derived by multiplying likelihood of an event occurring by consequence. The ratings refer to the probability (likelihood) of the impact (consequence) occurring if a scheme is proposed based on attributes about the ecology of the aquatic biota and the riverine environment. The likelihood of an event happening according to the ratings in Table 17 is defined in
Table 18. The consequence refers to the scale of the potential failure or impact on other stakeholders based on knowledge of ecological impact of the scheme from previous similar schemes. The ratings are, where possible, based on scientific evidence otherwise expert judgment will be required. The latter introduces a level of uncertainty in the assessment procedure that must be accounted for. As a consequence, there is a need to introduce a further layer on the matrix that accounts for uncertainty in knowledge base or processes in nature (Table 19). Where possible, information should be drawn from the peer-reviewed literature or case studies of existing schemes. Where knowledge is deficient or uncertainty high, the precautionary principle should come into force to prevent unforeseen impacts.

Table 17: Risk Matrix. N = negligible; L = low, M = moderate; H = high; E = extreme

Likelihood	Consequence				
	Insignificant	Minor	Moderate	Major	Significant
Rare	N	L	L	M	M
Unlikely	N	L	M	H	H
Possible	N	L	H	H	E
Likely	N	M	H	E	E
Almost certain	N	M	E	E	E

Table 18: Likelihood rating

Rating	Description	Percentage
Rare	Event will only occur in exceptional circumstances	<5%
Unlikely	Event could occur but not expected	25%
Possible	Event could occur	50%
Likely	Event will probably occur in most circumstances	75%
Almost Certain	Event is expected to occur in most circumstances	>95%

Table 19: Proposed weighting to account for uncertainty of information about potential risks of proposed restoration scheme

Degree of certainty of risk from scheme	Description	Rating scale
High	Well established knowledge from assessment and post-project monitoring of existing restoration schemes.	0.5
Medium	Knowledge from limited assessment and post-project monitoring of existing restoration schemes, supported by documented ecological and environmental studies	1.0
Low	Little or no previous knowledge from assessment and post-project monitoring of existing restoration schemes, and little or no supporting ecological and environmental studies	3.0

One further element associated with risk is the degree of isolation or independency of the proposed restoration scheme relative to other schemes. It is important to recognise the potential cumulative impacts of multiple schemes in a river catchment. For, example, a single scheme in an upland area is likely to carry minimal risk compared with a large scheme in the lower reaches of a river that reconnects floodplain habitat. Consequently, as part of the assessment procedure a weighting factor can be applied to the scoring system to reflect the scale and degree of isolation (Table 20). The weighting scales provided in Table 20 are indicative and may be varied depending on the location, scheme design, intensity, scale and distribution of restoration measures in a catchment.

Table 20**:** Proposed weighting to account for degree of isolation of receiving water body

Degree of isolation of the receiving water body	Rating scale
Single scheme in an upland area dealing with a single pressure.	0.2
Single scheme in an upland isolated area dealing with local pressures and no linkages to downstream issues.	0.5
Single large scale scheme in an upland area across several reaches.	1.0
Multiple restoration schemes in several upland reaches that are intrinsically linked dealing with multiple pressures	2.0
Single scheme in a lowland area dealing with single pressure	1.0
Single scheme in a lowland area operating local pressures but with linkages to upstream or downstream issues.	1.5
Multiple restoration schemes in a lowland areas that are intrinsically linked dealing with multiple pressures	2.0

4.1.2 Drafting the restoration project management plan

Options to overcome the problems are generated and presented for the draft river basin management plan. It is critical that issues relating to existing and potential user groups are identified otherwise conflicts between user groups cannot be resolved in a satisfactory manner. The requirements of each user-group, in terms of demand on the aquatic resources and standards for water quality, must be addressed at this stage.

Maintenance and development of restoration activities in such multiple-user environments are fraught with cross-sectorial problems. For example, river fisheries are often considered marginal activities because the value of the resources is usually ill-defined and poorly represented from an economic and social perspective. Consequently, fisheries are given low priority in any consultation process. To overcome the problems there are two primary assessments that must be undertaken to provide the necessary input data to support individual stakeholder interests.

4.1.3.1 Identification of projects

Once the management plan has been formulated, and adequate consultation has been made with Government departments, institutions, user-groups, industry and the public, it should be possible to draw up action plans for the future development of the restoration meant for improving ecological status or delivery of improved services. This includes justification and prioritising of projects, project formulation, and outlining costs and budgetary considerations. When considering formulation of the action plans it is critical that the goals set are achievable, the costs of the action and who pays are identified, and finally the action represents value for money or has considerable non-tangible benefit. This can only be done if clear agreement over the issues is made between the various user groups. Clear priorities for the main problems and conflicts should emerge, with a statement of the consequences of the proposed actions. At this point the conflicts between user-groups can be resolved, and a compromise be drawn up that will have the minimum impact for all concerned. Persuading those responsible to action and arriving at the proper key issues is more likely to be successful using the aquatic resource management planning methodology than a purely descriptive one because it focuses upon all of the relevant scenarios and what can be justified and implemented.

It is critical that during this phase an economic appraisal of the project is undertaken to examine the relationship of the project to the overall development objective of the river basin management plan. This should include a cost benefit analysis of the proposed project options. The benefits accruing from the project option should be calculated and where possible compared to alternative projects or proposals. The main beneficiaries of the project are assessed, particularly in terms of the WFD objectives described earlier. Additionally, the economic component assesses the likelihood that additional public expenditure might be required for infrastructure, supporting services and other elements which may be required for efficient project operation, but which are not included in the project funds. At this stage, points of contention should be discussed and all the outstanding issues concerning the project's viability resolved in order that a decision to proceed with implementation can be agreed.

To support the development of the actions, it is recommended that project management tools such as Project Concept Notes (Appendix 3) and Logical Project Frameworks (Appendix 4) are used. These provide a clear and logical mechanism to define the overall project goal, objectives, and mechanisms for achieving the objectives and are a simple and effective way to justify the proposed project to managers and funding bodies.

4.1.3 Implementation

The culmination of the identification, preparation and appraisal phases of the project approach should result in a project that can be successfully implemented. Unfortunately all projects still face problems no matter how well a project has passed through the early stages of assessment. These problems may occur as a result of difficulties inherent in the development process or from more specific causes. In the example of fish easement given in the preparation section, no matter how careful the assessment of the project options there will be certain features of the project which should they become adverse could render cost-effective implementation impossible, e.g. long-term shortage of water of the correct quantity and quality, or extreme and adverse change in land use that affects sedimentation and erosion processes. Those who implement the project may find that although the development objectives of the project are constant, implementation will often deviate from the route originally envisaged. The problems range over less severe scheduling and cost underestimating difficulties to severely distorting effects involving difficulties in land use change, project inflexibility and further degradation of resources (e.g. fish stocks, water quality).

This phase may also prove to be another source of conflict because there is a clear need to establish who is willing to pay for the restoration project, and what resources cost. Contingency valuation methods carried out as part of the consultation process will establish how much users are willing to pay for appropriate changes or how much they are willing to accept in terms of increased cost to still participate in the activity. Economic assessments of this type help avoid problems at the implementation because they take on the opinion of the user groups. Problems may also arise from introducing legislation and regulations. This is best achieved through the consultation process and devolving enforcement to the local communities (third sector involvement and community engagement).

Key to successful implementation includes:

- expanding the manager's view of who is affected by aquatic resource management (*stakeholder*);
- identifying and *understanding* stakeholder views;
- seeking *compromise* between competing and conflicting demands;
- improving *communication* between managers and stakeholders.

Restoration plans should not be based just on technical issues and their effectiveness or limitations. They must involve:

- regional policy framework;
- societal and prevailing ideas and values;
- institutional frameworks, i.e. fit within the regulations and legislation.

The implementation phase is characterised by the detailing of work plans and financial arrangements (Table 12). The logical framework drafts, which will have been refined several times since identification, will be translated into activity schedules. Disbursement of project funds into budget heads will be implemented and all the monitoring and control mechanisms should be in place.

It should be recognised that inputs to this phase of the planning will vary depending on the scale of the restoration project. Small individual projects such as fencing a section river to reducing bank poaching will require less investment in the planning process than a river basin plan, the latter of which requires the full investment in planning as described.

4.1.4 Project monitoring and evaluation

Monitoring and evaluation plays a key role within the framework because it enables identification of river restoration project success. Pre-monitoring helps identifying restoration goals, while restorations goals help defining specific monitoring objectives to guide the development of a monitoring and evaluation programme. Monitoring elements (usually WFD BQE) should be chosen with a rational to focus on those that respond to the restoration action and address the question outlined in the hypothesis (REFORM Deliverable 3.1). Selecting a monitoring design is essential to make the data meaningful for evaluation, i.e. determining the spatial and temporal scale for monitoring and identification of treatment, control and reference sites. Monitoring not only helps to define benchmarks and endpoints at the start of a project but also determines when the endpoint of a project has been reached. However, it can be difficult deciding when the restoration process is 'complete' and therefore, it is essential that an impact assessment monitoring design is employed to provide evidence, in statistical terms that an endpoint has been reached. A variety of impact assessments techniques are available to detect environmental change for rehabilitation project whose data collection methods differ spatially and temporally. A replicated BACI design is the most powerful design because it includes replication in both space and time and this is recommended. A resource calculation can be applied to determine how many years pre and post monitoring is required to isolate the environmental impact from natural variability.

The evaluation phase, for a rehabilitation project which has undergone the initial stages of the project approach, assesses the overall project effects (intentional and unintentional) and the sectoral impact of the project. Evaluation is only possible where a series of measurable indicators or endpoints has been established for the project, hence the value of establishing and updating the logical framework throughout. The evaluation phase will use the indicators to gauge how far the restoration project has developed in relation to the initial objectives and defined endpoints. Again the analysis will come back to the logical framework which was established at the outset and has been subsequently refined through the preparation and appraisal phase. It is the indicators laid down in the logical framework which are used to monitor the restoration project during implementation. In addition, the implementation criteria will be used in ex-post evaluation which takes place some years after completion of the restoration project is complete.

Assuming all goes well and the project is implemented, the evaluation phase should provide a steady feedback of information and results which will be useful in other restoration project situations. Progress reports should be formally produced and assessed, focussing on the key indicators of the project in order that lessons may be learned and problems avoided in future restoration programmes.

4.2 *Testing protocol against existing project*

To test the basic steps in the protocol, an example was used from the River Alagnon in the Allier/Loire basin, France (Table 21). The project involved the removal of the Stalapos Dam on the Alagnon[1]. This dam removal, channel geometry reconstruction, and riparian planting project were undertaken in a Natura 2000 site to open the migratory path to historic reproduction sites for Atlantic salmon. The project is part of a removal programme of 20 obstacles along 36 km of river. Post-implementation monitoring showed a significant negative impact on the trout population at the construction site and a significant increase in trout redd density upstream and stabilization of the reconstructed channel. Trout redd monitoring is ongoing.

Table 21**:** Example of the protocol applied to dam removal in the River Alagnon (France).

Step #	Step	Step Outcomes	Project Details
Project Identification			
1	Review current status of water body and/or other aquatic resources	WFD status	"good" status 2015
2 (3)	Identify regional policy objectives	RBMP, other plans	RBMP Loire, PoM 2010-15 ; Natura 2000: FR8301095 (rivière à Loutre)
3 (2)	Identify water body goals and specific objectives	Reference Condition Bench Marks (BM)	Historic Atlantic salmon reproduction
Project Formulation			
4	Compare water body status with objectives	Quality Element (QE) deficits	Fish migration blocked
5a (5)	Identify HYMO issues affecting the water body both directly and indirectly	HYMO causes	Mill dam, migration obstacle
5b (5)	Identify appropriate HYMO process rehabilitation actions	HYMO processes to rehabilitate to meet End Points (EP)	Restore flow continuity, channel geometry, riparian zone to permit fish migration, EP = increased density of trout redds upstream
6	Review and select appropriate HYMO rehabilitation techniques	HYMO rehabilitation techniques	Diverted channel, dried sediment, removed dam, constructed new channel, returned flow, planted riparian zone
7	Prioritization of rehabilitation projects and justification	Costs in €	173 800
8	Design monitoring programme (BACI/BA/CI) and key indicators	Monitoring program w/ key indicators	CarHYCE (simplified) HYMO - 3 yrs, trout redd count - indefinite; pre-removal electro-fishing
Project Implementation			

[1]http://www.onema.fr/IMG/Hydromorphologie/21_2_rex_r1_alagnon_vbat.pdf; http://wiki.reformrivers.eu/index.php/Alagnon_river_-_Stalapos_weir

Step #	Step	Step Outcomes	Project Details
9	Implementation	Engineering design and implementation	Dam removal, new channel geometry (400 m), floodplain planting
Post-project Actions			
10	Monitoring	Monitoring data	Long profile stabilized; trout redd density increasing
11	Evaluation	Monitoring results evaluation	EP achieved
12	Update goals and restoration management actions	Future planning	Remove 15 additional obstacles by 2015

4.3 *Conclusions and recommendations*

Despite growing interest in applying river restoration techniques to solve environmental problems, little is known on what represents a successful river restoration effort; hence there is a substantial need of assessing river restoration projects and exchange good river restoration practices, which could be fulfilled through the initiation of river restoration development projects.

Some of the most common problems or reasons for failure of a restoration programme or project include:

- Not addressing the root cause of habitat degradation
- Upstream processes or downstream barriers to connectivity and habitat degradation that affect ecosystem functioning
- Not establishing reference condition benchmarks and success evaluation endpoints against which to measure success
- Failure to get adequate support from public and private organizations
- No or an inconsistent approach for sequencing or prioritizing projects
- Poor or improper project design
- Inappropriate uses of common restoration techniques because of lack of pre-planning (one size fits all)
- Inadequate monitoring or appraisal of restoration projects to determine project effectiveness
- Improper evaluation of project outcomes (real cost benefit analysis)

Part of the problem is that the ecological status or potential of a water body is used as the target status of the restoration measure and the biological quality elements are not necessarily sensitive enough to detect the change (Bernhardt et al., 2005; Palmer et al., 2010 and references therein; Violin et al., 2011; Stranko et al., 2012, but see also Lorenz et al., 2012; Haase et al. 2013). Good ecological status or potential is intended to describe the extent to which ecological quality deviates from what would be expected under near natural conditions and should not necessarily be the goal of restoration; it fundamentally needs better formulated targets or end points.

Because it is unrealistic to expect that any restoration measure will return a river reach to a completely undisturbed state, the potential for restoration should be defined to reflect a realisable target condition (Kamp et al., 2007; Haase et al. 2013), and this does not necessarily need to be reflected in biological quality but may be improvement in, for example, hydromorphology (Lepori et al., 2005; Jähnig et al., 2009, 2010).

It was concluded that the concepts of reference condition benchmarks and success evaluation endpoints need to be more highly developed and promulgated in a way that is useful to river managers, project partnerships, and stakeholder groups.

To support this process this task developed a restoration planning protocol using project management techniques to solve problems and produce a strategy for the execution of appropriate projects to meet specific environmental and social objectives. This is summarised in (Figure 21).

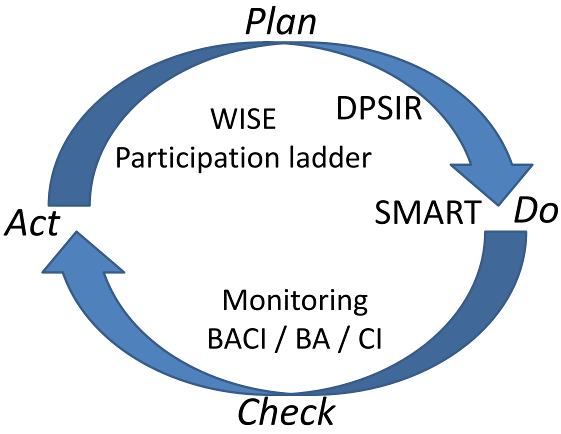

Figure 21 The simplified protocol applying various project management techniques (see text for further explanation).

It provides knowledge of the technical policy and background to conflicts of multiple users of resources and develops a plan for comparison of status with objectives. Such resource planning should become an integral part of the river basin management, and full consultation with all aquatic user groups is essential to promote optimal, sustainable use of the water body whilst meeting WFD targets.

Specifically the protocol aims to overcome the limitations of planning identified in the majority of existing projects and to:

- promote and implement programmes and projects aimed at achieving defined objectives;
- develop programmes and projects that conform to national, regional and international policies and agreements, in addition to satisfying the objectives of funding agencies;
- benefit a wide cross section of society;
- directly or indirectly contribute positively to the economic, social, cultural, environmental and institutional development of the state.

In using this strategy it is important to recognise that each restoration scheme proposal should be treated individually as no situation is alike. It is therefore impossible to provide threshold criteria on which to make decisions about the best scheme; this must be the responsibility of an expert panel, which will assess the information provided and evaluate the overall risk of a scheme not having environmental, economic and social benefits that is commensurate with costs.

The decision support tools allow the proposal to be evaluated at different levels and stages and will effectively curtail a proposal at an early stage should the proposal be potentially impractical or unviable.

One of the underlying causes for the weaknesses in measuring restoration project performance was inadequate funding to support post project appraisal. It may thus help to link project funding and permitting to the use of reference condition benchmarks and success evaluation endpoints, although it is recognised that it is difficult to evaluate success where a project aims to deliver something whose existence is costly or technically challenging to monitor, and something whose status may be affected (positively or negatively) by a range of influences that have nothing to do with the project (Jones 2012).

It is also recommended that European policy drivers must include intelligent monitoring programmes, methods for data management and dissemination, protocols for data analysis, and publication of results in formats that are useable by river managers.

5. References

Amoros, C., 2001. The Concept of Habitat Diversity Between and Within Ecosystems Applied to River Side-Arm Restoration. Environmental Management Vol. 28, No. 6, pp. 805–817.

Amoros, C., Elger, A., Dufour, S., Grospretre, L., Piegay, H., & Henry, C., 2005. Flood scouring and groundwater supply in rehabilitated side-channels of the Rhone River, France: sedimentation and aquatic vegetation response. Archiv für Hydrobiologie Supplement 155/1-4, p. 147 – 167. Large Rivers Vol. 15, No 1-4.

Anderson, D.H. Bousquin, S.G., Williams G.E., & Colangelo D.J., 2005. defining success: expectations for restoration of the Kissimmee River. South Florida Water Management District, West Palm Beach, Florida, USA.Technical Publication ERA #433.

Angermeier, P.L., & Karr J.R., 1994. Biological integrity versus biological diversity as policy directives. BioScience, 44, 690–697.

Anon, 1982. The logical framework approach (LFA). Norwegian Agency for Development Corporation, Oslo, Norway.

Arlinghaus, R., Mehner, T., & Cowx, I.G., 2002. Reconciling traditional inland fisheries management and sustainability in industrialised countries, with emphasis on Europe. Fish and Fisheries 3, 261–316.

Arscott, D.B., Tockner, K., & Ward, J.V. 2005., Lateral organization of aquatic invertebrates along the corridor of a braided floodplain river. Journal of the North American Benthological Society, 24, 934–954.

Arthington, A.H., Brizga, S.O., & Kennard, M.J., 1998. Comparative Evaluation of Environmental Flow Assessment Techniques: Best Practice Framework. LWRRDC Occasional Paper 25/98. ISBN 0 642 26744 8.

Arthington, A.H., Bunn, S.E., Poff, N.L., & Naiman, R.J., 2006. The challenge of providing environmental flow rules to sustain river ecosystems. Ecological Applications **16**, 1311-1318.

Avarello T., 2011. Assessment of LIFE & INTERREG funded river restoration projects in Europe. M.Sc.-thesis. Deltares & Université Francois-Rabelais, Tours.

Ayres A., Goeller B., Lago M., & Gerdes H., 2013. Inventory of the cost of river degradation and the socio-economic aspects and costs and benefits of river restoration. REFORM D1.4 – DRAFT 04/07/2013.

Bain, M.B., & Stevenson, N.J., 1999. Aquatic habitat assessment: common methods. American Fisheries Society, Bethesda, Maryland.

Bain, M. B., J. T. Finn, & H. E. Brooke. 1988. Streamflow regulation and fish community structure. Ecology 69:382-392.

Barbour, M., Diamond, J., & Yoder, C., 1996. Biological assessment strategies: applications and limitations. *In*: Grothe, D., Dickson, K., & Reed, D. (Eds.), Whole-effluent Toxicity Testing: An Evaluation of Methods and Predictability of Receiving Systems Responses. SETAC Publications, Pensacola, Florida, pp. 245–270.

Bash, J.S., & Ryan, C.M., 2002. Stream restoration and enhancement projects: is anyone monitoring? Environmental Management 29, 877–885.

Beechie, T., & Bolton, S., 1999. An approach to restoring salmonid habitat-forming processes in Pacific Northwest watersheds. Fisheries, 24(4), 6-15.

Beechie, T.J., Pess, G., Kennard, P., Bilby, R.E., & Bolton, S., 2000. Modeling recovery rates and pathways for woody debris recruitment in northwestern Washington streams. North American Journal of Fisheries Management 20, 436–452.

Beechie, T.J., Veldhuisen, C.N., Schuett-Hames, D.E., DeVries, P., Conrad, R.H., & Beamer, E.M. 2005. Monitoring treatments to reduce sediment and hydrologic effects from roads. *In* P. Roni, ed. *Monitoring stream and watershed restoration*, pp. 35-66, Bethesda, MD, American Fisheries Society. 350 pp.

Beechie, T.J*.*, Pess, G.*,* Roni, P., *&* Giannico G., 2008. Setting river restoration priorities: a review of approaches and a general protocol for identifying and prioritizing actions*. North American Journal of Fisheries Management,* **28***,* 891–905.

Beechie, T.J., Pess, G.R., Pollock, M.M., Ruckelshaus, M.H. & Roni, P., 2009. Chapter 33: Restoring rivers in the 21st century: science challenges in a management context. In: Beamish, R.J. & Rothschild, B.J. (eds) The future of fisheries science in North America, Springer, Heidelberg, pp. 695-716.

Beechie, T.J., Sear, D.A., Olden, J.D., George, R.P., Buffington, J.M., Moir, H., Roni, P., & Pollock, M.M., 2010. Processed-based principles for restoring river ecosystems. Biological Sciences 60, No 3.

Bernhardt, E.S., Palmer, M.A., Allan, J.D., Alexander, G., Barnas K., Brooks, S., Carr, J., Clayton, S., Dahm, C., Follstad-Shah, J., Galat, D., Gloss, S., Goodwin, P., Hart, D., Hassett, B., Jenkinson ,R., Katz, S., Kondolf, G.M., Lake, P.S., Lave, R., Meyer, J.L., O'Donnell, T.K., Pagano, L., Powell, B., & Sudduth, E., 2005. Synthesizing US river restoration efforts. Science 308 (5722), 636-637.

Bernhardt, E.S., & Palmer, M.A., 2007. Restoring streams in an urbanizing world. Freshwater Biology 52, 738–751.

Block, W.M., Franklin, A.B., Ward, J.P. Jr., Ganey, J.L., & White, G.C., 2001. Design and implementation of monitoring studies to evaluate the success of ecological restoration on wildlife. Restoration Ecology 9, 293–303.

Boon, P.J., Calow, P. & Petts, G.E. 1992. River Conservation and Management*,* Wiley, Chichester.

Boon, P. J., & Raven, P. J., 2012. Front Matter, in River Conservation and Management, John Wiley & Sons, Ltd, Chichester, UK. doi: 10.1002/9781119961819.fmatter.

Brierley, G. J., & Fryirs, K.A., 2008. River Futures: an integrative scientific approach to river repair. Island Press, Washington, US.

Brierley, G., Reid, H., Fryirs, K., & Trahan, N., 2010. What are we monitoring and why? Using geomorphic principles to frame eco-hydrological assessments of river condition. Science of the Total Environment 408, 2025–2033.

Brookes, A., & Shields, D., 1996. River Channel Restoration: guiding principles for sustainable projects. John Wiley & Sons Ltd., Chichester, England.

Brookes, A., 1985. River channelisation: traditional engineering methods, physical consequences and alternative practices. Progress in Physical Geography 9, 44–73.

Brookes, A., 1992. Recovery and restoration of some engineered British River Channels. *In*: Boon, P.J. Calow, J. & Petts, G.E., (eds.) *River Conservation and Managemen*t. John Wiley & Sons Ltd., Chichester, England, pp. 337–352.

Brookes, A., 1996. Floodplain restoration and rehabilitation. *In*: Anderson, M.G., Walling, D.E., & Bates, P.D. (eds.) Floodplain Processes. John Wiley & Sons Ltd., Chichester, England, pp. 553–576.

Brown, K., 2000. Urban stream restoration practices: An initial assessment. Center for Watershed Protection; for the U.S. Environmental Protection Agency, Office of

Wetlands, Oceans, and Watersheds and Region V. [Ellicott City, MD (8391 Main St., Ellicott City 21043): The Center.

Bruce-Burgess, L., 2001. An Evaluation of UK River Restoration Appraisal Procedures-results from a National survey, Department of Geography, available at www.qmw.ac.uk/~fa9128/final2.doc.

Buijse, A.D., Coops, H., Staras, M., Jans, L.H., Van Geest, G.J., Grift, R.E., Ibelings B.W., Oosterberg, W., & Roozen, CJM., 2002. Restoration strategies for river floodplains along large lowland rivers in Europe. Freshwater Biology 47, 889–907.

Buijse T., Klijn F., Leuven R.S.E.W., Middelkoop H., Schiemer F., Thorp J.H. & Wolfert H.P., 2005. Rehabilitation of large rivers: references, achievements. Archiv für Hydrobiologie Supplement Large Rivers, 155, 715–720.

Bunn, S.E. & Arthington, A.H., 2002. Basic principles and ecological consequences of altered Hasler, C.T., Mossop, B., Patterson, D.A., Hinch, S.G., & Cooke, S.J. 2012. Swimming activity of migrating Chinook salmon in a regulated river. Aquatic Biology, **17** 1, 47-56.flow regimes for aquatic biodiversity. Environmental Management **30**, 492-507.

Cairns J. Jr,, McCormick P.V. & Niederlehner B.R., 1993. A proposed framework for developing indicators of ecosystem health. Hydrobiologia, 263, 1–44.

Choi, Y.D., 2004. Theories for ecological restoration in changing environment: towards 'futuristic' restoration. Ecological Research 19, 75–81.

Chovanec, A., Jager, P., Jungwirth, M., Koller-Kreimel, K., Hoog, O., Muhar, S., & Schmutz, St., 2000. The Austrian way of assessing the ecological integrity of running waters: a contribution to the EU Water Framework Directive Hydrobiologia 422, 445–452.

Christophe, P., Henry., Amoros C., & Roset N., 2002. Restoration ecology of riverine wetlands: A 5-year post-operation survey on the Rhöne River, France. Ecological Engineering 18; 543–554.

CIRF (Centro Italiano per La Riqualificazione Fluviale), 2006. *La riqualificazione fluviale in Italia*. Mazzanti Editori, Venice, Italy.

CIS-ECOSTAT, 2012. Common Implementation Strategy Ecostat Workshop. Hydromorphology – Conclusions and recommendations. www.reformrivers.eu/system/files/Conclusions%20of%20hymo%20workshop%20(June%202012).pdf

Clarke, S.J., Bruce-Burgess, L., & Wharton, G., 2003. Linking form and function: towards an ecohydromorphic approach to sustainable river restoration. Aquatic Conservation in Marine Freshwater Ecosystems 13, 439–50.

Clewell, A., & Aronson, J., 2008. Ecological Restoration: principles, values, and structure of an emerging profession. Island Press, Washington.

Clewell, A., & Rieger, J.P., 1997. What Practitioners Need from Restoration Ecologists. Restoration Ecology, 5: 350–354. doi: 10.1046/j.1526-100X.1997.00548.

Collares-Pereira, M.J., & Cowx, I.G., 2004. The role of catchment scale environmental management in freshwater fish conservation. *Fisheries Management and Ecology* 11, 303-312.

Comiti, F., Mao, L., Lenzi, M.A., & Siligardi, M., 2009. Artificial steps to stabilize mountain rivers: a post-project ecological assessment. River Research & Applications 25, 639-659.

Conquest, L.L., 2000. Analysis and interpretation of ecological field data using BACI design: discussion. Journal of Agricultural, Biological, and Environmental Statistics 5, 293-296.

Cooper, S.D., & Barmuta, L.A., 1993. Field experiments in biomonitoring. Pages 399-441 *in* Rosenberg D.M. & Resh V.H, editors. Freshwater biomonitoring and benthic macroinvertebrates. Chapman and Hall, New York, New York, USA.

Covich, A., Palmer, M., & Crowl, T., 1999. The role of benthic macroinvertebrate species in freshwater ecosystems. Bioscience 49, 119–127.

Cowx, I.G., 1994. Strategic approach to fishery rehabilitation. *In*: Cowx I.G. editors. Rehabilitation of freshwater fisheries. Fishing News Book. Blackwell Scientific Publications Ltd. pg. 3-10.

Cowx, I. G. & Welcomme, R.L., 1998. Rehabilitation of Rivers for Fish. Fishing News Books, Oxford.

Cowx, I.G., Noble, R.A.A., Nunn, A.D., Harvey, J.P., Welcomme, R.L., & Halls, A. 2004. Flow and level criteria for coarse fish and conservation species. Environment Agency Science Report SC020112/SR, 166 pp.

Cunningham, S., 2002. The restoration economy: the greatest new growth frontier—immediate and emerging opportunities for businesses, communities, and investors. Berrett-Koehler, San Francisco, California

Defra., 2004. Making Space for Water: Developing a New Government Strategy for Flood and Coastal Erosion Risk Management in England Department for Environment, Food and Rural Affairs, http://www.defra.gov.uk/corporate/consult/waterspace/.

Dewberry, T.C., 1996. Can we diagnose the health of ecosystems? Northwest Science and Photography. Florence. 176 pp *in* Downs, P.W., & Kondolf, G.M., 2002. Post-project appraisals in adaptive management of river channel restoration. Environmental Management 29(4), 477–496.

Dobson, M., & Cariss, H., 1999. Restoration of afforested upland streams – what are we trying to achieve? Aquatic Conservation: Marine and Freshwater Ecosystems 9, 133–139.

Doran, G.T., 1981. There's a S.M.A.R.T. way to write management's goals and objectives. Mangement Review 10(11, AMA FORUM), 35-36.

Downs, P.W., & Kondolf, G.M., 2002. Post-project appraisals in adaptive management of river channel restoration. Environmental Management 29(4), 477–496.

Downs, B.J., Barmuta, L.A., Fairweather, P.G., Faith, D.P., Keough, M.J., Lake, P.S., Mapstone, B.D., & Quinn, G.P., 2002. Monitoring ecological impacts: concepts and practise in flowing waters. Cambridge Univeristy Press, Cambridge UK.

Doyle, M.W., Miller, D.E., & Harbor, J.M., 1999. Should River Restoration Be Based on Classification Schemes or Process Models? Insights from the History of Geomorphology. ASCE International Conference on Water Resources Engineering, Seattle, Washington.

Eden, S., & Tunstall, S., 2006. Ecological versus social restoration? How urban river restoration challenges but also fails to challenge the science - policy nexus in the United Kingdom. Environment and Planning C: Government and Policy 24, 661-680.

Edgar, B., Schofield, N., & Campbell, A., 2001. Informing river management policies and programs with science. Water Science and Technology 43(9), 185-195.

EEA, 2012 Towards efficient use of water resources in Europe. Report 1/2012. European Environment Agency, Copenhagen, Denmark.

Ellis, J.I., & Schneider, D.C., 1997. Evaluation of a gradient sampling design for environmental impact assessment. Environmental Monitoring and Assessment 48, 157–172.

England, J., Skinner, K.S., & Carter, M.G., 2007. Monitoring, river restoration and the Water Framework Directive. Water and Environment Journal.

EPPO. 2000. EPPO Standards. Pest Risk Analysis. Document PM 5/1–4. European and Mediterranean Plant Protection Organization, Paris. 24 pp.

European Commission Environment – LIFE Programme, 2011. *The LIFE Programme.* [Online] Available at: < http://ec.europa.eu/environment/life/about/index.htm> [Accessed 23 August 2011].

Fairweather, P.G., 1991. Statistical power and design requirements for environmental monitoring. Australian Journal of Marine and freshwater Research 41, 555-567.

Faith, D.P., Humphrey, C.L., & Dostine, P.L., 1991. Statistical power and BACI design in biological monitoring: comparative evaluation of measures of community dissimilarity based on benthic macroinvertebrate communities in Rockhole MineCreek, North Territoty, Australia. Australian Journal of Marine and Freshwater Research 41, 589-602.

FAO, 2008. Inland fisheries. 1. Rehabilitation of inland waters for fisheries. FAO Technical Guidelines for Responsible Fisheries 6 (Supplement 1), Rome.

Fausch, K.D., Torgersen, C E., Baxter, C E., & Li, H W. 2002. Landscapes to riverscapes: Bridging the gap between research and conservation of stream fishes. Bioscience **52**, 483-498.

Findlay, S.J., & Taylor, M.P., 2000. Why rehabilitate urban river systems? Area 38.3, 312-325.

Findlay, S.J. & Taylor, M.P. 2006. Why rehabilitate urban river systems? Area 38, 312–325.

FISRWG (Federal Interagency Stream Restoration Working Group), 1998. Stream Corridor Restoration: principles, processes, and practices. GPO Item No. 0120-A. USDA, Washington, DC.

Formann, E., Schober, S., & Habersack, H.M., 2004. Monitoring and modelling of river widening processes in an alpine river. *In*: Ninth International Symposium on River Sedimentation, October 18–21, 2004 (Eds C. Hu, Y. Tan & X. Shao), pp. 1627–1634. Yichang, China. Proceedings available on CD; ISBN 7-89494-565-X.

Frissell, C.A., & Nawa, R.K., 1992. Incidence and causes of physical failure of artificial habitat structures in streams of western Oregon and Washington. North American Journal of Fisheries Management 12, 182–187.

Frissell, C.A., & Ralph, S.C., 1998. Stream and watershed restoration. In R.J. Naiman & R.E. Bilby, eds. River Ecology and Management: Lessons from the Pacific Coastal Ecoregion, pp. 599–624. New York, Springer. 705 pp.

Frissell, C.A., Liss, W. J., Gresswell, R.E., Nawa, R.K., & Ebersole, L., 1997. A resource in crisis: changing the measure of salmon management. Pages 411-446 *in* D.J. Stouder, P.A. Bisson, and R.J. Naiman, eds. Pacific salmon and their ecosystems: status and future options. Chapman and Hall, New York

Geist, J., 2010. Strategies for the conservation of endangered freshwater pearl mussels (Margaritifera margaritifera L.): a synthesis of conservation genetics and ecology. Hydrobiologia, 644, 69–88.

Giller, P.S., 2005. River restoration: seeking ecological standards. Editors Introduction. Journal of Applied Ecology 42, 201-207.

Gillilan, S., Boyd, K., Hoitsma, T., & Kauffman, M., 2005. Challenges in developing and implementing ecological standards for geomorphic river restoration projects: a practitioner's response to Palmer et al (2005)' Journal of Applied Ecology 42, 223-227.

Gittinger, J.P. 1982. *Economic Analysis of Agricultural Projects*, Second Edition, A World bank Publication, The John Hopkins University Press, Baltimore and London.

Green, R.H., 1979. Sampling design and statistical methods for environmental biologists. John wiley & Sons, New York.

Green, R.H., 1989. Power analysis and practical strategies for environmental monitoring. Environmental Research 50, 195-205.

Haase, P., Hering, D., Jahnig, S.C., Lorenz, A.W., & Sundermann, A. 2013. The impact of hydromorphological restoration on river ecological status: a comparison of fish, benthic invertebrates, and macrophytes. Hydrobiologia, 704, 475–488.

Harvey, G. L., & Clifford, N.J., 2008. Microscale hydrodynamics and coherent flow structures in rivers: implications for the characterisation of physical habitat. *River Research and Applications* 25 (2): 160-180.

Haslam, S.M., 1996. Enhancing river vegetation: conservation, development and restoration. Hydrobiologia 340, 345–348.

Hasler, C T., Mossop, B., Patterson, D A., Hinch, S G., & Cooke, S J. 2012. Swimming activity of migrating Chinook salmon in a regulated river. Aquatic Biology, 171, 47-56.

Hatton-Ellis, T., 2008. The hitchhiker’s guide to the Water Framework Directive. Aquatic Conservation: Marine and Freshwater Systems, 18, 111–116.

Henry, C.P. & Amoros, C., 1995. Restoration ecology of riverine wetlands: I. A scientific base. Environmental Management 19, 891–902.

Henry, C.P. & Amoros, C., 1996. Restoration ecology of riverine wetlands: III. Vegetation survey and monitoring optimization. Ecological Engineering 7, 35–58.

Henry, C.P., Amoros, C. & Giuliani, Y., 1995. Restoration ecology of riverine wetlands: II. An example in a former channel of the Rhoˆne River. Environmental Management 19, 903–913.

Hering, D., Borja, A., Carstensen, J., Carvalho, L., Elliott, M., Feld, CK., Heiskanen, A-S., Johnson, R.K., Moe, J., & Pont, D. 2010. The European Water Framework Directive at the age of 10: a critical review of the achievements with recommendations for the future. Science of the Total Environment 408, 4007–4019.

Hermoso, V., Pantus, F., Olley, J., Linke, S., Mugodo, J., & Lea, P., 2012. Systematic planning for river rehabilitation: integrating multiple ecological and economic objectives in complex decisions. Freshwater Biology 57, 1–9.

Hey, R.D., 1992. River mechanics and habitat creation. Fisheries in the Year 2000 *(eds* K.T.O'Grady*,* A.J.B.Butterworth*,* R.P.Spillet*), pp.* 271–285*.* Institute of Fisheries Management, Nottingham, UK.

Hillman, M,. & Brierley, G., 2005. A critical review of catchment-scale stream rehabilitation programmes. Progress in Physical Geography 29(1), 50–76.

Hobbs, R.J., 2007. Setting Effective and Realistic Restoration Goals: Key Directions for Research. Restoration Ecology 15(2), 354–357.

Hobbs, R.J., & Harris, J.A., 2001. Restoration Ecology: Repairing the Earth’s Ecosystems in the New Millennium. Restoration Ecology Vol. 9(2), 239–246.

Hobbs, R.J., Hallett, L.M., Ehrlich, P.R., & Mooney, H.A., 2011. Intervention Ecology: Applying Ecological Science in the Twenty-first Century. BioScience 61(6), 442-450.

Hodder, K.H., Douglas, S., Newton, A.C., Bullock, J.M., Scholefield, P., Vaughan, R., Cantarello, E., Beer, S., & Birch, J., 2010. Analysis of the costs and benefits of alternative solutions for restoring biodiversity. Report to Defra December 2010 - WC0758/CR0444.

Holl, K.D,. & Cairns, J. Jr., 1996. Restoration ecology: some new perspectives. In: Preservation of Natural Diversity *in* Transboundary Protected Areas: Research Needs/Management Options (Eds A. Breymeyer & R. Noble), pp. 25–35. National Academy Press, Washington D.C.

Hooke, J.M., 1979. An analysis of the processes of river bank erosion. Journal of Hydrology 42, 39-62.

Howarth, W,. 2006. The progress towards ecological quality standards. Journal of Environmental Law 18, 3–35.

Howe, C., & Milner-Gulland, E. J., 2012. Evaluating indices of conservation success: a comparative analysis of outcome- and output-based indices. Animal Conservation 15, 217–226.

Hughes, D.A., & Münster, F., 2000. Hydrological information and techniques to support the determination of water quantity component of the ecological reserve for rivers. Water Research Commission Report N TT 137/00, 91 pp, Pretoria, South Africa.

Hughes, F.M.R., Stroh, P.A., Mountford, J.O., Warrington, S., Gerrard, C., & Jose, P., 2008. Monitoring large-scale wetland restoration projects: Is there an end in sight? *In*: P. Carey, (Ed.), Landscape ecology and conservation. Proceedings of the 15th Annual Conference of the International Association for Landscape Ecology (UK Chapter), Cambridge, UK, September 8–11th, 2008, pp. 170–179.

Hunsaker, C.T., & Carpenter, D.E., 1990. Ecological Indicators for the Environmental Monitoring and Assessment Program. EPA 528/3-90-060. U.S. Environmental Protection Agency, Office of Research and Development, Research Triangle Park, North Carolina.

Hunt, R.L., 1993. Trout Stream Therapy. University of Wisconsin Press, Madison, WI.

Hunter, C.J., 1991. Better Trout Habitat: a guide to stream restoration and management. Island Press, Washington D.C.

Interact, 2011. *INTERREG.* [Online] Available at: < http://www.interacteu.net/interreg/interreg/342/5898> [Accessed 20 August 2011].

Irvine, K., 2012. The tragedy of the threshold: revising perceptions for aquatic conservation. Aquatic Conservation of Marine and Freshwater Ecosystems 22, 705–711.

Iversen, T. M., Kronvang, B., Madsen, B. L., Markmann, P., & Nielsen, M.B., 1993. Re-establishment of Danish streams: restoration and maintenance measures. Aquatic Conservation: Marine and Freshwater Ecosystems 3(2), 73–92.

Jähnig, S.C., Brunzel, S., Gacek, S., Lorenz, A.W., & Hering, D., 2009. Effects of re-braiding measures on hydromorphology, floodplain vegetation, ground beetles and benthic invertebrates in mountain rivers. Journal of Applied Ecology 46, 406–416.

Jähnig, S.C., Brabec, K., Buffagni, A., Erba, S., Lorenz, A.W., Hering, D., Ofenbock, T., Verdonschot, P.F.M., & Hering, D., 2010. A comparative analysis of restoration measures and their effects on hydromorphology and benthic invertebrates in 26 central and southern European rivers. Journal of Applied Ecology. 47, 671–680.

Jansson, R., Backx, H., Boulton, A.J., Dixon, M., Dudgeon, D., Hughes, F., Nakamura, K., Stanley, E., & Tockner, K., 2005. Stating mechanisms and refining criteria for ecologically successful river restoration: a comment on Palmer et al. (2005). Journal of Applied Ecology, 42, 218–222.

Jansson, R., Nilsson, C., & Malmqvist, B., 2007. Restoring freshwater ecosystems in riverine landscapes: the roles of connectivity and recovery processes. Freshwater Biology 52, 589–596.

Johnson, g.E., Ebberts, B.D., Thom, R.M. et al., 2003. An Ecosytem-Based Approach to Habitat Restoration Projects wih Emphasis on Salmonids in the California River estuary. Report no.PNNL-14412, Battelle Pacific Northwest National Laboratory, Sequim, Washington.

Jones, J.P.G., 2012. Getting what you pay for: the challenge of measuring success in conservation. Commentary. Animal Conservation 15, 227–228

Jones, J., Collen, B., Atkinson, G., Baxter, P., Bubb, P., Illian, J., Katzner, T., Keane, A., Loh, J., MacDonald-Maddon, E., Nicholson, E., Pereira, H., Possingham, H., Pullin, A., Rodrigues, A., Ruiz-Gutierrez, V., Sommerville, M., & Milner-Gulland, E.J., 2011. The 'why', 'what' and 'how' of global biodiversity indicators: looking beyond 2010. Conservation Biology*,* 25, 450–457.

Jungwirth, M., Muhar, S., & Schmutz, S., 1995. The effects of recreated instream and ecotone structures on the fish fauna of an epipotamal river. Hydrobiologia 303, 195–206.

Jungwirth, M., Muhar, S., & Schmutz, S., 2002. Re-establishing and assessing ecological integrity in riverine landscapes. Freshwater Biology, 47, 867–887.

Kail, J., & Hering, D., 2009. The influence of adjacent stream reaches on the local ecological status of central European mountain streams. River Research and Applications, 25, 537–550.

Kamp, U., Binder, W., & Hölzl, K., 2007. River habitat monitoring and assessment in Germany. Environmental Monitoring and Assessment, 127, 209–226.

Karr, J.R., 1981. Assessment of biotic integrity using fish communities. Fisheries 6, 21-27.

Karr, J.R., 1991. Biological integrity: a long neglected aspect of water resource management. Ecological Applications 1, 66–84.

Katz, S,L., Barnas, K., Hicks, R., Cowen, J., & Jenkinson, R., 2007. Freshwater habitat restoration in the Pacific Northwest: a decade's investment in habitat improvement. Restoration Ecology, 15, 494–505.

Kemp, J.L., Harper, D.M., & Crosa, G.A., 1999. Use of 'functional habitats' to link ecology with morphology and hydrology in river rehabilitation. *Aquatic Conservation of Marine Freshwater* Ecosystems 9(1), 159–178.

Kershner, J.L., 1997. Monitoring and adaptive management *in* Willians J. E., Wood C.A. and Dombeck M.P, editors. Watershed restoration: principles and practise. American Fisheries Society, Bethesda, MarlandKirkby & Morgan 1980.

King, J.M., & Louw, D., 1998. Instream flow assessments for regulated rivers in South Africa using the building block methodology. *Aquatic Ecosystem Health and Management* 1, 109-124

Knighton, D., 1998. Fluvial forms and processes. Arnold, London, UK.

Koebel, J.W., Jones, B.L., & Arrington, D.A., 1999. Restoration of the Kissimmee River, Florida: water quality impacts from canal backfilling. Environmental Monitoring and Assessment 57, 85-107.

Kondolf, G.M., 1995. Geomorphological stream channel classification in aquatic habitat restoration – uses and limitations. Aquatic Conservation-Marine and Freshwater Ecosystems 5, 127–141.

Kondolf, G.M., & Micheli, E.R., 1995. Evaluating stream restoration projects. Environmental Management 19, 1–15.

Kondolf, G.M., & Downs, P.W., 1996. Catchment approach to planning channel restoration. *In*: Brookes, A, Shields, F.D, editors. River channel restoration: guiding principles for sustainable projects. Chichester: Wiley. pg. 103–26.

Kondolf, G.M., Boulton, A., O'Daniel, S., Poole, G., Rahel, F., Stanley, E., Wohl, E., Bang, A., Carlstrom, J., Cristoni, C., Huber, H., Koljonen, S., Louhi, P., & Nakamura, K., 2006. Process-based ecological river restoration: visualizing three-dimensional connectivity and dynamic vectors to recover lost linkages. *Ecology and Society* 11(2): 5. [online] URL: http://www.ecologyandsociety.org/vol11/iss2/art5/.

Kusek, J.Z., & Rist, R.C., 2004. *Ten Steps to a Results-Based Monitoring and Evaluation System.* Washington DC, The World Bank. Lepori, F., Palm, D., Brännäs, E., & Malmqvist, B., 2005. Does restoration of structural heterogeneity in streams enhance fish and macroinvertebrate diversity? Ecological Applications 5, 2060–2071.

Leopold, L.B., 1994. A view of the river. Harvard University Press, Cambridge, Massachusetts, USA.

Letcher, R.A., & Giupponi, C., 2005. Policies and tools for sustainable water management in the European Union. Environmental Modelling & Software 20, 93-98.

Lichatowich, J., Mobrand, L., Lestelle., & Vogel, T., 1995. An approach to the diagnosis and treatment of depleted Pacific salmon populations in Pacific Northwest watersheds. Fisheries 20(1), 10-18.

Lockwood, J.L., & Pimm, S.L., 1999. When does restoration succeed? 363–392 *in* E. Weiher, and P. Keddy, editors. Ecological assembly rules: perspectives, advances, retreats. Cambridge University Press, Cambridge, United Kingdom.

Lobb, M. D., & Orth, D.J., 1991. Habitat use by an assemblage of fish in a large warmwater stream. Transactions of the American Fisheries Society 120:65-78.

Lorenz, C.M., VanDijk, G.M., VanHattum, A.G.M., & Cofino ,W.P., (1997). Concepts in river ecology: implications for indicator development. Regulated Rivers: Research and Management 13, 501–516.

Lorenz, A.W., Korte, T., Sundermann, A., Januschke, K., & Haase, P., 2012. Macrophytes respond to reach-scale river restorations. Journal of Applied Ecology 49, 202–212.

Lucas, M., & Marmulla, G., 2000. An assessment of anthropogenic activities on and rehabilitation of river fisheries: current status and future direction – *In*: Management and Ecology of River Fisheries (Ed) I.G. Cowx, Fishing News Books, Oxford 261-278.

Mainstone, C.P., & Clarke, S.J., 2008. Managing multiple stressors on sites with special protection for freshwater wildlife — the concept of Limits of Liability. Freshwater Reviews 1, 175–187.

Mainstone, C.P., & Holmes, N.T.H., 2010. Embedding a strategic approach to river restoration in operational management processes — experiences in England. Aquatic Conservation of Marine Freshwater Ecosystems.

Maloney, K.O., Dodd, H.R., Butler, S.E., & Wahl, D.H., 2008. Changes in macroinvertebrate and fish assemblages in a medium-sized river following a breach of a low-head dam. Freshwater Biology 53, 1055–1068.

May, R., 2006. ‘‘Connectivity’’ in urban rivers: Conflict and convergence between ecology and design. Technology in Society 28, 477–488.

Mills, D., 1991. Strategies for the Rehabilitation of Salmon rivers. The Atlantic Salmon Trust, The Institute of Fisheries Management, & The Linnaean Society of London, London.

Minns, C.K., Kelso, J.R.M. ,& Randall, R.G., 1996. Detecting the response of fish to habitat alterations in freshwater ecosystems. Canadian Journal of Fisheries and Aquatic Science 53, 403-414.

Montgomery, D.R., & Buffington, J.M., 1997. Channel-reach morphology in mountain drainage basins, Geological Society of America Bulletin 109, 596-611.

Montgomery, D.R., 1997*.* ‘What’s best on the banks’*, Nature* 388*,* 328–329.

Morrisey, D.J., 1993, ‘Environmental impact assessment – A review of its aims and recent developments’, Marine Pollution Bulletin 26(10), 540–545.

Moss, B., 1998. Shallow lakes, biomanipulation and eutrophication. Scope News Letter 29, 1–45.

Moss, B., 2008. The Water Framework Directive: total environment or political compromise? Science of the Total Environment 400, 32–41.

Nagrodski, A., Raby, G.D., Hasler, C.T., Taylor, M.K., & Cooke, S.J., 2012. Fish stranding in freshwater systems: sources, consequences, and mitigation. Journal of Environmental Management 103, 133-14

Nehlsen, W., Williams, J.E., & Lichatowich, J.A., 1991. Pacific salmon at the crossroads: stocks at risk from California, Oregon, Idaho, and Washington. Fisheries 16(2), 4-21.

Newson, M.D., 2002. “Geomorphological concepts and tools for sustainable river ecosystem management”, *Aquatic Conservation-Marine and Freshwater Ecosystems* 12(4), 365–379.

Norris, R.H., Webb, J.A., Nichols, S.J., Stewardson, M.J., & Harrison, E.T., 2012. Analyzing cause and effect in environmental assessments: using weighted evidence from the literature. Freshwater Science.

NRC (National Research Council), 1992. Restoration of aquatic ecosystems: science, technology, and public policy. National Academy Press, Washington, D.C.

Nunn, A.D., Harvey, J.P. & Cowx, I.G. 2012. Restoring river connectivity: prioritizing passage improvements for diadromous fishes and lampreys . *Ambio* **41**, 402-409.

NZ MAF, 2002. Import Risk Analysis – Animals and Animal Products. New Zealand Ministry of Agriculture and Forestry, Wellington. 183 pp. ISBN 040-478-07660-6.

O’Grady, M., 2006. Channels &Challenges: the enhancement of salmonid rivers. Irish Freshwater Fisheries Ecology and Management Series: Number 4. Central Fisheries Board, Dublin, Ireland.

Ormerod, S.J., 2004. A golden age of river restoration science? Aquatic Conservation of Marine and Freshwater Ecosystems. 14, 543–9.

Opperman, J.J., Galloway, G.E., Fargione, J., Mount, J.F., Richter, B.D., & Secchi, S., 2009. Sustainable floodplains through large-scale reconnection to rivers. Science 326, 1487–1488.

Osenberg, C.W., Holbrook, S.J., & Schmitt, R.J., 1992. Implications for the design of environmental assessment studies. Pages 75-90 *in* Grifman P.M & Yoder S.E, editors. Perspectives on the marine environment. Sea Grant Institution Prgram, Hancock Institute for Marine Studies, University of Southern California, Los Angeles, California, USA.

Osenberg, C.W., Schmitt, R.J., Holbrook, S.J., Agu-Saba, K.E., & Flegal, R., 1994. Detection of environmental impacts: natural variability, effect size, and power analysis. Ecological Applications 4, 16-30.

Palmer, M.A., & Allan, D., 2006. Restoring rivers. Issues Science and Technology 22, 40–48.

Palmer, M.A., Hakenkamp, C.C., & Nelson-Baker, K., 1997. Ecological heterogeneity in streams: why variance matters. Journal of the North American Benthological Society 16, 189–202.

Palmer, M.A., Bernhardt, E., Chornesky, E., Collins, S., Dobson, A., Duke, C., Gold, B., Jacobson, R., Kingsland, S., Kranz, R., Mappin, M., Martinez, M.L., Micheli, F., Morse, J., Pace, M., Pascual, M., Palumbi, S., Reichman, O.J., Simons, A., Townsend, A. & Turner, M., 2004. Ecology for a crowded planet. Science 304, 1251–1252.

Palmer, M.A., Bernhardt, E.S., Allan, J.D., Lake, P.S., Alexander, G., Brooks, S., Carr, J., Clayton, S., Dahm, C.N., Shah, J.F., Galat, D.L., Loss, S.G., Goodwin, P., Hart, D.D., Hassett, B., Jenkinson, R., Kondolf, G.M., Lave, R., Meyer, J.L., O'Donnell, T.K., Pagano, L. & Sudduth, E., 2005. Standards for ecologically successful river restoration. Journal of Applied Ecology 42, 208–217

Palmer, M.A., Menninger, H.L., & Bernhardt, E., 2010. River restoration, habitat heterogeneity and biodiversity: a failure of theory or practice? Freshwater Biology 55, 205–222.

Pasternack, G.B., 2008. Spawning Habitat Rehabilitation: Advances in Analysis Tools. American Fisheries Society Symposium 65, 321-348.

Peter, A., Kienast, F. & Woolsey, S., 2005. River rehabilitation in Switzerland: scope, challenges and research. Archiv für Hydrobiologie Supplement Large Rivers, 155, 643–656.

Poff, N.L**.,** & Zimmerman, J.K.H., 2010. Ecological responses to altered flow regimes: a literature review to inform environmental flows science and management. *Freshwater Biology* 55:194-20.

Poff, L.N., Allan, D.J., Bain, M.B., Karr, J.R., Prestegaard, K.L., Richter, B.D., Sparks, R.E.. Stromberg, J.C., 1997. The natural flow regime. A paradigm for river conservation and restoration. BioScience 47, 769-784.

Possingham, H., 2012. How can we sell evaluating, analyzing and synthesizing to young scientists. Commentary. Animal Conservation 15, 229–230.

Postel, S., & Richter, B., 2003. *Rivers for Life: Managing Water for People and Nature*. Island Press, Washington, DC.

Postel, S.L., Daily, G.C., & Ehrlich, P.R., 1996. Human appropriation of renewable freshwater. *Science* **271**, 785–788.

Potter, K., Cubbage, F., Blank, G., Schaberg, R., 2004. A watershed-scale model for predicting nonpoint pollution risk in North Carolina. Environmental Management 34, 62–74.

Pretty, J.L., Harrisson, S.S.C., Shepherd, D.J., Smith, C., Hildrew, A.G., & Hey R.D., 2003. River rehabilitation and fish populations: assessing the benefit of instream structures. Journal of Applied Ecology 40, 251-265.

Reeves, G.H., Hall, J.D., Roelofs, T.D., Hickman, T.L. & Baker, C.O., 1991. Rehabilitating and modifying stream habitats. Pages 519–557 *in* W. R. Meehan, editor. Influences of forest and rangeland management on salmonid fishes and their habitats. *American Fisheries Society*, Special Publication **19**, Bethesda, Maryland.

Reeves, G.H., Benda, L.E., Burnett, K.M., Bisson, P.A., & Sedell, J.R., 1995. A disturbance-based approach to maintain and restoring freshwater habitat of evolutionary significant units of anadromous salmonids in the Pacific Northwest. Pages 334-349 *in* Nielsen J.L, editor. Evolution and the aquatic ecosystem: defining unique units in population conservation. *American fisheries society, Symposium* **17**, Bethesda, Maryland.

Rheinhardt, R.D., Rheinhardt, M.C., Brinson, M.M., & Fraser, K.E., 1999. Application of reference data for assessing and restoring headwater ecosystems. Restoration Ecology 7, 241–251.

Rhoads, B.L., Wilson, D., Urban, M. & Herricks, E.E., 1999. Interaction between scientists and non scientists in community based watershed management: emergence of the concept of stream naturalization. Environmental Management 24, 297–308.

Richter. B.D., Baumgartner, J.V., Wigington, R. & Braun, D.P.. 1997. How much water does a river need? Freshwater Biology **37**, 231-249.

Rohde, S., Hostmann, M., Peter, A., & Ewald, K.C., 2006. Room for rivers: an integrative search strategy for floodplain restoration. Landscape and Urban Planning 78, 50–70.

Roni, P., 2005. Monitoring Stream and Watershed Restoration. American Fisheries Society, Bethesda, Maryland.

Roni, P.. & Beechie, T., 2013. Stream and watershed restoration – A guide to restoring riverine processes and habitats. John Wiley & Sons, Ltd.

Roni, P., Beechie, T.J., Bilby, R. E., Leonetti, F.E., Pollock, M.M. & Pess, G.R., 2002. A review of stream restoration techniques and a hierarchical strategy for prioritizing restoration in Pacific Northwest watersheds. North American Journal of Fisheries Management 22, 1–20.

Roni, P., Liermann, M. & Steel, A., 2003. Monitoring and evaluating responses of salmonids and other fishes to in-stream restoration. Pages 318–339 *in* D. R. Montgomery, S. Bolton, and D. B. Booth, editors. Restoration of Puget Sound rivers, University of Washington Press. Seattle

Roni, P., Hanson, K., Pess, G., Beechie, T., Pollock, M., & Bartley. D., 2005. Habitat Rehabilitation for Inland Fisheries: Global Review of Effectiveness and Guidance for Restoration of Freshwater Ecosystems. Fisheries Technical Paper 484. Food and Agriculture Organization of the United Nations, Rome, Italy, pp. 116.

Roni, P., Hanson, K., & Beechie, T., 2008. Global review of the physical and biological effectiveness of stream habitat rehabilitation techniques. North American Journal of Fisheries Management 28, 856–890.

Root, R.B., 1967. The niche exploitation pattern of the blue-gray gnatcatcher. Ecological Monographs 37, 317-350.

Rosgen, D.L., 1994. A classification of natural rivers. Catena 22, 169-199.

Rosgen, D. L. 1996. Applied river morphology. Wildland Hydrology Books Inc., Pagosa Springs, Colorado, USA.

RRC, 1999. *Manual of River Restoration Techniques*. River Restoration Centre, UK. - RRC Manual.

Roux, A.L., Bravard, J.P., Amoros, C., & Pautou G., 1989. Ecological changes of the French Upper Rhône River since 1750. Pages 323-350 in G. E. Petts (ed.), Historical change of large rivers: Western Europe. John Wiley & Sons, Chichester, UtC.

Ruiz-Jaen, M. C., & Mitchell, A T., 2005. Restoration success: how is it being measured? Restoration Ecology 13, 569–577.

Rumps, J.M., Katz, S.L., Morehead, M.D., Jenkinson, R., & Goodwin, P. (2007) Stream restoration in the Pacific Northwest: Analysis of interviews with project managers. Restoration Ecology 15, 506-515.Ryder, D.S., & Miller, W., 2005. Setting goals and measuring success: linking patterns and processes in stream restoration. *Hydrobiologia* 552, 147–158.

Sala, O., Chapin, F.S., Armesto, J.J., Berlow, E., Bloomfield, J.,Dirzo, R., Huber-Sanwald, E., Huenneke, L.F., Jackson, R.B., Kinzig, A., Leemans, R., Lodge, D.M., Mooney, H.A., Oesterheld, M., Poff, N.L., Sykes, M.T., Walker, B.M, Walker, M., & Wall, D.H., 2000. Global biodiversity scenarios for the year 2100. Science 287, 1770–1774.

Sawyer, A.M., Pasternack, G.B., Merz, J.E., Escobar, M., & Senter, A,E., 2009. Construction constraints on geomorphic-unit rehabilitation on regulated gravel-bed rivers. River Research and Applications 25, 416-437.

Schiemer, F., Baumgartner, C., & Tockner, K., 1999. Restoration of floodplain rivers. The 'Danube Restoration Project'. Regulated Rivers: Research and Management 15, 231–244.

Schmid, A., 1879. Die Flusskorrektionen im Kanton Thurgau. Mitteilungen der Thurgauischen Naturforschenden Gesellschaft 4, 207–225.

Schouten, M.G.C., 1996. Disturbance, conservation and restoration of ecological systems – dreams and realities. Disturbance and Recovery in Ecological Systems (eds P.S. Giller & A.A. Myers), pp. 101–118. Royal Irish Academy, Dublin, Ireland.

Schweizer, S., 2006. Predicting the Consequences of River Rehabilitation Measures on Morphology, Hydraulics, Periphyton and Invertebrates. PhD Thesis, ETH Zurich, Switzerland.

Schweizer, S., Borsuk, M.E., Jowett I., & Reichert, P., 2007. Predicting joint frequency distributions of depth and velocity for instream habitat assessment. River Research and Applications 23, 287–302.

Sear, D.A., Briggs, A., & Brookes, A., 1998. A Preliminary analysis of the morphological adjustment within and downstream of a lowland river subject to river restoration. Aquatic Conservation of Marine and Freshwater Ecosystems 8, 167–183.

Sear, D.A., 1994. River restoration and geomorphology. Aquatic Conservation 4, 169–177.

Sedgwick, R.W., 2006. Manual of Best Practice for Fisheries Impact Assessments. Science Report SC020025/SR.

SER (Society for Ecological Restoration) International Science & Policy Working Group. 2004. The SER International Primer on Ecological Restoration (available from http://www.ser.org) accessed in September 2006. Society for Ecological Restoration International, Tucson, Arizona.

Sheldon, A. L., & Meffe, G.F., 1995. Path analysis of collective properties and habitat relationships of fish assemblages in coastal plain streams. Canadian Journal of Fisheries and Aquatic Sciences 52:23-33.

Shields, F.D., Cooper, C.M., Knight, S.S., & Moore, M.T., 2003. Stream corridor restoration research: a long and winding road. Ecological Engineering 20, 441–454.

Skidmore, P.B., Thorne, C.R., Cluer, B.L., Pess, g.R., Castro, J.M., Beechie, T, J., & Shea, C.C., 2011. Science base and tools for evaluating stream engineering, management and restoration proposals. NOAA Technical Memorandum NMFS-NWFSC-112.

Skidmore, P., Beechie, T., Pess, G., Castro, J., Cluer, B., Thorne, C., Shea, C., & Chen, R., 2013. Developing, Design, and Implementing Restoration Projects. *In*: Roni, P. & Beechie, T.,

2013. Stream and watershed restoration – A guide to restoring riverine processes and habitats. John Wiley & Sons, Ltd.
Slaney, P.A., & Zaldokas, D., 1997. Fish Habitat Rehabilitation Procedures. British Columbia, Ministry of Environment, Lands and Parks and Ministry of Forests, Vancouver, B.C., Canada.
Smith, S.M., & Prestegard, K.L., 2005. Hydraulic Performance of a Morphology-Based Stream Channel Design. Water Resources Research 41.
Smith, P.E., Orvos, D.R., & Cairns J., (1993). Impact assessment using the before-after-control-impact (BACI) model: concerns and comments. Canadian Journal of Fishereis and Aquatic Sciences 50, 627-637.
Smokorowski, K.E. & Pratt, T.C. 2007. Effect of a change in physical structure and cover on fish and fish habitat in freshwater ecosystems – a review and meta-analysis. Environmental Reviews **15**, 15-41.
Smokorowski, K.E., Metcalfe, R.A., Finucan, S.D., Jones, N., Marty, J., Power, M., Pyrce, R.S., & Steele, R. 2011. Ecosystem level assessment of environmentally based flow restrictions for maintaining ecosystem integrity: a comparison of a modified peaking versus unaltered river. Ecohydrology **4** 6, 791-806.
Stanford, J,A., Ward, J.V., Liss, W.J., Frissell, C.A., Williams, R.N., Lichatowich, J.A., & Coutant, C.C., 1996. A general protocol for restoration of regulated rivers. Regulated Rivers 12, 391-413.
Statzner, B, Gore, J.A., & Resh, V.H., 1988. Hydraulic stream ecology: observed patterns and potential applications. Journal of the North American Benthological Society 7, 307–360.
Statzner, B., Bady, P., Dolédec, S., & Schöll, F., 2005. Invertebrate traits for the biomonitoring of large European rivers: an initial assessment of trait patterns in least impacted river reaches. Freshwater Biology 50, 2136–2161.
Steel, E.A., Fullerton, A., Caras, Y., Sheer, M.B., Olson, P., Jensen, D., Burke, J., Maher, M., and McElhany, P., 2008. A spatially explicit decision support system for watershed-scale management of salmon. Ecology and Society 13, 50-81.
Stewart-Oaten, A., Murdoch, WW., & Parker, K.R., 1986. Environmental impact assessment: "pseudoreplication" in time? Ecology 67, 929-940.
Strange, R.M., 1999. Historical biogeography, ecology, and fish distributions: conceptual issues for establishing IBI criteria. *In*: *Assessing the Sustainability and Biological Integrity of Water Resources Using Fish Communities.*T. P. Simon (ed.): 65–78. CRC Press, Boca Raton, Florida, USA
Stranko, S.A., Hildebrand, R.H., & Palmer, M.A., 2012. Comparing the fish and benthic macroinvertebrate diversity of restored urban streams to reference streams. Restoration Ecology. doi:10.1111/j.1526-100X.2011.00824.x.
Suding, K.N., Gross, K.L., & Housman, D.R., 2004. Alternative states and positive feedbacks in restoration ecology.Trends in Ecology and Evolution 19, 46–53.
Szaro, R.C., Berc, J., Cameron, S., Cordle, S., Crosby, M., Martin, L., Norton, D., O'Malley, R., & Ruark, G., 1998. ``The ecosystem approach: science and information management issues, gaps and needs'' Landscape and Urban Planning 40, 89-101.
Tarzwell, C.M., 1937. Experimental evidence on the value of trout stream improvement in Michigan. American Fisheries Society 66, 177–187.

Tilman, D., Fargione, J., Wolff, B., D'Antonio, C., Dobson, A., Howarth, R., Schindler, D., Schlesinger, W.H., Simberloff, D., & Swackhamer, D., 2001. Forecasting agriculturally driven global environmental changes. Science 292, 281–284.

Tompkins, M.R., & Kondolf, G.M., 2007. Systematic post project appraisals to maximise lessons learned from river restoration projects: case study of compound channel restoration projects in northern California. Restoration Ecology 15, 524–537.

Toth, L.A. 1993. The ecological basis of the Kissimmee River Restoration Plan. Florida Scientist 56:25-51.

Tullos, D.D., Penrose, D.L., & Jennings, G.D., 2006. Development and application of a bioindicator for benthic habitat enhancement in the North Carolina Peidmont. Ecological engineering 27, 228-241.

UK DoE, 1995. A Guide to Risk Assessment and Risk Management for Environmental Protection. HMSO, Department of the Environment. ISBN 011-753091-3.

UNESCO. 2011. *Results-Based Programming, Managing and Monitoring (RBM) approach as applied at UNESCO. Guiding Principles.* Paris, Bureau of Strategic Planning, UNESCO.

US ANS Task Force, 1996. Report to the aquatic nuisance species task force. Generic nonindigenous aquatic organisms risk analysis review process (For Estimating Risk Associated with the Introduction of Nonindigenous Aquatic Organisms and how to Manage for that Risk). US Fish & Wildlife Service and National Oceanic & Atmospheric Administration (http:// www.anstaskforce.gov/gennasrev.htm).

Van der Meulen, S. & Brils, J. (2008). Ecosystem Services in river basin management – background information and discussion document, RISKBASE project.

Vaughn, I.P., Diamond, M., Gurnell, A.M., Hall, K.A., Jenkins, A. Milner, N.J, Naylor, L.A., Sear, D.A., Woodward, G. & Ormeron, S.J., 2009. Integrating ecology with hydromorphology: a priority for river. Aquatic Conservation: Marine and Freshwater Ecosystems.

Vermaat, J., Ansinkb, E. Wagtendonkb, A., & Brouwerb R., 2013. Valuing the ecosystem services provided by European river corridors – an analytical framework. Reform Deliverable D 2.3.

Verdonschot, P. F. Spears, M.B., Feld, C.K., Brucet, S., Keizer-Vlek, H., Gunn, I., May, L., Meis, s., Borja, A., Elliott, M., Kernan M., & Johnson R, 2013. A comparative review of recovery processes in rivers, lakes, estuarine and coastal waters. Hydrobiologia 704.

Violin, C.R., Cada, P., Sudduth, E.B., Hassett, B.A., Penrose D.L., & Bernhardt, E.S., 2011. Effects of urbanization and urban stream restoration on the physical and biological structure of stream ecosystems. Ecological Applications 21, 1932–1949.

Waal. L.C., Large, A.R.G., & Wade, P.M., 1998. Rehabilitation of River: Principles and Implementation. Wiley, Chichester.

Ward, D., Holmes, N., & José, P., 1994. The New Rivers & Wildlife Handbook. The Royal Society for the Protection of Birds, Bedforshire, UK.

Ward, J.V., Tockner, K., Uehlinger, U., & Malard, F., 2001. Understanding natural patterns and processes in river corridors as the basis for effective river restoration. Regulated Rivers: Research and Management 17, 311–323.

Ward, J.V., Tockner, K., Edwards, P.J., Kollmann, J., Bretschko, G., Gurnell, A.M., Petts, G.E. and Rossaro, B. 1999. A reference river system for the Alps: The "Fiume Tagliamento." Regulated Rivers 15:63–75.

Ward, J.V., 1989. The four-dimensional nature of lotic ecosystems. *Journal of the North American* Benthological Society 8, 2–8.

Welcomme, R.L., Winemiller, K.O., & Cowx, I.G., 2006. Fish environmental guilds as a tool for assessment of ecological condition of rivers. Regulated Rivers: Research and Management 2, 377–396.

Wheaton, J.M., Pasternack, G.B., & Merz, J.E., 2004. Spawning habitat rehabilitation – I. Conceptual approach and methods. International Journal of river Basin Managment 2(1), 3-20.

White, P.S., & Walker, J.L., 1997. Approximating nature's variation: selecting and using reference information in restoration ecology. Restoration Ecology 5, 338–349.

Wohl, E., Angermeier, P.L., Bledsoe, B., Kondolf, G.M., MacDonnell, L., Merritt, D.M., Palmer, M.A., Poff, N.L., & Tarboton, D., 2005. River restoration, Water Resources 41.

Wolter, C., 2010. Functional vs Scenic restoration – challenges to improve fish and fisheries in urban waters. Fisheries Management and Ecology 17, 176-185.

Wolter, C., Lorenz, S., Scheunig, S., LehmannN., Schomaker L. & Nastase A. 2013. Review on ecological response to hydromorphological degradation and restoration, Reform Deliverable D 1.3.

Woolsey, S., Weber, C., & Gonser, T., 2005. Handbuch für die Erfolgskontrolle bei Fliessgewässerrevitalisierungen. Publikation des Rhone-Thur Projektes, Eawag, WSL, LCH-EPFL, VAW-ETHZ, Switzerland, 112 pp.

Woolsey, S., Capelli, F., Gonser,T., Hoehn, E., Hostmann, M., Junker, B., Paetzold, A., Roulier, C., Schweizer, S., Tiegs, S.D, Tockner, K., Weber, C., & Peter, A., 2007. A strategy to assess river restoration success. Freshwater Biology 52, 752–769.

Wyzga, B., Amirowicz, A., Radecki-Pawlik, A., & Zawiejska, J., 2009. Hydromorphological conditions, potential fish habitats and the fish community in a mountain river subject to variable human impacts, The Czarny Dunajec, Polish Carpathians. River Research & Applications.

Yoccoz, N., Nichols, J., & Boulinier, T., 2001. Monitoring of biological diversity in space and time. *Trends in Ecological Evolution* 16, 446–453.

Young, T.P., Petersen, D.A., & Clary, J.J., 2005. The ecology of rehabilitation: historical links, emerging issues and unexplored realms. Ecology Letters 8, 662–673.

Zar, J. H., 1999. Biostatistical analysis. Prentice Hall, Upper Saddle River, New Jersey.

Appendix 1: Overview of ONEMA river hydromorphology restoration projects (Abbreviations: WQ: water quality; NA: not applicable; Q: flows; HYMO: hydromorphologic, channel geometry, sediment transport, flow; Pre: Pre-implementation ; Post: post-implementation ; RC : reference condition site data)

Restoration Project (Control + click for webpage)	Quantitative/Qualitative Reference Condition Benchmarks (RC, historic, model)	Pre/Post Biological Endpoints	Pre/Post Monitoring (Time Frame)	European Policy Drivers
Obstacle Removal				
Démantèlement du barrage de Laparayrié sur l'Agout	None given	Post : riparian vegetation ; HYMO	Pre : banks, WQ Post : WQ During work: sediment transport, bank stability	No
Effacement du seuil de Stalapos sur l'Alagnon	Qual : Historic Atlantic salmon fishery	Post : Trout redds present	Pre : redds count, Carhyce HYMO Post: HYMO (3 yrs, 2-3x/yr), redds count (indef)	Natura 2000 (http://inpn.mnhn.fr/docs/natura2000/fsdpdf/FR8301095.pdf): near Birds Directive and Habitats Directive Sites
Effacement du barrage sur l'Allier à Saint-Étienne-du-Vigan	Qual : Historic Atlantic salmon fishery	Post : Salmon redds present	Pre: sediments Post : photo of banks (3 yrs), helicopter red count (1/yr) During work: suspended sediment, ammonia	Natura 2000 (http://inpn.mnhn.fr/docs/natura2000/fsdpdf/FR8301075.pdf); Habitats Directive Site
Arasement du vannage du moulin de Reveillon et réaménagement du lit mineur de la Blaise	None given	Post : Vegetation, redds	Pre : invertebrates, diatoms Post : fish	WFD « objectives »
Arasement du seuil du pont Paillard sur un bras secondaire de l'Aume	None given	Post : vegetation	Pre: No Post : photos of riparian zone and long profile (every 15 days 3 mos, 3-4x/yr), long-profile and x-sec surveys (1x), photos of facets and vegetation	WFD « objectives »
Effacement du barrage de Fatou sur la Beaume	None given	Post : fish, redds	Pre : fish inventory During work : physio-chemical WQ	Natura 2000 (http://inpn.mnhn.fr/docs/natura2

Restoration Project (Control + click for webpage)	Quantitative/Qualitative Reference Condition Benchmarks (RC, historic, model)	Pre/Post Biological Endpoints	Pre/Post Monitoring (Time Frame)	European Policy Drivers
			Post: electrofishing, redds count (2 yrs)	000/fsdpdf/FR8301096.pdf); Habitats Directive Site
Des actions pour le rétablissement de la continuité sur la Canche et ses affluents classés	None given	None given	Pre : « initial state » Post : NA	No
Rétablissement de la continuité écologique sur la Canche à Hesdin	None given	None given ; HYMO	Pre: coring of sediments for thickness and physio-chemical sampling Post: visual of long profile	No
Arasement d'un seuil sur la Corrèze au sein de l'agglomération de Tulle	None given	None given ; HYMO	Pre : bank stability and riparian vegetation, long profile of water surface and streambed, 26 x-secs, topographic survey, HYMO, sediment transport Post: fish, redds, bank stability and riparian vegetation, HYMO (3 yrs)	No
Effacement de vingt petits ouvrages et diversification du lit mineur du Couasnon	None given	Post : fish; HYMO	NA	No
Effacement d'un seuil à la Roche d'Alès sur la Dême	Qual : Historic trout fishery	Post : Trout ; HYMO	Pre : No Post : HYMO, trout reproduction	No
Effacement du barrage de Kernansquillec sur le Leguer	None given	Post : Salmon, vegetation ; HYMO	Pre : No During work : WQ Post : invertebrates, salmon abundance (1x/yr)	Natura 2000 (http://inpn.mnhn.fr/site/natura2000/FR5300008?lg=en); Habitats Directive Site
Effacement du seuil de Cussy sur le ruisseau de la Maria	None given	Post : Trout alevins upstream, sculpin recolonisation, riparian vegetation ; HYMO	Pre : fish Post : fish (2x)	Natura 2000 (http://inpn.mnhn.fr/docs/natura2000/fsdpdf/FR2600986.pdf); Habitats Directive Site
Arasement du seuil du moulin du Viard sur l'Orne	None given	Post : sea lamprey redds; HYMO	Pre : No Post : salmon juveniles abundance	WFD (HYMO reference station)

Restoration Project (Control + click for webpage)	Quantitative/Qualitative Reference Condition Benchmarks (RC, historic, model)	Pre/Post Biological Endpoints	Pre/Post Monitoring (Time Frame)	European Policy Drivers
Arasement d'un seuil industriel sur le Rhins	None given	No	Pre : No Post : bank stability	No
Arasement du seuil de Sainte-Marie sur la Roanne	None given	None given	Pre : channel geometry, geotechnical Post : No	No
Gestion adaptative des ouvrages hydrauliques de la Sèvre nantaise et du Thouet	None given	Post: WQ, riparian vegetation, macroinvertebrates, fish	Pre/Post : fish, diatoms, macroinvertebrates, macrophytes, plants, WQ, HYMO	Natura 2000 (http://inpn.mnhn.fr/docs/natura2000/fsdpdf/FR5400442.pdf) ; Habitats Directive Site
Rétablissement de la continuité écologique sur le bassin de la Touques	Quant : Historic sea trout population (1978, 1981)	None given	Pre: No Post: sea trout count at fish passage (annual ?, 2001)	No
Effacement du barrage-clapet sur la Touques à Lisieux	Qual: Historic sea trout and eel populations	None given	No	No
Démantèlement et ouverture de quatre vannages sur la Vence	None given ; chub, trout, brook lamprey, minnow, loach, dace, roach, and gudgeon populations exist	Post : fish , macroinvertebrates ; HYMO	Pre: No Post: fish and macroinvertebrate; HYMO	No
Effacement du barrage de l'ancien moulin Maurice sur le Ventron	None given	Post : trout redds	No	No
Effacement du barrage de Maisons-Rouges sur la Vienne	Qual: Historic fishery for salmon, shad, sea lamprey, and eels	Post: riparian vegetation, large migratory fish (particularly shad)	Pre: initial monitoring (1995, 1998) Post: HYMO and sedimentology, macroinvertebrates, large migratory fish, and riparian vegetation (1/yr 1999-2005, 2009) Post: No	No
Abaissement et démantèlement de trois clapets sur l'Orge aval	None given	Post : minor increase in chabots, eels, dace, macroinvertebrates, riparian vegetation	Pre : fish (2009), macroinvertebrates, diatoms (2008, 2009), HYMO (2009) Post: fish (2010, 2011, 2012); aquatic vegetation bed erosion, WQ	No
Effacement du seuil du	None given	Post : marine lamprey	Pre : WQ, macroinvertebrates, diatoms	No

Restoration Project (Control + click for webpage)	Quantitative/Qualitative Reference Condition Benchmarks (RC, historic, model)	Pre/Post Biological Endpoints	Pre/Post Monitoring (Time Frame)	European Policy Drivers
Moulin de Ver sur la Sienne		redds, presence of salmon; HYMO	Post : WQ (/2 mos) ; marine lamprey redds and HYMO (1, 6, 12 mos, future dates undetermined); salmon (2011) Post: NA	
Arasement du seuil des Treize Saules sur la Quilienne	None given	Post: increase in trout and chabot density and trout reproduction	Pre : fish, flow facets Post : fish, flow facets (1/yr 2009-14)	No
Démantèlement de l'ouvrage du Pont Fourneau sur la Selle	Quant: an upstream reach for fish	Post: macrophytes, riparian vegetation, chabot; HYMO	Pre: cross-sections, Qs (2010) During work: additional cross-sections Post: fish (2011, 2013), HYMO (2013)	No
Démantèlement de neuf ouvrages sur le cours de l'Aa	None given	None given ; hydraulic	Pre : macroinvertebrates, macrophytes, fish (2008, 2011 , 2014) Post : hydraulic (2011	Natura 2000 (1 obstacle) (http://inpn.mnhn.fr/site/natura2000/FR3100487); Habitats Directive Site
Effacement du seuil du moulin du Bourg sur le Vicoin	None given ; proliferation of warm water species	Post: aquatic vegetation improvement, reduction in Nuphar lutea; diversification and augmentation of intolerant invertebrates; HYMO	Pre: HYMO (2008); HYMO, WQ macroinvertebrates, diatoms, amphibians, and chiroptera (2011) During work: WQ, flora and fauna inventory Post: unspecified resurvey (2013); diatoms, biologic (2012, 2013, 2014)	Natura 2000 (http://inpn.mnhn.fr/site/natura2000/FR3100487)
Effacement partiel de 14 seuils sur le Mutterbach et l'Hosterbach à Holving et Hoste	No	None given ; HYMO, odors	Pre : No Post : photos	No
Effacement du seuil du Moulin d'Hatrize sur l'Orne	None given	Post : improved density of flowing water fish species, HYMO	Pre : fish, macroinvertebrates, HYMO (Carhyce) Post: fish, HYMO (2011, 2014, 2016, 2021)	No
Effacement du seuil des Brosses sur le Soanan	None given	Post : improved density if chabot and juvenile trout and of redds ; disappearance of flatwater fish species; HYMO	Pre : HYMO, fish, riparian vegetation, trout redds Post: same (2011)	No
Effacement partiel du	None given	Post : increase in trout	Pre : trout redds, state of the banks and	No

Restoration Project (Control + click for webpage)	Quantitative/Qualitative Reference Condition Benchmarks (RC, historic, model)	Pre/Post Biological Endpoints	Pre/Post Monitoring (Time Frame)	European Policy Drivers
seuil Cros sur la Dunière		redd count; HYMO	riparian vegetation Post: HYMO photos, redd counts (2009, 2010)	
Effacement du seuil de Chelles Basse sur le Miodet	None given	None given ; HYMO	No	No
Effacement du seuil du Martinet sur la Bave	None given	None given ; HYMO	Pre : HYMO Post : No	WFD ? (« moderate status »)
Effacement du seuil de Carayon sur le Thoré	None given	None given ; HYMO	Pre : WQ, HYMO Post : channel geometry (1/yr, after channel forming flows)	No
Effacement partiel de cinq seuils sur le ruisseau du Bagas	None given	Post : fish passage restricted by defects in project design ; HYMO	Pre : fish Post : fish (2010, 2013) ; HYMO (limited to banks)	No
Effacement partiel du seuil de Vas sur le Céans	Historic trout and cyprinidae fishery (particularly Barbus meridionalis) (data type not given)	None given	Pre: long profile Post: No	No
Effacement partiel d'un seuil sur l'Artuby à la Martre	None given	No ; HYMO	No	No
Effacement du seuil de la Seine Granitière sur la Seine amont	No	Post : minimal colonization by trout and chabot, significant reduction in flatwater species; colonization by moving water macroinvertebrates (family Brachycentridae)	Pre : fish, macroinvertebrates ; cross-sections, velocity, sediment transport Post: fish (2011), macroinvertebrates (2010, 2011), cross-sections (2012), temperature (2008, 2011)	No
Remeandering and other modifications to bed geometry				
Reméandrage du Hardtbach à Wissembourg	None given	Post : lamprey redds, odonatae, birds, macroinvertebrate biodiversity and biomass	Pre : flow, piezometry, fish, macroinvertebrates, WQ Post: same (2-3 yrs after work)	Natura 2000 (http://inpn.mnhn.fr/site/natura2000/FR3100487) Habitats Directive Site

Restoration Project (Control + click for webpage)	Quantitative/Qualitative Reference Condition Benchmarks (RC, historic, model)	Pre/Post Biological Endpoints	Pre/Post Monitoring (Time Frame)	European Policy Drivers
		decline		
Restauration de la sinuosité sur la Trie à Toeufles	None given	Post : monitoring program defects prevented analysis ; HYMO	Pre : visual survey of bank stability, channel geometry, substrate, flow facets, macroinvertebrates Post: fish and macroinvertebrates (2008, 2009); riparian vegetation, flow facets, substrate, geometry, bank stability, habitats (2011, 2012, 1/(2-3 yrs))	Natura 2000 (http://inpn.mnhn.fr/site/natura2000/FR2200346) downstream
Reconstitution des écoulements de surface de deux affluents temporaires de la Clauge amont	None given	Post : improved oak tree survival and macroinvertebrate density (particularly threatened checkered caddisfly), HYMO	Pre : macroinvertebrates, piezometry Post : piezometry (2008, 2009, manual 1/10 days, auto 1/12 hrs), macroinvertebrate imagos sampling	Natura 2000 (http://inpn.mnhn.fr/site/natura2000/FR4301317) Birds Directive Site, Habitats Directive Site ; CDDA, Habitat/Species Management Area ; LIFE, Headwaters and Associated Heritage Fauna; Forecaster
Remise en eau des méandres du Colostre	Qual: Beaver recorded in this area	Post: helohytes, beaver ;HYMO	Pre: fish Post: fish (2001, 2002)	No
Le reméandrage de la Drésine et du ruisseau de Remoray	None given	Post : new odonatae species, birds, appearance of Rana temporaria, improved trout reproduction, increased macroinvertebrate recolonization; HYMO	Pre : No Post : flora, fauna, hydrobiology, piezometry (weekly), flow elevation, fish (1/5 yrs), macroinvertebrates, vegetation (1/(3-5 yrs))	Natura 2000 (http://inpn.mnhn.fr/site/natura2000/FR4301283) Birds Directive Site, Habitats Directive Site ; CDDA, Habitat/Species Management Area ; LIFE, Headwaters and Associated Heritage Fauna (nearby) ; Forecaster
Reméandrage du Drugeon et gestion intégrée de son bassin versant	Quant : plant, animal, insect, bird present (historic)	Post: Improvement in fish and macrobenthics, WQ limitations (algae blooms), cooler temperatures; HYMO	Pre: biologic potential, HYMO Post: fish, crayfish (1/yr indef.), hydrobiology; HYMO, piezometry, temperature, WQ (1/ years 1, 2, 3, 6),	Natura 2000 (http://inpn.mnhn.fr/site/natura2000/FR43012830) Birds Directive Site, Habitats Directive Site ; CDDA, Protected Landscape ;

Restoration Project (Control + click for webpage)	Quantitative/Qualitative Reference Condition Benchmarks (RC, historic, model)	Pre/Post Biological Endpoints	Pre/Post Monitoring (Time Frame)	European Policy Drivers
				LIFE, Headwaters and Associated Heritage Fauna; Forecaster
Reméandrage du Mardereau à Sorigny	None given	Post : 30 plant species have reappeared, dragonfly species; HYMO	Pre : flora, macroinvertebrates, long profile, cross-sections Post: diatoms, macroinvertebrates, photos	No
Reméandrage du Marolles à Genillé	None given	Post: Decrease in fish population, relative increase in moving water and alintolerant fish species, dragonfly species increased; HYMO	Pre: No Post : (over 5 yr period) general biology, diatoms, Carhyce HYMO , piezometry, temperature, photos	No
Le reméandrage du Nant de Sion	Qual : Historic Thymallus thymallus fishery	None given; HYMO	Pre: physical, WQ, fish Post: same (for 3 yrs); control site also studied	No; Forecaster
Reméandrage de la Petite Veyle en amont du moulin du Geai	None given	Post : Minor reduction in biomass with in crease in fish density (particularly Cyprinidae); HYMO	Pre : physical and biological Post : invertebrates, plant survey, fish	No; Forecaster
Reméandrage du Vistre et création d'un chenal d'étiage sur le Buffalon	None given	Post : appearance of facultative and tolerant moving water invertebrates, invasive vegetation; HYMO and WQ	Pre : No Post : flora, fauna (2006-2007); macrophytes, invertebrates, WQ (2008, 2009, 2010)	No; Forecaster
Le reméandrage du ruisseau des Vurpillières	None given	Post : new odonata species, return of birds, reproducing Rana temporaria; HYMO	Pre: No Post : hydrobiology, piezometry (weekly), water elevation, flora, fauna, fish (every 5 yrs), invertebrates, vegetation plots (every 3-5 yrs)	Natura 2000 (http://inpn.mnhn.fr/site/natura2000/FR4301283) Birds Directive Site, Habitats Directive Site ; CDDA, Habitat/Species Management Area ; LIFE, Headwaters and Associated Heritage Fauna; Forecaster

Restoration Project (Control + click for webpage)	Quantitative/Qualitative Reference Condition Benchmarks (RC, historic, model)	Pre/Post Biological Endpoints	Pre/Post Monitoring (Time Frame)	European Policy Drivers
Disconnection of ponds from stream channels				
Effacement d'un chapelet de huit étangs sur la Bildmuehle	None given	Post : trout recolonization	Pre : invertebrates, fish, plants, amphibians, HYMO Post : fish, HYMO (2011, 2013-2014)	Natura 2000 (http://inpn.mnhn.fr/site/natura2000/FR410028) Habitats Directive Site ; CDDA Protected Landscapes ; Forecaster
Réduction de l'impact de trois étangs sur cours d'eau dans le bassin du Cousin	None given	Post : chabot colonization, trout not well recolonized	Pre : fish, mussels, invertebrates Post : fish (2008)	Natura 2000 (http://inpn.mnhn.fr/site/natura2000/FR2600992) Habitats Directive Site; CDDA Protected Landscapes
Contournement d'un plan d'eau de loisirs sur le Gratteloup au niveau de la commune de La Ville-aux-Clercs	None given	Post: riparian vegetation, mosses, active redds	Pre : No Post : salmonid redds	No
Suppression d'une digue d'étang en barrage sur un affluent du Petersbach	None given	Post : trout recolonization; HYMO	Pre : fish, amphibians Post : fish (2009)	Natura 2000 (http://inpn.mnhn.fr/site/natura2000/FR4201795) unidentified; CDDA Protected Landscapes
Effacement d'un chapelet de cinq étangs sur le ruisseau du Val des Choues	None given	Post: riparian vegetation, amphibian, white-clawed crayfish, river trout, brook lamprey recolonization	Pre: biologic and physical state Post: invertebrates, fish, amphibians, habitats, HYMO	Natura 2000 (http://inpn.mnhn.fr/site/natura2000/FR2600959) Birds Directive Site, Habitats Directive Site ; LIFE, Headwaters and Associated Heritage Fauna , Forests and linked habitats in Burgundy; Forecaster
Dérivation et recréation du lit mineur de la Veyle au droit de la gravière de Saint-Denis-lès-Bourg	Quant: New channel geometry based on historic geometry	None given	Pre: WQ, fish, macroinvertebrates, physical habitat Post: unknown (5 yrs starting 2010)	No; Forecaster
Effacement du plan d'eau	None given	Post : None given; HYMO	Pre : No	No

Restoration Project (Control + click for webpage)	Quantitative/Qualitative Reference Condition Benchmarks (RC, historic, model)	Pre/Post Biological Endpoints	Pre/Post Monitoring (Time Frame)	European Policy Drivers
de Coupeau sur le Vicoin et réaménagement du lit mineur			Post : No	
Effacement d'un plan d'eau de loisirs sur la Zinsel du Sud	None given	Post : aquatic fauna recolonization, trout ; HYMO	Pre : No Post : physical micro-habitats	No
Reconnecting orphaned parts of hydraulic systems				
Restauration des annexes hydrauliques de la Loire et de ses affluents	None given	Post : 138 taxon of benthic macrofauna, homogenous vegetation (particularly Phalaris arundinacea), pike reproduction; HYMO	Pre : vegetation, fish Post : WQ, hydraulic function, invertebrates, zooplankton , fish, vegetation (2002), additional (2007)	Natura 2000 (308 sites in the Loire catchment)
Restauration de l'annexe hydraulique de Bellegarde et recharge sédimentaire de la rivière d'Ain	None given	Post : vegetation ? ; HYMO	Pre : WQ, botanical, HYMO, fish Post : vegetation, fish (every 2 yrs), long profiles (2011), WQ (for 3 yrs after)	Natura 2000 (http://inpn.mnhn.fr/site/natura2000/FR8201653) Habitats Directive Site; CDDA, Habitat/Species Management Area ; LIFE, Conservation of habitats created by the River Ain ; Forecaster
Reconnexion d'un bras secondaire du Rhin : le Schafteu	None given	None given; HYMO	Pre : No Post : No	Natura 2000 (http://inpn.mnhn.fr/site/natura2000/FR4201797) Habitats Directive Site; CDDA, Habitat/Species Management Area ; LIFE, Restoration of the dynamics of Rhine alluvial habitats on Rohrschollen Island
Bedload transport				
Reconstitution du matelas alluvial sur l'Ardèche : un exemple non réussi	None given	Post : structural failure of project	Pre : No Post : No	Natura 2000 (http://inpn.mnhn.fr/site/natura2000/FR8201657) unknown directive

Restoration Project (Control + click for webpage)	Quantitative/Qualitative Reference Condition Benchmarks (RC, historic, model)	Pre/Post Biological Endpoints	Pre/Post Monitoring (Time Frame)	European Policy Drivers
Restauration du matelas alluvial de la Clouère par recharge granulométrique	None given	Post : recolonization by moving water species (particularly wall-eye minnows), reduction in flat water species density; HYMO	Pre : fish ; physical Post : fish, invertebrates, temperature (2009), photos (2011)	No
Restauration des habitats de l'écrevisse à pieds blancs par la recharge sédimentaire du ruisseau de Saulny	None given	Post : improved crayfish counts even though gravels are again filled with fine sediments	Pre : crayfish count Post : crayfish counts (1/yr starting in 2009)	No
Rehaussement du fond du lit du Trec et valorisation paysagère du site	None given	None given; HYMO	Pre : riparian inventory, topography, macrophytes, fish Post: No	No
Reconnecting the floodplain				
Restauration de la dynamique naturelle de l'Adour amont	None given	Post : No ; HYMO	Pre : flow facets, erosion zones, secondary channels Post : No (observation walks)	No
Suppression des protections de berges sur l'Orge aval	None given	Post : bank vegetation	Pre : No Post : No	No
Création de chenaux de crues et restauration des échanges entre lit majeur et lit mineur sur la Vezouze	None given	Post : expected wetland species assemblage, some uncommon species of plants (particularly helophytes)	Pre : hydrology, hydrography, topography, geology Post : habitats, flora and fauna (2010-2014)	No
Channel geometry changes				
Restauration de l'Hermance dans la traversée du bourg de Veigy-Foncenex	None given	Post : recolonization of Barbatula barbatula, sunfish, wall-eye minnows, chub, stickleback; HYMO	Pre : hydrology, soils, fish Post : fish (2011)	No

Restoration Project (Control + click for webpage)	Quantitative/Qualitative Reference Condition Benchmarks (RC, historic, model)	Pre/Post Biological Endpoints	Pre/Post Monitoring (Time Frame)	European Policy Drivers
Travaux ponctuels de diversification du lit mineur et de valorisation paysagère sur le bassin versant de l'Hers-Mort	None given	Post : WQ causing algae blooms	Pre : HYMO, flow facets, riparian vegetation by aerial photos and walking Post: No	No
Aménagement d'un chenal d'étiage sinueux sur le Lange	None given	Post : recolonization by trout, wall-eye minnows; stickleback, flow facets, improved WQ	Pre : topography, fish, invertebrates, WQ Post : same (2008, frequency unknown), fish (2009), WQ (2010)	No
Création d'un chenal d'étiage sinueux sur le Merloz	None given	Post : trout and whitefish redds ; HYMO	Pre : WQ, physical habitat, redds Post : same (frequency unknown)	No
Création d'un chenal d'étiage sinueux en milieu urbain sur le ruisseau de Montvaux	Qual : upstream reach in good HYMO state	Post: vegetation on inner benches, improved flow velocity and substrate	Pre: "preliminary" (variables unknown) Post: No	No
Returning streams to original thalwegs				
Retour de la Fontenelle dans son lit d'origine à Saint-Wandrille-Rançon	Quant : original thalweg	Post : recolonization by trout, eels, aquatic vegetation (particularly false watercress, phragmites, water starworts macroinvertebrates (particularly Gammaridae, diptera Chironomidae, Ephemeroptera, trichoptera Glossosomatidae); HYMO	Pre : fish, biology Post : flow facets, sediment sizes, riparian vegetation, benthic macrofauna, fish amphibians, birds, mammals, insects (1/yr, 2011-2016)	Natura 2000 (http://inpn.mnhn.fr/docs/natura2000/fsdpdf/FR2300123.pdf): Birds Directive Site, Habitats Directive Site ; CDDA Protected Landscapes
Remise en eau de l'ancien lit du Fouillebroc à Touffreville	Quant : original thalweg	Post : white-clawed crayfish have not returned ; HYMO	Pre : No Post : HYMO (Carhyce), hydrobiology, fish (2010, 2014, 2017), white-clawed crayfish	Natura 2000 (http://inpn.mnhn.fr/docs/natura2000/fsdpdf/FR2300145.pdf): Habitats Directive Site
Remise en eau d'un	Quant : original channel	Post : improved fish and	Pre : physical and biology	No; Forecaster

Restoration Project (Control + click for webpage)	Quantitative/Qualitative Reference Condition Benchmarks (RC, historic, model)	Pre/Post Biological Endpoints	Pre/Post Monitoring (Time Frame)	European Policy Drivers
ancien lit du Dadon et restauration de l'habitat aquatique		macroinvertebrate populations, trout goals not reached ; HYMO	Post : same (2007), fish (regular), hydrobiology (1/3-4 yrs until 2012, then longer)	
Retour de la Doquette dans son talweg d'origine	Quant : original channel	Post : riparian vegetation ; HYMO	Pre : No Post : longitudinal and cross-section profiles, photos	No
La restauration du Merlue et de son marais	Quant : original channel (infrared imagery)	Post : increase in trout and chabots; HYMO	Pre : fish, crayfish, invertebrates, water table Post: piezometry, fish (2009)	Natura 2000 (http://inpn.mnhn.fr/docs/natura2000/fsdpdf/FR4301334.pdf): Birds Directive Site, Habitats Directive Site ; CDDA, Habitat/Species Management Area
Retour du Steinbaechlein dans son talweg d'origine	Quant : original channel	Post : improved fish density, trout reproduction, Macrophytes, helophytes, willows; HYMO	Pre : No Post : No	No
Daylighting				
Remise à ciel ouvert du ruisseau du Trégou à Luc-la-Primaube	No	Post : riparian vegetation ; HYMO	Pre : No Post : vegetation, channel slope, erosion	No
Réouverture d'un tronçon de la Bièvre en milieu urbain	No	Post : aquatic vegetation, ducks and other birds, fish, amphibians, aquatic insects observed; HYMO	Pre : No Post : invertebrates, fauna, flora (« regularly »)	No
Remise à ciel ouvert du ru d'Orval à Cannectancourt	No	None given ; HYMO	Pre : No Post : No	No
Remise à ciel ouvert du Redon à Margencel	No	Post : lake trout ; WQ is a limiting factor	Pre : topography, fish Post : fish (2011), biology (2009)	No

Appendix 2: Thur River Case study Relevance of indicators recommended for selected rehabilitation measures: 3-very relevant, 2-moderatly relevant, 1-not relevant. Level of survey effort: A: <2. B: 2-3. C: >3 person days (Source: Woolsey et al. 2005).

N°	Indicator group	Indicator	Effort level	Relevance of indicator for different measures							
				Widening the river bed	Opening culverts	Structuring the river bed	Structuring the river bank	Side channels	Backwaters, oxbows and floodplains	Longitudinal connectivity	Bedload rehabilitation
1	Project acceptance	Acceptance by interest group	A	3	3	2	3	3	3	2	1
2	Project acceptance	Acceptance by entire public	B	3	3	2	3	3	3	2	1
3	Project acceptance	Acceptance by project work group	A	3	3	2	3	3	3	2	1
4	Longitudinal connectivity	Barrier-free migration routes for fish	A	2	3	2	2	2	2	3	1
5	Recreational use	Number of visitors	A	3	3	2	3	3	3	2	1
6	Recreational use	Variety of recreational opportunities	A	3	3	2	3	3	3	2	1
7	Recreational use	Public site accessibility for recreation	A	3	3	1	3	3	3	2	1
8	Fish	Age structure of fish population	C	3	3	2	3	3	3	3	2
9	Fish	Fish species abundance and dominance	C	3	3	2	3	3	3	3	2
10	Fish	Diversity of ecological guilds of fish	C	3	3	2	3	3	3	3	2
11	Fish habitat	Presence of cover and instream structures	A	3	3	3	3	2	3	1	2
12	Bedload	Bedload regime	C	3	1	3	1	1	1	3	3
13	Hydrogeomorphology and hydraulics	Inundation dynamics; duration, frequency and extent of flooding	A	3	3	1	2	3	3	1	1
14	Hydrogeomorphology and hydraulics	Variability of visually estimated wetted channel width	A	3	3	3	2	1	1	2	2
15	Hydrogeomorphology and hydraulics	Variability of visually estimated wetted channel width	B	3	3	3	2	1	1	2	2
16	Hydrogeomorphology and hydraulics	Variability of flow velocity	C	3	3	3	2	2	1	2	2
17	Hydrogeomorphology and hydraulics	Depth variability at bankful discharge	B	3	3	3	2	2	1	2	2
18	Cost	Project cost	A	3	3	3	3	3	3	3	1
19	Landscape	Diversity and spatial arrangement of habitat types	C	3	3	1	3	3	3	3	2

N°	Indicator group	Indicator	Effort level	Relevance of indicator for different measures							
				Widening the river bed	Opening culverts	Structuring the river bed	Structuring the river bank	Side channels	Backwaters, oxbows and floodplains	Longitudinal connectivity	Bedload rehabilitation
20	Landscape	Aesthetic landscape value	A	3	3	2	3	3	3	2	1
21	Macroinvertebrates	Richness and density of terrestrial riparian arthropods	B	3	3	1	3	3	3	2	1
22	Macroinvertebrates	Occurrence of both surface water and ground water organisms in the hyporheic zone	A	3	3	1	1	1	2	1	2
23	Macroinvertebrates	Taxonomic composition of macroinvertebrate community	B	3	3	1	3	3	3	2	1
24	Macroinvertebrates	Presence of amphibiotic species in the groundwater	A	3	3	1	1	1	2	1	2
25	Organic material	Short-term leaf retention capacity	A	3	3	3	2	1	2	2	1
26	Organic material	Quantity of large wood	A	3	3	3	2	1	2	3	1
27	Organic material	Quantity and composition of floating organic matter and abundance and diversity of colonising snails	A	2	1	1	2	2	2	3	1
28	Stakeholder participation	Satisfaction of interest groups with the design of the participation process	A	3	2	2	2	3	3	2	1
29	Stakeholder participation	Satisfaction of the public with participation opportunities	A	3	2	2	2	3	3	2	1
30	Stakeholder participation	Satisfaction of the public with participation opportunities	A	3	2	2	2	3	3	2	1
31	Refugia	Availability of three types of Refugia (hyporheic Refugia, shoreline habitats, and intact tributaries)	C	3	3	2	3	3	3	2	2
32	River bed	Clogging if hyporheic sediments	B	2	3	1	1	2	2	2	2
33	River bed	Temporal changes in diversity of geomorphic river bed structures	B C	3	2	3	1	1	1	2	3
34	River bed	Clogging if hyporheic sediments	A	2	3	1	1	1	1	2	2
35	River bed	Grain-size distribution of substratum	A	3	2	3	1	1	1	1	3

N°	Indicator group	Indicator	Effort level	Relevance of indicator for different measures: Widening the river bed	Opening culverts	Structuring the river bed	Structuring the river bank	Side channels	Backwaters, oxbows and floodplains	Longitudinal connectivity	Bedload rehabilitation
36	River bed	Diversity of geomorphic river bed structures	A B	3	2	3	1	1	1	2	3
37	River bed	Degree and type of anthropogenic modification	A	3	3	3	1	1	2	2	1
38	Temperature	Spatial and temporal variation in water temperature	A	3	3	2	3	2	3	1	1
39	Transition zones	Food subsidies across land-water boundaries	C	3	2	1	3	3	3	1	1
40	Transition zones	Exchange of dissolved nutrients and other solutes between river and groundwater	C	2	3	1	1	2	3	2	2
41	Transition zones	Community composition and density of small mammals on floodplains	C	3	2	1	2	2	3	1	1
42	River bank	Width and degree of naturalness (vegetation, composition of ground) of riparian zone	A	3	3	1	3	2	2	1	1
43	River bank	Temporal changes in the quantity and spatial extent of morphological units	A	3	2	1	3	2	2	2	1
44	River bank	Shoreline length	A	3	3	1	3	3	3	2	2
45	River bank	Quantity and spatial extent of morphological units	A	3	2	1	3	2	2	2	1
46	River bank	Degree and type of anthropenic modification	A	3	3	2	3	2	3	2	1
47	Vegetation	Presence of typical floodplain species	A	3	3	1	2	2	2	1	1
48	Vegetation	Succession and rejuvenation of plant species on floodplains	C	3	3	1	2	2	2	1	1
49	Vegetation	Temporal shift in the mosaic of floodplain vegetation categories	B	3	3	1	2	3	3	1	1
50	Vegetation	Composition of floodplain plant communities	A	3	3	1	2	3	3	1	1

Annex 3. The Project Concept Note

Concept

The project concept note (PCN) presents a systematic and disciplined approach to the processes of project creation and screening. Such an approach commences early in the phase of project identification within the project cycle.

In small restoration projects the PCN may wholly replace the project identification report but even in longer projects it can assist with either the screening (rejection) of the project or with assisting an improved project in the identification phase. It can also be used in association with the Logical Project Framework Technique (LPF). Generally the success of techniques of this kind can be assessed by their level of adoption and in this case this has been widely observed for many donor organisations and in some of them become mandatory. The advantages of PCN are clear relative to a more tradition approach to identification.

- It is less expensive to carry out the process of project creation and screening.
- The discipline and system it imposes create an auto training facility for project staff in the early stages of a project.
- Provision of a concise document for the marketing of a project to colleagues, agencies and funding sources.
- Eases communication between appropriate parties.
- Considers the wider issues and the beneficiaries (The beneficiaries are those who gain social, economic or environmental advantage from the restoration activity, methodology or knowledge transfer activities of the target institution. They may be identified in, for example, the local, river basin or the global community).
- Sets up the initial monitoring and control facility.

The limitations to the PCN include:

- Unsuitable for large wide ranging projects, e.g. the building of a dam.
- A project with qualitative outputs (endpoints) will need special care and consideration.

Project Concept Note Preparation Guidelines

The PCN should be 2-4 A4 pages maximum. It is useful for project screening and identification. It can take the place of project identification for small projects.

1. TITLE
2. BACKGROUND (1-2 para)
    1. History
    2. Previous phase (what has been done before)
    3. Prior work (if needed)
3. PROJECT SUMMARY (1 para)
    1. Objective(s) of the project
    2. Project beneficiaries
    3. Costs and inputs
    4. Time scale
    5. Project management ideas

4. RELEVANCE TO WFD (1 para)
    1. Environmental policy
    2. Other stakeholder objectives
    3. Overlap
5. PROJECT DESCRIPTION (1-2 para)
    1. Description
    2. Activities
    3. Timing (Gantt Chart)
    4. Inputs
    5. Outputs (Are the expected research results or products appropriate to the project purpose? Include identified promotion pathways to target institutions and beneficiaries.)
    6. Target institutions (formal or informal institutions that will benefit from the restoration activity and engage in the process of transferring knowledge/technology/methodology to the beneficiaries).
6. ECONOMIC, SOCIAL AND ENVIRONMENTAL CONSIDERATIONS (2 para)
    1. External factors
    2. Costs and benefits
    3. Sustainability
    4. Impact on ecosystem services and functioning
    5. Impact on environmental protection
7. BUDGET (1 para)
    1. Sources of finance
    2. Levels of finance
    3. Phasing
8. INSTITUTIONAL ASPECTS OF IMPLEMENTATION (1 para)
    1. Project management
    2. Team structure and human resources
    3. Consultants
    4. Government links
    5. Sustainability
9. MONITORING AND EVALUATION (1 para)
    1. Project framework
    2. Frequency of reports
    3. Management meetings
10. RISKS AND ASSUMPTIONS (1 para)
    1. Main potential causes of failure (Include those factors which might contribute to the project failing to achieve its objectives.
    2. Design of project to reduce risks
    3. Economic risks
    4. Technical and other risks

Important assumptions are external conditions or factors over which the project chooses not to exert control or does not have control, but on which the accomplishment of objectives depends.

Financial Summary

Items	Year 1	Year 2	Year 3	Total
Staff				
Travel				
Overseas Costs				
Consumables				
Capital Equipment				
Training/Publications				
Overheads				
Contingency				
TOTALS				

Appendix 4. Preparation of Logical Framework for a Project

The logical framework aims to promote good project design by clearly stating the defined project logic and components. The logical structure linking the components takes the form: IF [activities] AND [assumptions] THEN [outputs], IF [outputs] AND [assumptions] THEN [purpose], and so on.

The logical framework consists of a 4 x 4 matrix, with a vertical hierarchy of objectives at the (i) goal, (ii) purpose, (iii) output, and (iv) activity levels. The horizontal components are (i) summaries of the objectives at each level, (ii) performance indicators for achievement of those objectives, (iii) the sources needed to verify the indicators, and (iv) the important assumptions for moving from one level of objectives to the next.
The form is thus:

PROJECT STRUCTURE	Measureable indicators	Means of verification	External factors / assumptions
Goal: sectoral objectives			
Purpose: specific objective			
Outputs			
Activities	Inputs		

The components of the matrix are defined as follows:
a) The goal is the higher level objective or longer-term impact of the restoration project on regional, national or EU WFD objectives.
b) The purpose is the measurable near-term impact of the restoration project which is the final accomplishment of the project.
c) The outputs are the results of deliverables of the project that the project manager can guarantee.
d) The activities are the key activities undertaken by the implementation team that summarise the action strategy to produce the outputs.
e) The indicators are measurements (endpoints) to verify to what extent the objectives at each level are achieved, targeted in terms of quantity, quality and time.
f) The means of verification are the specific sources of data necessary to verify the indicators at each objective level.
g) The assumptions are important events, conditions and decisions outside the control of the restoration project that are necessary for meeting the objectives.

The procedures for constructing the logical framework is:

1. Assumptions which are not fulfilled can derail a project as often as poorly executed outputs; e.g. good cooperation amongst diverse stakeholders, appropriate scale of the restoration project, access to suitable land for undertaking project.
2. The purpose plus assumptions at that level should describe the critical conditions for achieving the goal.
3. The outputs plus the assumptions at that level should produce the necessary and sufficient conditions for achieving the purpose.
4. The assumptions at the activity level should not include any pre-conditions; these may be placed underneath the activity level assumptions.
5. Define the measurable indicators
   i) at the purpose level
   ii) at the output level
   iii) at the goal level
   iv) at the activities level show a Budget Summary
6. Indicators should define in measurable detail the endpoints required by the objectives, and thus state what will be a sufficient performance to assume that the next level of objective can be reached. Targeting involves putting numbers and dates on indicators, and this is important if monitoring (at the output level) and evaluation (at the purpose level) are to be carried out objectively, e.g. 50% increase in the number of adult migrating salmon, or X% reduction in sediment run off in five years, 3 working papers in year two, a 1:25,000 species distribution map in year 3.

   The purpose of indicators is to measure what is important; have quantity, quality and time measures; and be independent from the outputs.

   The output and goal level indicators should be objectively verifiable in terms of quantity, quality and time.
7. Define the means of verification
   i) at the purpose level
   ii) at the output level
   iii) at the activity level
   iv) at the goal level
8 Sources of information for verifying the indicators, and thus for demonstrating what has been accomplished. At the activity level these would follow the programme requirements e.g. quarterly, annual and final reports. At the output level these will often be the publication details for papers, articles, talks. At the higher (developmental) objective levels these will often be publication of river basin management plans and government or agency statistics on WFD achievements.
9. The activities should identify any actions required for gathering means of verification.