Environment Agency

Evidence

Weir removal, lowering and modification: A review of best practice

Report: SC070024

The Environment Agency is the leading public body protecting and improving the environment in England and Wales.

It's our job to make sure that air, land and water are looked after by everyone in today's society, so that tomorrow's generations inherit a cleaner, healthier world.

Our work includes tackling flooding and pollution incidents, reducing industry's impacts on the environment, cleaning up rivers, coastal waters and contaminated land, and improving wildlife habitats.

This report is the result of research commissioned and funded by the Environment Agency.

Published by:
Environment Agency, Horizon House, Deanery Road, Bristol, BS1 5AH
www.environment-agency.gov.uk

ISBN: 978-1-84911-312-0

Further copies of this report are available from our publications catalogue: http://publications.environment-agency.gov.uk or our National Customer Contact Centre: T: 08708 506506
E: enquiries@environment-agency.gov.uk.

Lead author(s):
Nicholas Elbourne; Diana Hammond, Jenny Mant (River Restoration Centre)

Contributors(s):
Environment Agency staff including: Fisheries and Biodiversity Area Technical Specialists, FCRM, Evidence Research and Geomorphological Technical Services

Dissemination Status:
Publicly available

Keywords:
Water Framework Directive; weir removal, weir lowering, weir modification; evidence base; best practice; river restoration; river management

Research Contractor:
River Restoration Centre, Cranfield Campus, Cranfield, Bedfordshire, MK43 0AL

Environment Agency's Project Managers:
Natalie Kieboom (nee Phillips),Judy England, Evidence Directorate

Project Number:
SC070024

Evidence at the Environment Agency

Evidence underpins the work of the Environment Agency. It provides an up-to-date understanding of the world about us, helps us to develop tools and techniques to monitor and manage our environment as efficiently and effectively as possible. It also helps us to understand how the environment is changing and to identify what the future pressures may be.

The work of the Environment Agency's Evidence Directorate is a key ingredient in the partnership between research, guidance and operations that enables the Environment Agency to protect and restore our environment.

The Research & Innovation programme focuses on four main areas of activity:

- **Setting the agenda**, by providing the evidence for decisions;
- **Maintaining scientific credibility**, by ensuring that our programmes and projects are fit for purpose and executed according to international standards;
- **Carrying out research**, either by contracting it out to research organisations and consultancies or by doing it ourselves;
- **Delivering information, advice, tools and techniques**, by making appropriate products available.

Miranda Kavanagh

Director of Evidence

Executive summary

This report reviews the latest scientific evidence on the impact of weir removal, lowering and modification on rivers and their ecosystems. Removing or altering the height of a weir is a potential way of improving longitudinal connectivity and associated hydromorphological and ecological benefits in rivers and catchments, to help meet EU Water Framework Directive (WFD) objectives. The report does not cover the potential socio-economic benefits of reinstating or maintaining weirs for hydropower, nor does it discuss alternatives to weir removal such as fish bypass channels and constructed passes. Also outside the scope of this report are the changes to flood risk that can result from the alteration or removal of weirs. This is an important factor requiring specific assessment alongside the guidance given in the report.

The aims of the report are to:

- Explore the impact of weir removal, lowering and modification on river biology and hydromorphology.
- Identify potential benefits, constraints and considerations that must be accounted for, in the context of the EU Water Framework Directive programme of measures, which includes EU protected areas.
- Assess considerations in past projects and draw on lessons learnt to identify trends and provide guidance for future projects.

Our findings suggest that weir removal, lowering or modification can generate a range of hydromorphological and ecological benefits, although in some instances there may also be undesirable impacts. The evidence, however, is heavily reliant on anecdotal observation. Whilst there is a willingness to consider weir removal, a lack of confidence and funding to appraise projects continues to curtail implementation of this measure.

Public consultation is a lengthy process, but dialogue with all those involved or affected is important to the success of any project. In designing and delivering a project, a clear message about its intentions will ensure that people’s expectations are not unrealistic. Other common concerns include localised or more extensive geomorphic instability that may result from weir removal and the difficulty in demonstrating a project’s success in terms of improved river connectivity and associated habitat gain. However, river restoration can help to restore more natural physical processes to the reach, helping to support recovery and improve biodiversity. The ability of a channel to erode and deposit sediment, and therefore modify its bed and banks, is a key part of this ‘naturalisation’, for this reason projects should consider both local and wider impacts

Critically, the removal of any water structure should be assessed with a thorough appreciation and understanding of reach hydromorphology, river corridor connectivity and catchment sediment dynamics. It is also possible that weir removal will require a flood risk assessment to ensure that there is not an increased flood risk to others. It is recommended that there is early consultation with the Lead Local Flood Authority to identify if a flood risk assessment or flood defence consent is needed. Best practice case studies illustrate some of the challenges faced, while the report also identifies situations where removal, lowering or modification may be inappropriate (e.g. in high flood risk areas).

Contents

1 Introduction

1.1 Background

Removing, lowering and modifying weirs is a potential way of improving longitudinal connectivity and associated hydromorphological and ecological benefits which can contribute to EU Water Framework Directive (WFD) targets for rivers and catchments. However, information on past projects in England and Wales has not generally been well monitored, documented or disseminated, leading to conjecture about the effectiveness of such measures.

This report, commissioned by the Environment Agency, pulls together the current scientific evidence on the impact of weir removal in England and Wales, with information from elsewhere assessed where applicable. This information should help to identify success and failure criteria related to weir removal, lowering or modification, as well as gaps in our understanding. The report does not cover the potential socio-economic benefits of reinstating or keeping weirs for hydropower and navigation purposes, nor does it discuss alternatives to weir removal such as fish bypass channels and close-to-nature fish pass design; one such comprehensive guide of the latter is *Fish passes – Design, dimensions and monitoring* (FAO/DVWK, 2002). Also beyond the scope of this report are the changes to flood risk that can result from the alteration or removal of weirs. This is an important factor requiring specific assessment alongside the guidance given in the report. It is recommended that there is early consultation with the Lead Local Flood Authority to identify if a flood risk assessment or flood defence consent is needed.

1.2 Aims

The aims of this report are to:

- explore the impact of weir removal, lowering and modification on river biology and hydromorphology;
- identify potential benefits, constraints and considerations that must be accounted for, in the context of the EU WFD programme of measures; which include EU protected areas,
- assess considerations in past projects and draw on lessons learnt to identify trends and provide guidance for future projects.

2 Methodology

This report consists of a number of parts that together provide current information on weir removal/lowering. Information has been collected from a number of sources: a review of the academic and grey literature, an analysis of the River Restoration Centre (RRC) National River Restoration Inventory (NRRI), and an associated online survey of practitioners and river managers involved in projects of interest to this study. Key messages and recommendations are then stated with information supported by case studies given in Appendix B.

2.1 Literature review

Section 3 contains a review of academic papers and grey literature, undertaken to assess the main themes of current scientific and academic debate on weir removal/lowering. Given the time and resource constraints on this work, this review should be considered an overview of information and scientific knowledge that is available, rather than a detailed review. Journal articles were identified through searches by using the RRC's extensive resource base as the UK information centre for river restoration, sustainable river management, habitat enhancement and best practice management. The approach taken should lead to the development of evidence that is robust and auditable in line with the Centre for Evidence-Based Conservation's guidelines for undertaking a thorough systematic review (CEBC, 2009).

2.2 RRC National River Restoration Inventory

The RRC's National River Restoration Inventory (NRRI) is the UK's most comprehensive database of information on river restoration, sustainable river management and habitat enhancement projects, strategies and visions across the UK, and in some cases further afield. It is a useful tool for identifying current trends in river restoration. An important role of the RRC is to disseminate this information to the river restoration and river management community.

The NRRI was used here to help identify datasets and information to:

- Evaluate the effectiveness of past and ongoing projects;
- Examine common themes and comments;
- Help consolidate the evidence base to increase confidence in decision-making and reduce risks associated with any future weir lowering or removal.

Multiple criteria searches ensured a thorough assessment and following a filtering process based on expert judgement, 111 appropriate entries were identified.

2.3 Survey to evaluate the impact of projects

The RRC and the Environment Agency jointly designed an online survey to collect detailed information about the aims and motivations of completed projects on or related to weir removal/alteration (see Appendix A and Section 4.2 for details). The survey included questions about the extent and nature of monitoring undertaken and available documentation.

The survey was hosted by the website SurveyMonkey.com. The period of time where entries could be submitted was advertised through the RRC's detailed network of contacts by email and through social media marketing.

2.4 Case studies

Building on the interrogation of the database and the weir removal survey, detailed case studies were chosen to describe a range of issues experienced in a variety of projects. These were used to compile a list of 'lessons learnt' that could potentially be transferred to other projects. In particular, these focused on how project objectives tie in with WFD pressures and mitigation measures. These can be found in Appendix B.

3 Current knowledge about weir removal and adaptation

3.1 Introduction

Alongside North American streams, European rivers are the most regulated with 12 major river basins having less than a quarter of their main channel length free-flowing (Tullos *et al.*, 2009). Weir removal or modification is increasingly advocated as a measure to restore degraded river corridors and it is often seen as a preferential option to artificial fish/eel passes if viable and appropriate. Weir removal improves connectivity along the river corridor allowing for the redevelopment of natural processes such as sediment transport, flows and morphology, as well as improving habitat. Even Larinier (2001), whose name is synonymous with technical fish pass design, states that weir removal simultaneously solves both upstream and downstream passage problems, which are difficult to achieve by other means. The removal of some weirs can also restore river floodplain connectivity and create more storage which can be important from a flood risk perspective. In other instances the removal may increase flood risk so it is important that the Lead Local Flood Authority is contacted at the start of the project to discuss potential issues and if a flood risk assessment is needed.

Regarding fish passage, the Environment Agency has some powers under The Salmon and Freshwater Fisheries Act (1975) to ensure the provision of fish passes and screens for salmon and migratory trout. However, these are not entirely adequate, and there is no statutory requirement to provide passes for other migratory and freshwater species that need access to different parts of the fluvial environment. The deficiencies in the legislation led to several key recommendations in the Salmon and Freshwater Fisheries Review 2000 that were, in part, accepted. This included key pieces of legislation: the Marine and Coastal Access Act 2009 and secondary legislation made under it; the salmon and sea trout byelaws and the Eel (England and Wales) Regulations 2009. The new laws include an increase in the protection available for salmon, sea trout and eel and how fish passage can be improved around barriers to fish migration. On 15th January 2010, the Eels (England and Wales) Regulations 2009 came into force. These regulations afford new powers to the Environment Agency to implement measures for the recovery of European eel stocks and have important implications for the management and operation of weirs. The additional legislation will help England and Wales meet their obligations under the Water Framework Directive 2000/60/EC (to improve the status of surface water bodies), Habitats Directive (Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora), and EU Eels Regulation (Council Regulation No 1100/2007 establishing measures for the recovery of European eel stocks).

While legislative requirements help drive action, there is a need to develop a firm evidence base to support decision-making. This report gives an indication of the effectiveness of weir removal, lowering and modification and outlines what best practice weir and river management should involve. This review identifies:

- the different functions of weirs;
- the drivers and research agenda of weir removal science;
- the case for weir removal;
- considerations in the weir removal/lowering process.

3.2 Function of weirs

Weirs have historically been installed for one of four reasons:

- water level management, many in connection with water mills, and, navigation and flood risk management;
- flow (discharge measurement);
- environmental enhancement; e.g. maintain water levels for water meadows.
- channel stabilisation; e.g. when a reach has been straightened.

Many weirs no longer serve their original purpose (for example, many watermills are no longer used). Therefore, the case for removing or lowering weirs for habitat enhancement should be considered in many locations. However, this requires a case-by-case assessment to account for other functions, which might include an unacceptable loss of a coarse fishing amenity or heritage value, or recreational use. More details about the different functions and types of weirs are given in the Department for Environment, Food and Rural Affairs (Defra)/Environment Agency *River Weirs – Good Practice Guide* (Defra/Environment Agency, 2003).

For the purposes of this report, a definition of a 'weir' is given as:

> *"An artificial obstruction in any watercourse that results in increased water surface level upstream for some, if not all, conditions. A structure in a river, stream, canal, or drain over which free-surface flow occurs. May be used variously for control of upstream water levels, diversion of flow, and/or measurement of discharge" (*Defra/Environment Agency*, 2003: xi)*

3.3 Weir removal

Following the implementation of the WFD, steps have been made to translate European water policy requirements into practice within the first cycle of the Environment Agency's River Basin Management Plans (RBMPs). Physical pressure is one of the main reasons for failure to achieve Good Ecological Status (GES). In addition one of the stated measures to achieve Good Ecological Potential (GEP) for Heavily Modified Water Bodies (HMWBs) is to 'remove obsolete structures' and this report provides an opportunity to examine the effectiveness of weir removal and lowering as a measure in this context.

3.3.1 Strategies

Connecting science and policy is a key concept at the basis of weir removal decision-making (Gregory *et al*., 2002). Kemp and O'Hanley (2010) outline actions in a number of European countries in response to the WFD, including England and Wales. They highlight the benefit of using 'optimisation modelling' instead of standard score-and-ranking systems that, in the past, have failed to identify the need for catchment-scale assessment that prioritises the removal of in-stream structures. More specifically, the national fish passage prioritisation methodology has been developed by the Environment Agency as a consistent means to categorise barriers to fish movement, primarily eels, to improve the population of a number of priority species. In addition, this method can help to meet other targets including the National Fisheries Strategy, local recreational goals and WFD obligations. River prioritisation studies are already being developed. For example, Kings College London has worked with the Environment Agency Thames Region to assess the impact of existing in-river structures on fish passage in the Upper Lee, to produce a prioritised list of structures and associated actions (Longstaff, 2010).

A Geographic Information Systems (GIS) dataset has been developed to assess the opportunity for hydropower, driven by obligations to increase our renewable energy potential (Environment Agency, 2010). This estimates that there are up to 25,000 impoundments in British rivers alone, of which 3,000 require resolution to meet WFD targets and the Eel (England and Wales) Regulations 2009. The cost of providing passes and screens on 3,000 or more structures may in the short term be prohibitive and in some cases, weir removal may be a more long-term, cost-effective and sustainable measure. The report also stresses the importance of considering barriers as a network rather than a large number of independent structures, as recommended in Kemp and O'Hanley (2010). In Scotland, a similar effort to develop a geospatial inventory of identified structures and pressures is being led by the Scottish Environment Protection Agency. This includes an initiative to develop and validate a coarse-resolution, structural barrier assessment methodology (Kemp *et al*., 2008), considering both anthropogenic and natural barriers. More recently, Shaw *et al.* (2011) presented a multidisciplinary, integrated barrier assessment methodology developed by Atkins and successfully applied on 40 sites for the Environment Agency and the Scottish Environment Protection Agency. Clearly, weir removal remains a developing science as it did at the start of the twenty-first century (Hart and Poff, 2002).

Further afield, the political impetus to consider weir removal in the United States of America has been strongly influential since the Fishery Conservation Act (1976) which stated that habitat issues must be included in all fisheries management plans. The Sustainable Fisheries Act (1996) specified the long-term protection of essential fish habitats and investigations were initiated with the aim of providing answers to gaps in scientific knowledge on habitat suitability and the relations between geomorphology, ecology and hydrology. American Rivers *et al.* (1999) offers a comprehensive insight into dam removal in the United States, with twenty-five detailed case studies covering a wide breadth of river types and issues faced. A similar set of case studies for European member states would help in the development of a practical evidence base to improve decision-making and is a suggested aim, albeit one which is beyond the objectives of this report. Strong working relationships between the scientific community, the public and those involved in policy-making, as advocated in Tilt *et al.* (2009), should ensure that research continues in line with policy and local community requirements.

3.3.2 Impact on geomorphic processes (sediment)

The removal or lowering of a weir will typically have a direct impact on sediment transport and geomorphic processes. Attempting to establish some kind of equilibrium after initial adjustment may take several decades, depending on the river type, bedload material, and size of in-stream structure removed. The response of the reach to the original construction of the weir may indicate the adaptive capacity of the river to re-adjust following removal (Babbitt, 2002; Defra/Environment Agency, 2003). The effect of removing a weir on river form and process is explained by Pizzuto (2002) and Doyle *et al.* (2002) who examine geomorphic response and the possible trajectories of channel evolution following removal. It is, however, universally accepted that geomorphic change resulting from weir removal or lowering is site-specific in nature and will depend on the local bed gradient and sediment load. The rate at which change occurs relates partly to the stream power of the river. Specific stream power represents the amount of work that a river may do. It is calculated using this equation:

$$\omega = (\rho g Q S)/w$$

where Q is the discharge (in $m^3 s^{-1}$), w is the width of the water surface (in m), S is the longitudinal slope (in $m m^{-1}$), p is the fluid density (in $kg m^{-3}$) and g is the acceleration due to gravity (in $m s^{-2}$). The result is given in the units of $W m^{-2}$. In order to allow comparisons between different rivers, the bankfull discharge is generally taken, in which case w is the width between the banks at the level of overflow. An increase in slope for the same hydraulic discharge, for example, results in an increase in stream power with the extra energy available to transport sediment.

Where the channel has adjusted to the presence of a structure over a long period of time (e.g. several decades to >100 years) there may be deposition of sediment behind the structure where flow velocities are reduced due to the impoundment. There may be a steep fall in elevation downstream of the structure (caused by the difference in bed elevation introduced by the weir itself, but also increased scour/erosion caused by excess stream power). Removal of the weir and, therefore, the barrier that 'holds' this artificial fall in gradient in place, may locally destabilise the reach. Geomorphic processes are likely to respond by 'flattening out' this irregularity in the local longitudinal profile. This may take place first through the upstream propagation of a knick-point (also known as 'headwards erosion' or a 'headcut') and second through the accelerated downstream propagation of sediment (i.e. the material that was 'trapped' behind the impounding structure). This process essentially undoes the geomorphic change that took place following the installation of the weir (e.g. Waterhouse, 2004). However, it should not be assumed that the resultant conditions will be exactly the same as those that existed before the weir was constructed, as local factors and human impact on the river system may be significantly different in the present day. The majority this geomorphic work will be done during high flows that are competent to transport bedload. Upstream of the former structure the gradient may steepen as a result of erosion, resulting in steeper banks and potential for accelerated bank collapse. Downstream the gradient may flatten as a result of deposition. The rate of morphological change will depend on the amount of sediment that is able to be transported during these competent flows and the ability of the river to erode its bed and banks (bed or bank reinforcement, for example, would significantly hinder the ability of the river morphology to adjust to the new conditions). The magnitude and frequency of floods or competent flows will also have and influence.

Anecdotal evidence suggests, however, that sediment redistribution can restore a river and its habitats to pre-weir conditions, revealing natural gravels underneath accumulated material held up by a structure. Sand, silt or gravel deposits may also be found downstream of the structure depending on the river substrate and its capacity to move material. Some good examples of this have been identified from the River Restoration Centre database on the River Irwell and other high-energy gravel bed rivers. In these situations, where there is no local infrastructure close by, a riffle or bar has formed downstream, fine sediments stored behind the weir have been washed through during high flows and little indication is left that a weir was present.

An increase in sediment load may raise local downstream bed elevation and increase lateral movement of the river (e.g. bank erosion) and connectivity with the floodplain. This may have a positive impact on the colonisation of aquatic species (Bednarek, 2001). Depending on local conditions, accelerated downstream deposition may increase flood risk for downstream areas. As such, a precautionary approach to sediment movement must be adopted as stability can vary dramatically on a case-by-case basis. Strategic planning at a catchment scale can aid the prioritisation process, determining where and when removal should take place if there are a number of weir structures, ideally starting at the bottom of the river catchment. Consideration of the potential impacts to flood risk, both upstream and downstream of the weir, should also be reviewed. The consideration for the need to retain or the potential to remove weirs may have been considered within Catchment Flood Management Plans (CFMPs) or System Asset Management Plans (SAMPs) undertaken by the Environment Agency or the Lead Local Flood Authority

Sudden mobilisation of sediment also brings with it the potential risk of water contamination through the remobilisation of sediment bound pollutants (Macklin, 1996; Dennis et al., 2003). Diverting the river flow through pipes or the temporary construction of a diversion channel can isolate the weir and allow contaminated sediments to be excavated before reconnection, but the additional cost of a diversion channel needs to be considered. While Pizzuto (2002) suggests that sediment removed as aggregate for concrete or for construction fill could be used to offset costs in river restoration, in practice this is rarely considered. The practicality of reselling or reusing sediment is complex with many constraints, thus it is often easier to completely remove all material and import new fill material. The release of large quantities of fine sediment or contaminants could have a significant impact on the river ecology, thus addressing one WFD pressure could lead to a number of other biological or chemical failures further downstream. Understanding the catchment context and the impact of industrial legacies is important and it is critical to understand sediment geochemistry before considering weir removal.

With effective project planning and decision-making process prior to removal, potential detrimental impact can be predicted and mitigations and monitoring put in place. On the Isle of Man in 2006, for example, there was an expressed desire to remove a dilapidated weir which was restricting the upstream passage of salmon and sea trout, leaving them vulnerable to poachers. However, severe head-cutting upstream (knick-point erosion) was anticipated if the weir was removed without other mitigating works. As a solution, a rock ramp design was chosen to replace the weir and bed levels upstream and downstream of the ramp were maintained. The design incorporated a low-flow channel, thereby aiding dispersion of resident brown trout, and was £180,000 cheaper than a like-for-like replacement of the weir. The 250m reach has since been used simultaneously by juvenile salmon and trout due to improved habitat variety; a count recorded over 1,000 fish, demonstrating the effectiveness of the new fish passage design (Figure 3.1). Using natural stone materials meant the design was aesthetically pleasing, and the gradient of the new rock ramp presented limited geomorphic risk, according to those involved in the project.

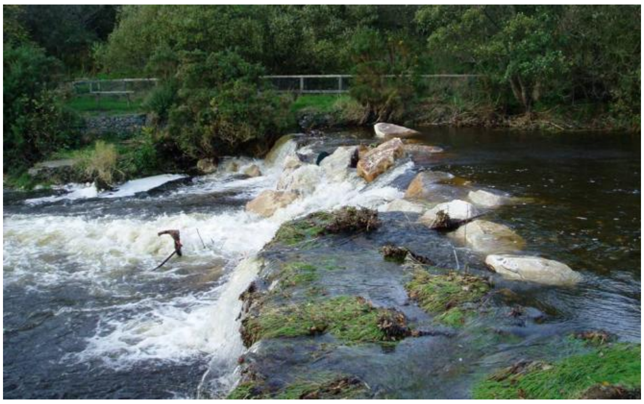


Figure 3.1: Dilapidated weir and rock ramp replacement, River Neb, Isle of Man.

3.3.3 Impact on hydrology and hydraulic processes

Immediately following removal, lowering or modification, water levels upstream of a weir will lower throughout the flow range and the velocity will increase (Magilligan and Nislow, 2005). The increased flow velocity will impact directly upon the sediment within the channel. Most natural river beds consist of cohesionless grains of sand, gravel or both fractions. This bed material is immobile in ordinary flow conditions and moves (is 'entrained') only during relatively high flows. The critical flow condition for entrainment is therefore of interest to geomorphologists, sedimentologists, aquatic ecologists and river engineers. There are a range of methods than can be applied to estimate this threshold state, such as critical power analysis (where the power needed to move a given size of sediment is calculated and compared to the unit stream power at different discharges) or critical shear stress analysis (where the critical velocity needed to move a given size of sediment may ultimately be estimated). These methods are based on channel hydraulics, and sound data input on channel dimensions, sediment size and flow are needed. However, sediment transport is far from a precise science and results from these methods should always be treated with caution and not used in isolation. Locally, weir removal may morphological alteration to weir removal (section 3.3.2) may influence channel hydraulics (bankfull capacity, width-depth ratio of the channel, gradient of the channel etc.). The impact of these changed hydraulic conditions on sediment transport should be considered as part of any weir removal project in order to determine the level of geomorphic risk that the works may introduce.

Super saturation (the process by which velocity and air pressure are increased above natural conditions) can occur if a reservoir/pool behind the weir is drawn down too quickly (Bednarek, 2001). However an American study (Wik, 1995) showed the impact on fish populations to be short-term and minimal, and suggested that a slow draw-down prior to removal can largely mitigate the effect of super saturation.

Bednarek (2001) suggests there may be a negative short-term impact with a corresponding increase in water temperature following removal, as the damming effect may create a thermal block to fish migration. For salmonid species, stress and infectious diseases tend to increase when water temperatures are at their highest and correspondingly, when flows are at their lowest (De Leaniz, 2008). These points strengthen the case for ensuring that the water level is controlled and maintained through the deconstruction phase. Projects appear to have been motivated in many cases by a desire to re-naturalise flow fluctuations, and Bednarek (2001) indicates that these have a direct positive effect on biodiversity and population densities of native aquatic organisms. In a study of the Chipola River in Florida (Hill *et al*., 1993 in Bednarek, 2001) for example, species diversity nearly doubled.

3.3.4 Impact on river biology and ecological processes

The impact of weir modification on river biology and the nature and timing of ecological response has been well studied, and there is much known about how removal will impact on vegetation, flora and fauna. This knowledge is largely built on site-specific (anecdotal) observations and empirical models. Hart *et al.* (2002) developed an approach for predicting dam removal outcomes based on stressor-response relationships by explaining how a spatial and temporal context can be used to examine the effects. This takes predictions based on studies of actual projects and compares these with mechanistic and empirical models, but the latter are based on simplistic assumptions. Thus, while evidence-based studies boost our understanding of the implications of weir removal, the application in practice is of equal importance and effective dissemination is central to improving implementation and good practice. This supports the role of the River Restoration Centre and other advisory organisations in reporting on case studies.

Impoundments to natural ecological flows are a major reason for the loss and local extinction of native fish such as Atlantic salmon (De Leaniz, 2008). Such impoundments prevent or delay migration along the river corridor and the cumulative impact of weirs (even if they are passed) has a substantial effect on the energy reserves of migratory species. This inevitably impacts their spawning success and reproductive rates, threatening the long-term livelihood of species. Where impoundment has a severe impact, population sizes may decrease substantially increasing genetic isolation, thus compromising evolutionary potential (Gregory *et al*., 2002). Impoundment also commonly leads to inadequate habitat patches and narrows the range of habitat types, which is an issue as species at different lifecycle stages rely on different flow velocities and habitats (Bunn and Arthington, 2002).

Bednarek (2001) offers probably the most comprehensive review of the short and long-term ecological impacts of removal to date and a key conclusion of this paper is that only now are the impacts on specific species being understood. De Leaniz (2008) focuses on the challenges facing migratory salmonids, while Dedecker *et al.* (2006) offer a migration model for the crustacean *Gammarus pulex*. American Rivers *et al.* (1999) review 25 case studies in the US and suggest that species on the whole benefit instantly, with recorded movement in the first year following removal. However, juveniles may take a couple of years to demonstrate similar patterns of movement. Stanley *et al.* (2002) similarly found that within one year, macro-invertebrate assemblages above formerly impounded river reaches in the Baraboo River, Wisconsin corresponded with those in upstream and downstream reference reaches.

Following removal, in-stream ecological dynamics will ensure that rivers regain a more natural flowing water conditions (Bunn and Arthington, 2002) favouring species more naturally found in these waters. Behind a weir structure, there is generally an increase in the number of exotic and invasive organisms as many exploit the degraded habitat (American Rivers, 2005). Whist plant species such as floating-pennywort (*Hydrocotyle ranunculoides*) and the water fern (*Azolla filiculoides*) may exploit these conditions there may be other instances where an impassable weir may reduce the upstream spread of an invasive fish or crayfish (Frings *et al*, 2013). Overcrowding of fish downstream of impoundments has been shown to facilitate the spread of parasites and infectious diseases, magnify the impact of pollution incidents and increase the risk of mass mortalities at low flows (De Leaniz, 2008). However in heavily impounded lowland rivers such as the Thames, weir pools can provide a vital habitat and increase fisheries diversity. They can be the only features that offer suitable spawning opportunities, clean gravel shallows, for flow-dependent species such as barbel, chub and dace. They can also act as refugia during flood or pollution events.

On the whole and in the long term, removal has a positive influence initiating natural processes. This includes greater lateral interconnection with the floodplain, which may offer refuge to native lentic species and fish fry whose habitat is disrupted or lost (American Rivers, 2005). Restoration measures can help to replace these or to create new inline nursery habitats or backwater areas offering new habitats in-stream. From a practical perspective, timing is critical to any weir removal, lowering or modification as it is much easier logistically to do so in low flow conditions. Nonetheless, due consideration must be given to ecological breeding seasons. In some cases, authorities' restrictions apply as to when in-stream river works can be undertaken. While water quality may deteriorate immediately following removal, in the long term, the ecological benefits as a result of removal tend to offset this. Indeed, evidence suggests that following the establishment of fish population sizes, communities and distribution, the water quality may recover to a condition that is an improvement on the pre-dam condition (De Leaniz, 2008).

3.4 Considerations

In planning a project, the complexity and diversity of considerations involved presents a number of challenges, and there are often many different perspectives to consider. This section aims to outline many of these, but is not an extensive review.

3.4.1 Safety

Structural and safety reasons have driven many weir removal projects globally (Doyle *et al*., 2003) with concerns over infrastructure and public safety. In areas prone to extremes in weather conditions such as drought or flash flooding, the impact may be exacerbated by the presence of structures (De Leaniz, 2008). An immediate concern with removal is the sudden mobilisation of sediment (Bednarek, 2001), which may exacerbate flood risk, particularly further down the catchment. This should be considered in all cases on a site-by-site basis and ideally modelled for larger structures to assess predicted flood risk and hydromorphological alteration. The need for modelling will depend on the nature of the corridor and catchment characteristics, the influence of other factors downstream, and whether the areas affected have been identified as being at risk from flooding (where modelling will be particularly important). An example of a weir removal project which had to consider public safety and structural stability in design is described in Figure 3.2 in the town of Tonder, Denmark. This project was carried out as part of a wider EU-LIFE project to restore passage for houting, an EU Habitat Directive protected species of fish.

Restoring Houting Passage

The aim of a £1.1 million project in the town of Tonder on the River Vida is to restore houting passage, retain parts of an old millpond as a nursery area, and create spawning grounds. While the mill wheel was no longer present at the start of the project, a two metre high weir created a physical obstruction to houting migration. The pond and the river have now been separated with the creation of a lateral sheet-piled, concrete-faced, broad-crested weir. Gravel bed and banks have been installed (*see **Figure 2***) and an otter pass has been built under the bridge just downstream of the reach shown. Two sluice gates and a fish ladder upstream of the mill bridge have been removed and downstream Tonder rowing club also have a new access point to the river to minimise disturbance. Flood banks on the northern side have been set back to ensure flood risk doesn't increase and eighty hectares of shallow-water lakes will form new nursery areas for houting fry. From Tonder, the watercourse meanders 700 metres down to wetlands and this is an increasingly popular walk for local residents.

Figure 2:
Looking upstream from the old Mill in the town of Tonder towards the town centre. The mill pond level is retained, but is separated by a lateral overspill weir from the new 'free-flowing' river with gravel bed and banks. October 2009

Figure 3.2: Restoring houting passage article (RR News, Issue 34, 2009, 1-3)

3.4.2 River corridor connectivity

Fragmentation is one of the main detrimental impacts of weirs on ecosystems (Nilsson *et al*., 2005) and a primary objective of many weir removal projects has been to mitigate for this, and improve connectivity. Opening passage to salmonids and other species largely affected by structures in a river is perhaps the most obvious and visual observation of removal. River connectivity is essential to migratory processes of aquatic fauna, nutrient and sediment transport and other natural processes along the river continuum across vertical and horizontal axes (Bunn and Arthington, 2002). Removing barriers may be the most cost-effective restorative measure as it provides multiple benefits: in addition to freeing passage, it can help restore endangered species populations (Robertson, 2005 in De Leaniz, 2008). Some weirs may be providing a physical barrier and reducing the rate of colonisation of non-native crayfish (Frings *et al*, 2013) and protecting native crayfish populations. In these instances it may be preferable for the weir to be retained.

3.4.3 Cost-efficiency

Often cited as one of the most cost-effective river restoration measures (Hart *et al*., 2002), weir removal has brought multiple benefits to the river ecosystem in past projects. The cost of removing weirs was estimated to vary between £17,500 and £80,000 in several projects in Spain (Brufao, 2006 in De Leaniz, 2008) while in the United States, the cost of removing small weirs (up to 10m in height) was around £40,000 on average, or £15,000 per metre height (Heinz Center, 2002). A further study found that for weirs up to three metres in height, the cost of removal is less than 20 per cent of the cost of constructing a Denil fish pass, and less than 12 per cent of the cost of building a pool and traverse fish ladder (De La Fuente and Araujo, 2001, in De Leaniz, 2008).

Additionally, the cost of maintenance to meet safety requirements must be factored in as weir removal works typically cost only a fraction of repairing an unsafe structure (Hjorth, 2001). In Wisconsin (USA), the actual cost of removing low-head dams was estimated to equate to only 20-50 per cent of the estimated reparation costs if the structure was retained (American Rivers *et al.,* 1999). A weir removal study on Dingman Creek (Canada) was found to be one of few cases where the estimated cost, effectiveness (advantages and disadvantages), net environmental effects (to the natural and social environment) and required mitigation measures was stated in detail (City of London, 2005) and this is suggested as a suitable template for use/further development in UK rivers.

3.4.4 Collapsing/non-operational weirs

Structures that are already in a state of collapse/disrepair tend to offer good potential for removal where they are not part of a flood risk management system. Natural processes such as erosion around a weir wing wall during high flow events may eventually lead to instability of the weir structure and if the nature of the collapse is not significant enough to present an obvious increased risk or if a structure no longer serves the function which it was originally constructed for, there is likely to be less opposition to its removal, and demolition costs should be lower. However, in the case of weir failure, immediate action may be required to avoid a flood or pollution incident and to safeguard further structures downstream, requiring potentially large financial expenditure (Defra/Environment Agency, 2003). The RRC (2006) found that at Browney Weir in County Durham for example, it would be more cost-effective to completely demolish a weir expected to naturally collapse. Particularly in the case of large weirs or a series of structures, expert judgement should always be considered. However, in some cases, partial collapse has resulted in natural processes occurring without the need for any additional intervention. There are a number of examples of these along upland gravel-bed catchments, which were historically areas with an industrial heritage. Weirs that provided a head of water to mills have degraded, and an example of this is shown in Figure 3.3 near Bury where partial decline has improved fish passage and spawning areas.

Figure 3.3: Collapsed weir on the River Irwell, near Bury.

3.4.5 Situations where weir removal, lowering or modification may be inappropriate

In some situations, the removal of weir structures may be inappropriate, for example where structures are in place to generate hydroelectric power. Structures on rivers that have been built for gauging purposes should normally be retained to ensure the continuation of long-term hydrological records. The alternative is to replace the structures with, for example, ultrasonic or electromagnetic gauging stations which do not require a structure to record flows, however these still require re-calibration and associated maintenance. Weir removal can reduce flood risk upstream of the weir by reducing water levels, but in turn can exacerbate flood risk downstream of the weir. Consequently a flood risk assessment may be needed prior to the removal; the responsible flood authority will be able to provide advice on the level of flood risk assessment needed.

The removal of weir structures may, in some instances, introduce significant geomorphic risk. Relatively high energy and high gradient rivers will have responded to the changed hydrological and sedimentological regime that was introduced when the structure was built. This is generally reflected through a relatively gentle gradient upstream of the structure (caused by the deposition of sediment behind the structure as flow velocities are reduced) and a steep fall in elevation downstream of the structure (caused by the difference in bed elevation introduced by the weir itself, but also increased scour/erosion caused by an excess of stream power). If the structure has been in place for a long time then the system is likely to have adjusted to this irregularity in its longitudinal profile. Removal of the structure and, therefore, the artificial fall in gradient, may locally destabilise the reach. The longitudinal profile is likely to respond by 'flattening out' this irregularity through knick-point erosions – as described in section 3.3.2.

Where any erosion is anticipated the geochemical properties of the floodplain sediments that make up the exposed river banks must be considered. For example, bank collapse may introduce a pulse of contaminated sediment into the system. Further, downstream deposition of sediment originally impounded behind the weir may reduce the cross-sectional capacity of the channel. This may lead to concerns from landowners and communities that they are more susceptible to flood risk.

Note however, that this is a simple model of geomorphic alteration to weir installation/removal. The response will be different from river to river. Local factors (substrate material, alterations to flow regime, riparian vegetation influence, rates and patterns of sediment supply, human interference) will all contribute to the behaviour of a river to the installation/removal of a weir. The geomorphic risks indicated above should be considered before any weir removal. Where appropriate the risks should be evaluated against the overall benefits introduced by removing the weir.

Many weirs have archaeological importance, heritage or aesthetic value and in these circumstances removal may not be appropriate. When working on structures that are protected for their archaeological or historic value permission will be need from English Heritage or their equivalent organisations. Lowering or removing weirs will reduce water levels upstream and this may have both ecological and aesthetic implications. Weir structures have been used historically for navigation, however the focus of this report is on structures without a navigational remit. There is also the current debate over the use of weir structures to generate hydropower (see Environment Agency, 2010 for further details).

3.4.6 Consent

Flood defence consent may be required to remove or partially remove an impounding structure. You may also require an impoundment licence. Contact the Environment Agency or your Lead Local Flood Authority (whichever is appropriate) at an early stage within your project so they can advise what permissions are needed to undertake the works. This should avoid delays and wasted effort.

3.4.7 Public interest

A number of groups have a vested interest in whether or not a weir is constructed, retained, modified or removed. The aesthetic value of water cascading over a weir face, for example, is identified by many as an attractive landscape feature (Shaw *et al*., 2010) and Babbitt (2002) argues that all stakeholders' views should be incorporated into the decision-making process of weir removal. Johnson and Graber (2002) state that this is particularly important in the case of small weirs, as a US study revealed that public perception of their impact is that they are generally non-detrimental. The Heinz Center (2002) points out that little research exists on the human or social science aspects of weir removal, despite it playing a very important role.

Weir pools have been traditionally fished as they offer a fixed spot where fish are often found. As such, the removal of such a structure may be perceived to be a negative measure by angling clubs. In addition, the deep, steady water found upstream of weirs can offer good fishing for coarse fish species and eurytopic species. In contrast, more sustainable salmonid populations have been found to flourish as a result of weir removal (De Leaniz, 2008), and reaches upstream of a weir may also become more suitable for fishing as faster flowing velocities remove silt, exposing spawning gravels which in turn create better habitat potential for salmonids and other rheophilic species. This illustrates the importance of sending a clear message to affected communities about what the removal aims to achieve and how it is expected to affect interested parties in the short, intermediate and long term. This should be outlined at an open public consultation when the benefits of removal or lowering can be ideally demonstrated and expressed in an appropriate manner. Case studies of past projects in a similar river setting are sometimes more suitable in a demonstration exercise than a theoretical model.

The retention of weirs of architectural and aesthetic value and those built to defend people and property from the risk of flooding, or to create reservoirs for purposes such as drinking water supply and hydroelectric power generation, all have socio-economic benefits which would need to be balanced against the ecosystem benefits gained if the structure were removed. Additionally, the requirement to apply for consent, licensing and in some cases planning permission depending on the project scope can take some time, particularly when there is opposition. While a recent study concluded that across Europe, the majority of structures on the whole are not listed (De Leaniz, 2008), a structure may still have cultural or heritage importance, and therefore it is important that due consideration is made of the historic environment and all options are considered.

Kirkstall weir in Leeds was the focus of a critical study whereby six different options were considered in a proposal to construct a white-water canoe course on the River Aire (Waterhouse, 2004). This study demonstrated the widely varying perspectives on modifying an existing weir, looking at a range of insights from hydrological and ecological impacts to the views of local visitors and archaeologists. Shaw *et al*. (2010) assessed the impact of modifications in the Don catchment in northern England and how this would affect the benefits people received from rivers using an ecosystem services framework. As part of the study being pioneered in URSULA (Urban River Corridors and Sustainable Living Agendas) at the University of Sheffield’s Catchment Science Centre, it is hoped that decision-making tools will be identified.

4 National River Restoration Inventory (NRRI)

4.1 Analysis of practice

The National River Restoration Inventory is the RRC's database of river restoration, river management and best practice habitat enhancement projects, and it is a resource that is continually updated by RRC members and other contributors. The NRRI represents the largest and most detailed database of its kind in the UK (see the Glossary for more information).

The projects included in this assessment of the NRRI were exported on 1 July 2010. This, as such, does not include the project information received in the online survey whose deadline for submissions was 15 July 2010. In some cases, survey projects had already been entered onto the NRRI, albeit not in the same detail.

Table 4.1 shows that the majority of completed weir related projects have not been monitored. The table also highlights that a lot more are proposed, with the current focus on weir removal as a potential measure.

Table 4.1: Number and percentage of weir removal projects by status.

Project status	Number of projects	Percentage of total projects (exported)
Completed (with monitoring)	13	12
Completed (no monitoring)	58	52
Active (design/in construction)	9	8
Proposed	31	28

Weir removal, lowering and modification projects occurred frequently between 1995 and 1999, and 2005 and 2009 (see Figure 4.1).

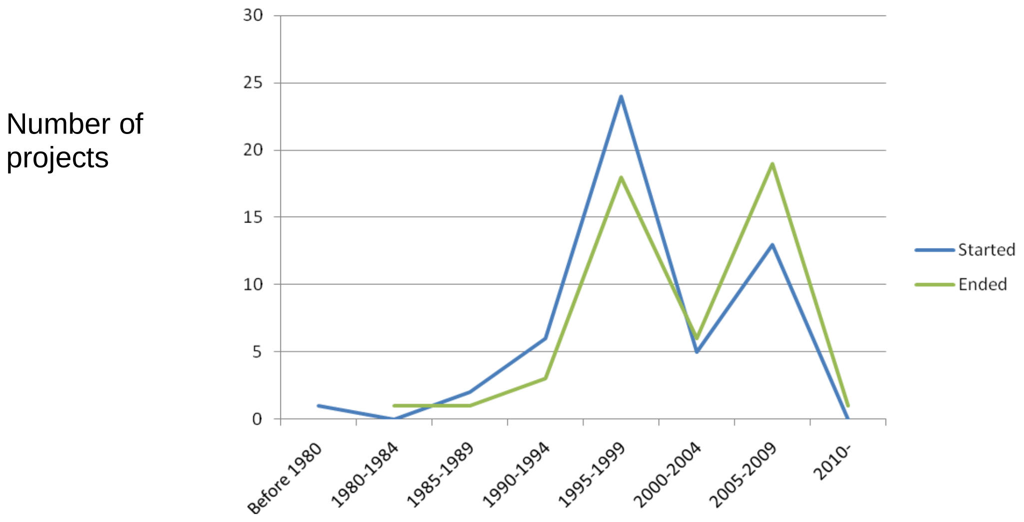


Figure 4.1:Timeline of weir removal/lowering projects start and end dates in UK.

The distribution map of NRRI projects suggests the majority of weir removal, lowering and modification projects have taken place in southern England (Figure 4.2).

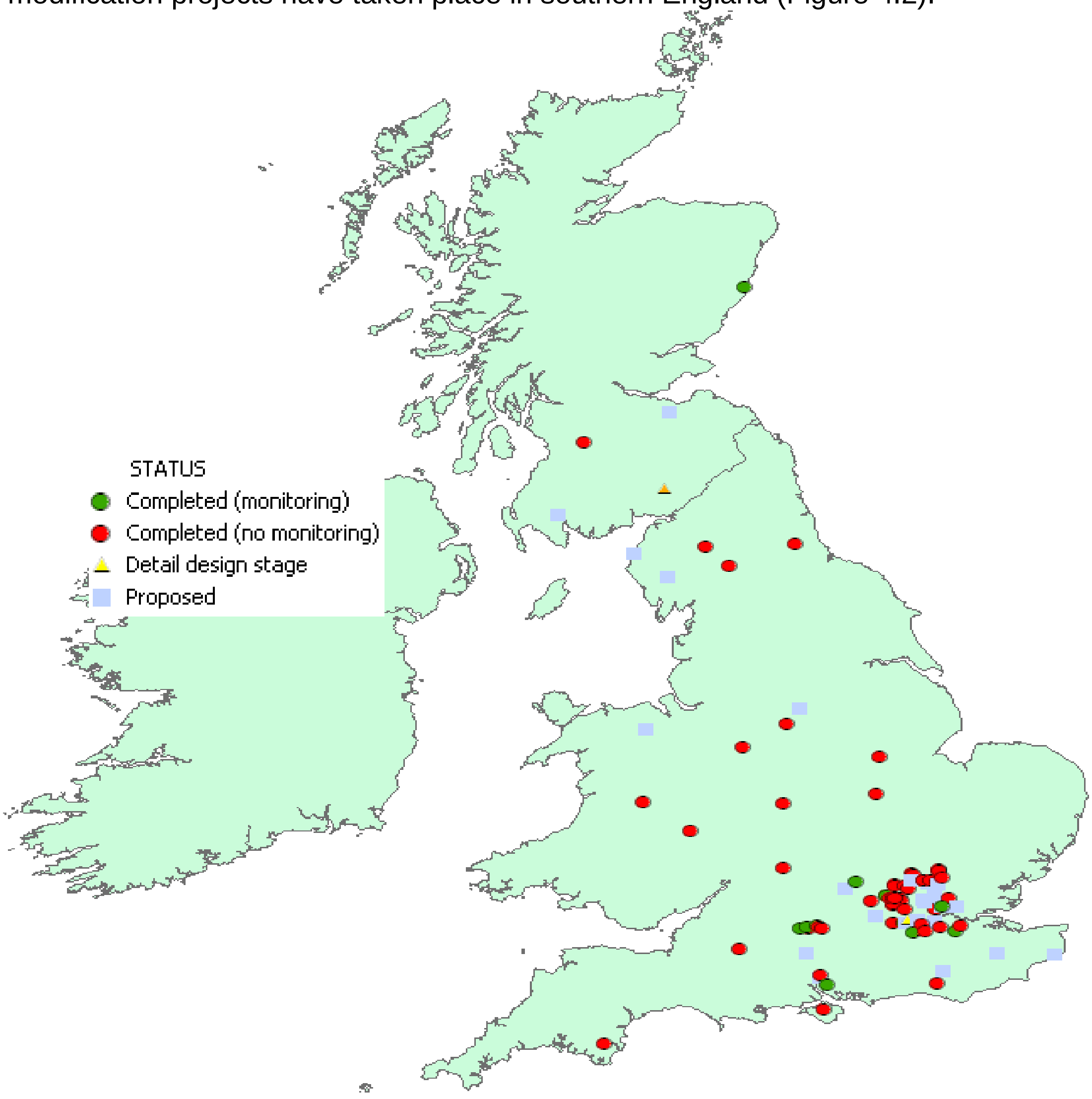


Figure 4.2: Distribution of weir removal/modification projects across the UK.

Of the projects assessed in our study, 50 per cent had an associated total cost ranging from £2,000 to £50,000. In many cases, however, the actual removal/modification works were only one part of a wider project so it was difficult to estimate the average cost per weir, per project on these grounds. There appeared to be little evidence of detailed monitoring programmes, and of the projects monitored, these were completed in recent years (post-2000).

Qualitative comments for projects on the whole suggest the following benefits:

- opened passage upstream for migratory species;
- improvements in river ecology, habitat and river corridor connectivity;
- kick-starting of natural rehabilitation and natural processes;
- good value for money;
- projects involved a wide number of affected groups.

Qualitative comments for projects on the whole suggest the following issues:

- mixed reactions from affected groups;
- where unsuccessful, weir removal resulted in perceived inappropriate channel morphology, energy, sediment inputs;
- lack of time/money to undertake formal ecological monitoring.

Habitat and fisheries legislation is the main driver behind projects (Figure 4.3).

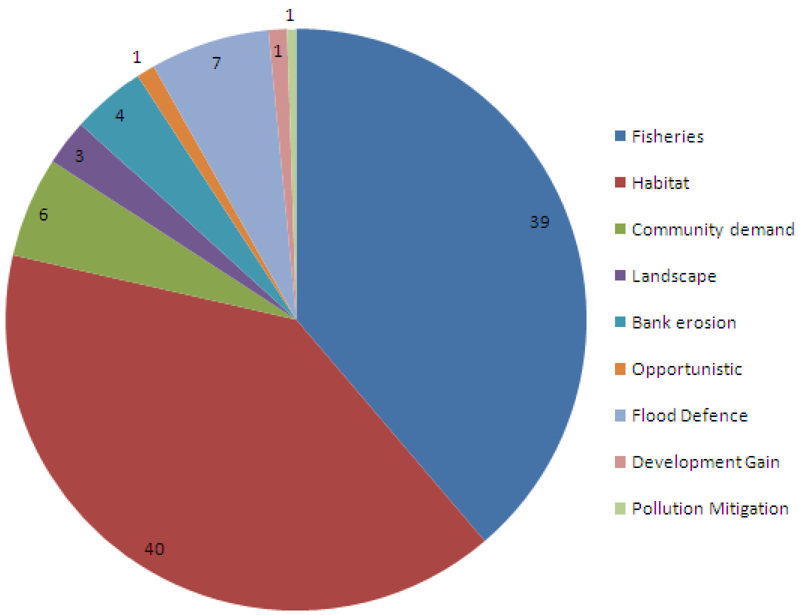


Figure 4.3: Main motivation(s) stated for weir removal/modification projects in UK.

4.1.1 Analysis

The NRRI provided a useful overview of the number, nature and distribution of projects, indicating where and when they have occurred, assessing both qualitative and quantitative datasets. This data is regularly updated as part of RRC's ongoing work, but does rely on information being provided to the Centre from all statutory agencies in England, Scotland and Wales. Nonetheless, it remains the best available resource to carry out an analysis of all UK projects. The results support the statements made in the literature that complete or partial removal of weir structures has been a more considered and applied river management/restoration measure since the early 1990s. This stems from recognition of the need to conserve river habitats to achieve a sustainable healthy river system, as well managing them for flood and water resources.

The national distribution map of projects (Figure 4.2) is based solely on an assessment of the NRRI. Assessing river typology, the results suggest a greater number have occurred in lowland clay/chalk rivers, while the lack of weir removal in upland catchments may reflect the potential risks involved. This is due to the character of steeper, flashier catchments and the association of upland areas with contaminated sediment from their industrial history. However, the NRRI data is constantly being updated, and as a result of this science report, it has been possible to identify a new trend in some higher energy catchments of increased weir removal activity. The Ribble pilot project is one such example, where new understanding of the catchment has found that sediment contamination is less than previously assumed and this, together with the need to deliver the EU-WFD programme of measures, provides the impetus for such work.

The length of increased fish passage that weir removal may open up is an important consideration and is an element that is not always captured. For example, the removal of one weir in a catchment may open up a stretch of 25km whereas removing six weirs in another catchment may only open up 15km of impounded watercourse, resulting in a debate about cost-effectiveness versus habitat enhancements. While cost-effectiveness is a critical determining factor, it was difficult to estimate the average cost of removing a structure per unit without a cost breakdown of each project, and in nearly all cases this information was lacking. For a few of the projects a more thorough breakdown of costs per unit was provided, but even these varied enormously and any useful statistical analysis would be misleading. It is recommended that costing details should be the subject of a separate project.

With respect to river project success, the majority appear to have met their basic requirements, by opening passage to fish or improving habitats, both of which can often be observed to some extent following removal; there was very little quantitative evidence to suggest an appreciation of aspects such as river ecology/biology or geomorphic state. This may relate to lack of post-project appraisal being built into the project process; however, such information would be useful in informing similar restoration sites in the future. The extent of available documentation was largely disappointing but it was encouraging to see that recent projects have put more effort into appraisal. Further analysis showed that pre- and post-project photographs, basic projects audits, and fisheries and invertebrate studies were the most common types of monitoring used. The use of simple fixed point photography should at the simplest level be a part of every project as it is rapid, cost-effective and a useful visual aid to demonstrate change following removal.

The main drivers for weir removal are diverse, as shown in Figure 4.3, and this may be a reflection of the associated and widely diverse aspirations of the groups involved. The NRRI has been shown to be a useful tool for pinpointing projects, and information collected from it has been a useful part of this work and has helped to target questionnaire respondents. What was not possible within the remit of this project was to use the information collected to carry out more detailed assessments of completed projects using RRC's rapid appraisal methods; case studies have primarily relied on the collection of secondary data.

4.2 Online survey

The online survey offered greater insight into the projects, as respondents were required to answer reflectively on the extent of the weirs' impact and the projects' successes/drawbacks. The short period of time for responses was a limiting factor; however despite this the survey captured 22 comprehensive responses. Importantly, the geographic coverage was good as a result of using a wide distribution of contacts throughout the UK.

4.2.1 Results

Table 4.2 shows that half of the projects submitted were completed (with monitoring).

Table 4.2: Number and percentage of projects by status.

Project status	Total number of projects	Percentage of projects (of total)
Completed (with monitoring)	11	50
Completed (no monitoring)	4	18
Active (detail design stage/ in construction)	4	18
Proposed	3	14

Table 4.3 shows that there was a mixture of complete and partial removal (lowering) and modification projects submitted, but no collapsed weir projects.

The Thorverton Mill Weir on the River Exe case study (Appendix B) was developed as a separate case to the online survey to illustrate the issues faced in this area with active sedimentation and dynamic fluvial processes following the unanticipated collapse of the weir structure.

Table 4.3: Number and percentage of projects by type of project.

Project status	Total number of projects	Percentage of projects (of total)
Complete removal	10	46
Partial removal	6	27
Modification	6	27
Collapsed weir	0	0

Weir removal/lowering projects, according to respondents' personal opinions, were seen to be largely beneficial and exceeded expectations in a number of cases. The respondents appeared to find Hydromorphological (physical) success easier to perceive than ecological success. More than a quarter of project managers did not know how ecologically successful the project had been, whereas only five per cent of the projects considered hydromorphological success ‘unknown’ (Figure 4.4). None of the projects had an overall unsuccessful physical/hydromorphological or ecological state following restoration.

Monitoring on the whole was very low across all documentation types (Figure 4.5). Photography, both pre- and post-restoration, was the most commonly available form of monitoring documentation for those projects listed; however, this was only available in around half of the projects stated.

Significantly, post-project appraisal data was collected in only five per cent of surveyed projects. In many cases, it was not clear if monitoring was done and if so, whether the information was available. This number is also reflective of projects currently in construction or proposed (32 per cent of the total); however, a further 18 per cent of these anticipate post-project data collection.

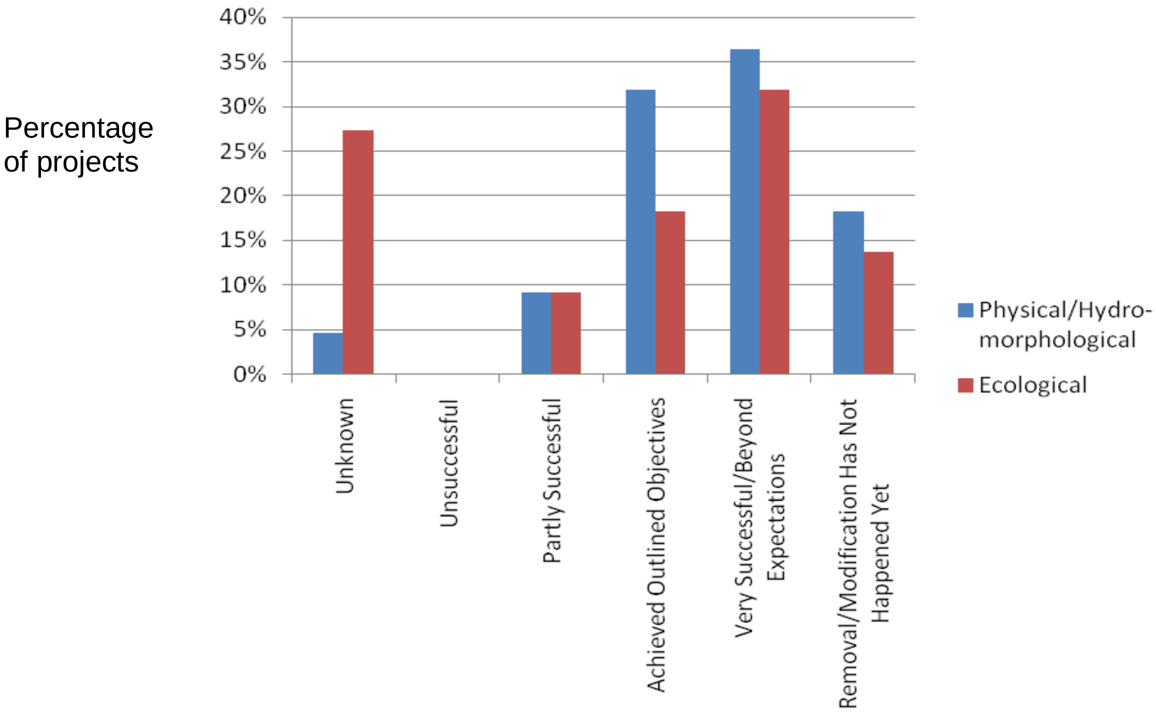


Figure 4.4: Physical/hydromorphological and ecological success of survey projects.

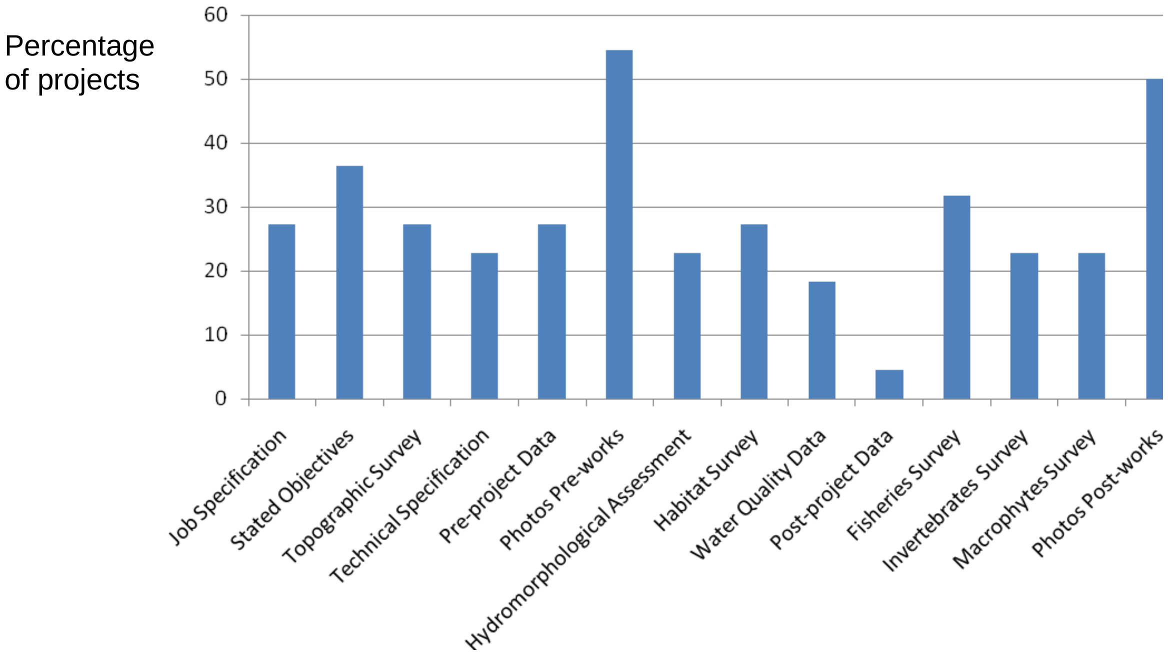


Figure 4.5: Monitoring output available (as a percentage) of total survey projects.

The survey included a question that did not focus on the case study, but on respondents' general perceptions on their respective projects on the whole. Generic benefits perceived were:

- Improved fish/other species passage; improvements to biodiversity; increased connectivity along watercourse and restoration of natural flow regime.
- Weir removal/lowering projects have a generally positive impact on the river ecology, hydrology and hydromorphology.
- The beneficial socio-economic nature of projects in interdepartmental working and building/developing partnerships with local interest groups and others was also encouraging.

Generic difficulties included:

- Project funding, physical constraints and access; public consultation and meeting local landowner and interest group expectations.
- Many of the difficulties raised were in fact not physical issues, but were related to the process of project management, bureaucracy and lack of expertise and knowledge to deliver projects effectively.

For the full list of benefits and difficulties, see Appendix A.

Impact score weighting analysis

A survey question asked the respondent to assess the impact of weir removal/lowering on a number of WFD-relevant objectives. The list of objectives was agreed by the River Restoration Centre, the Environment Agency and the project's steering group. The option was open for respondents to enter other impacts that were not stated to avoid any potential questionnaire bias. The attributes chosen were those identified as relevant to WFD outcomes, including hydromorphological and biological processes and forms.

To aid interpretation, a weighting was used to help interpret the qualitative results in a more useful manner. For projects where weir removal or lowering was seen to have a detrimental impact, a minus score was given (-1.5); if it was beneficial, it was given a corresponding positive score (+1 or +2 depending on the observed level of positive impact). Table 4.4 gives more information on the assigned weighting. As no distinction was made between negative and extremely negative impact in the design of the survey, negative was assigned with a -1.5 weighting to balance the positive (+1 and +2) weightings.

Table 4.4: Impact score and assigned weighting

Impact score	Assigned weighting
Negative	-1.5
No impact	0
Positive	+1
Extremely positive	+2

Essentially, the higher the average score per factor, the more positive the impact that weir removal, lowering or modification was seen to have on each WFD objective.

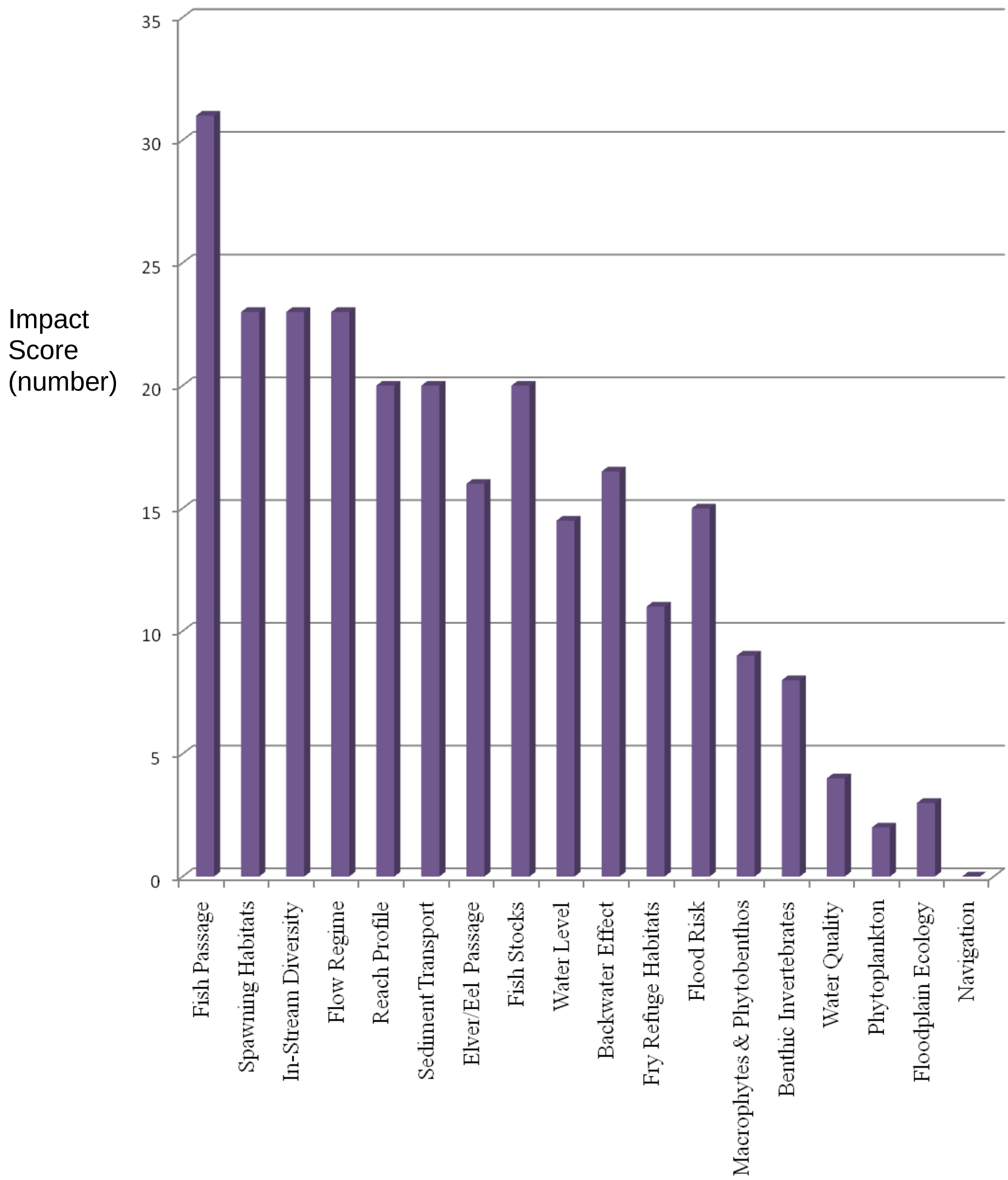


Figure 4.6: Impact score of weir removal/lowering on identified WFD objectives (shown on the X axis).

- Other than 'navigation', which was not identified as a measurable objective in any of the survey projects submitted (and was therefore assigned a value of zero by default), all other impact factors scored positively to different extents (Figure 4.6).
- Fish passage emerged as the most beneficial impact of weir removal/lowering according to the statistical weighting analysis.
- The impact upon spawning habitats, in-stream diversity and flow regime were also very positive as were the change in reach profile, sediment transport and fish stocks.

- Most other factors were seen to be beneficial in only one or two projects, hence their lower positive impact score.
- Very little impact of weir removal/lowering was identified by respondents on river water quality, phytoplankton or floodplain ecology.
- 'Water level' and 'backwater effect' were seen to have had a detrimental effect in one project each. However, generally weir removal/lowering was seen to have had a beneficial impact on these factors as in most cases the impacts on these attributes were deemed positive.

4.2.2 Analysis

The projects submitted in the survey reveal that partial or complete removal of weir structures generally has a positive impact on a number of ecological/biological and hydromorphological aspects. On the whole, many projects were considered to exceeded expectations; however, the majority of projects did not have specific objectives set. The River Restoration Centre's PRAGMO monitoring guidance (RRC, 2010b) explains how to set project and monitoring objectives. Hydromorphological success was considered easier to identify than ecological success. This may reflect the fact that it is much easier to identify changes to the bank profile (visible) than to river ecology (which may be submerged) or that in many cases, it is the river's form that it likely to exhibit change first. The level of projects with monitoring (50 per cent) was supportive of the NRRI results in that the majority of surveyed projects have occurred in recent years (post-2000) and this indicates that while there remains a lack of funding, time and/or resources, monitoring is now beginning to be built into the project process or be allocated funds.

Fish passage, river connectivity and biodiversity/habitat gains were the main benefits of weir removal in the survey responses. This was also reflected in the literature review and the NRRI analysis. This supports the statement that partial or complete weir removal can bring multiple benefits to a river. Issues identified included a lack of funding to initiate the scheme; physical constraints and access to the site; project management and its attaining consent, and a lack of expertise and understanding as to how to maximise benefits. Notably, the main benefits identified through the weighting analysis were similar to the perceived benefits of weir removal/lowering on the whole.

One issue raised was the difficulty of carrying out public consultation and the ability to fulfil promises made to local landowners based on their expectations before the project began. Inevitably, public engagement and managing expectations will always be problematic; however, this is an essential part of carrying out a river restoration or river management project on a catchment scale. Public involvement was also an issue raised in the literature review and in correspondence with practitioners. While some stated that they enjoyed meeting and informing the local public of their project, others suggested that the process could potentially delay the project. It is therefore essential to allocate sufficient project time to accommodate any possible issues and to have the ability to adapt where necessary.

There are a number of possible reasons behind the 'positive' nature of the results. As with the NRRI, the results can only be used as an indicative tool, and with more respondents, the validity of the results would have increased. It was agreed by the RRC and the Environment Agency at the onset that the questionnaire design must be sufficiently detailed while remaining succinct enough to ensure it was both convenient and quick to fill out and submit, to avoid discouraging respondents. Future studies may look to extend these results by developing the survey, asking further questions or by encouraging more detailed answers but this is beyond the scope of our investigation.

Many of the respondents were from a conservation/fisheries background and appropriately, according to the NRRI, they may have been the best placed to answer for the project as the respective project officers. While some questions might have been answered differently by those with a different perspective, every effort was made to make the questionnaire as publicly available and open as possible. This was done firstly by making all RRC contacts aware through email, secondly by posting the link on a social media website hosted by the RRC, and thirdly by encouraging opens sharing of the link to encourage the widest possible participation. The design of the questionnaire was also agreed by RRC and Environment Agency staff to minimise bias in terms of the questions posed.

The survey results reflect only a subset of projects and it would appear that 'success stories' dominate. This is an issue in that it is perhaps those projects that were abandoned or never started that would have offered a better insight into the difficulties of weir removal/modification projects and in particular, the difficulties faced in preparing a case. However, there is likely to be a reluctance to disseminate information when a project is perceived to have failed. Rigorous project screening and the use of scoping studies should ensure that any issues regarding structural integrity or increased flood risk would be identified where inappropriate weir removal/modification projects would not get beyond the initial screening stage. Projects should look at potential benefits whilst also considering any negative impacts and potential issues. The example of Padiham Weir, which has only had partial removal works carried out despite a prolonged planning phase, shows that while modification may not be a feasible option at a certain time, it may be worth considering at a later date. The Arborfield case study also highlights the difficulty and time involved in preparing a multifaceted and complex project, but shows that monitoring can ultimately be a useful way of providing evidence on any technical uncertainties, such as flood risk.

5 Discussion

There is a body of information indicating that weir removal and lowering can help achieve a range of hydromorphological and ecological benefits and can be part of the programme of measures in WFD River Basin Plans. Information on weir removal success, however, remains patchy and much is reliant upon anecdotal evidence or, in the case of the scientific literature, has focused primarily on geomorphic process and form variability following the removal of dams on high energy gravel-bed rivers in the USA. In essence, there remains a paucity of evidence provided by objective-focused pre- and post-project data collection in the UK.

Despite an almost universal acceptance in the literature that weirs have impacted upon rivers globally for decades and even millennia, we are only just beginning to demonstrate the importance of increasing river longitudinal connectivity and reinstating a more natural flow regime to support a range of organisms' lifecycles; these are clearly limited by weir structures. Whilst there is a willingness to consider weir removal, especially in situations where there is a lack of river connectivity to good spawning upstream, a lack of confidence and funding to complete and appraise projects continues to curtail this activity.

Most concerns related to weir removal refer to the geomorphic stability of a reach following removal, the potential to increase flood risk, or to demonstration of success of a project in terms of habitat gain. For the first of these, the data collected for this project shows that there is a dichotomy between allowing natural processes to attempt to re-establish a natural equilibrium and the concern that the banks will continue to undercut upstream for a significant length of the river. Anecdotal evidence, where weirs have naturally collapsed, however, suggests that often a river will 'repair' itself fairly rapidly after collapse provided there are no local issues such as, for example, a gauging station or bridge structure that may be negatively impacted by the hydromorphological induced change. Unfortunately, however, monitoring data that indicate channel morphology (both downstream and cross-channel) before and after weir removal/collapse are extremely rare. In the absence of such data it is logical to approach each weir removal with considerable caution. Anecdotal evidence may be biased and/or limited to a narrow range of river types.

Data from the online survey indicated that hydromorphological success is generally considered easier to assess than ecological improvement but whether this is due to timescales of recover, a lack of focus in monitoring measurable objectives or simply due to the interrelationship with other parts of the catchment is not clear. Very few negative impacts were identified on biology or physical processes, or on water quality or floodplain ecology – some factors which appear not to have been a consideration in previous weir removal projects.

Overall, the lack of evidence of ecological success has been noted throughout and monitoring recommended. Equally, we have pointed out that it may take decades for a river channel to adjust following weir removal. Monitoring success must therefore be cost-effective. A combination of 'benchmarking' through the use of existing long-term datasets and 'appropriate' morphological and ecological monitoring in terms of where and when (not only season but how many years after project completion) should help to increase the evidence base over time, as shown in Section 5.2.6 below.

Weir removal should not simply be considered in the reach-based context. Changes can occur temporarily and spatially as a result of weir removal and it is important to understand the potential impact of each scheme. Anecdotal observations and case studies can help to understand the extent of weir removal benefit for different river systems. Indeed, it has been shown that not all weirs need to be removed; in some instances removal may be unsuitable, unfeasible or impractical because of societal constraints or because sediment flushing impacts are not well understood, for example. In many cases river stability up and downstream will need to be modeled and assessed at the feasibility stage, but the level of modeling should be appropriate to the associated risk.

Consultation was identified as a difficult process in the literature and in the online survey, but it is clear that dialogue with local groups is essential to the smooth running of any project. Determining how long this process should take should not be underestimated, but it is important to set aside this time at the onset of the project. Those involved in designing and delivering the project must in effect 'sell' their vision with a clear picture/message about their intentions, to ensure that people's expectations are not unrealistic.

5.1 Limitations

A number of limitations are recognised in this report.

- Limited scope of this report, excluding consideration of alternatives to weir removal such as fish bypass channels, comprehensive assessment of weir removal on flood risk, and potential benefits of reinstating or keeping weirs for hydropower and navigation purposes.
- Time and resource cost constraints, given the scope of the project specification.
- Time restrictions on the survey collection period.
- Continual updating of the National River Restoration Inventory project data.

5.2 Recommendations

This section makes the following recommendations when contemplating weir removal or lowering projects, focusing on the need to collect evidence and monitor success.

5.2.1 The catchment

It is essential that any weir removal is set in the context of an understanding of the catchment. This means understanding the river type in terms of its hydrological regime, sediment dynamics, benefit of the project in terms of fish passage and any potential unacceptable effect on local infrastructure or flood risk. If there are weirs downstream or upstream of the proposed project area, do they have an impact on fish passage and if so, what is the benefit of one weir removal or should the whole river be considered for a more strategic approach to removal? It is important to consider physical processes and address the issue of connectivity. Removal is not appropriate for all weirs, and it is important that assessment is carried out on a case-by-case basis.

5.2.2 Weir information

Much information can be gleaned from an initial visual inspection and a walkover survey of the site that must include downstream (potential sediment deposition areas) and upstream (to identify the extent of the weir impact on sediment deposition and backwater impacts) areas. The amount of information that needs to be collected and the level of modelling will depend on the location of the weir, its size and the type of catchment, and whether it is within a high flood risk area, since removal can affect water levels both upstream and downstream locally. In many cases this will require a topographic survey of the river (both up and downstream) having identified the potential extent of impact, which will vary depending on the extent of historical intervention, sediment type and slope.

5.2.3 Topography and modelling

Topographic data is necessary to feed into any standard steady-state hydrological model (such as HEC-RAS or ISIS) or possibly CES (conveyance estimating system) to estimate the influence of flow regime after weir removal. Cross-section and longitudinal information needs to collected, usually at around 100m intervals or where there are clear breaks of slopes or widening of the river. The required extent of the survey can often be identified by clear hard bed points such as bridges or other structures but it must extend out of any backwater influence. A detailed topographic survey of the weir should also be included.

5.2.4 Sediment analysis

One of the key concerns over weir removal is that of sediment movement downstream and where it will be deposited. It is also essential to know how much sediment is deposited behind the weir, its composition and noting any specific sediment inputs into the river. Options might include taking a few sediment samples from behind the weir and estimating the composition in terms of average gravel size and percentage fines. This will need to be reviewed with an understanding of the stream power and the 'critical power' needed to move the sediment (see section 3.3.3). It is important to remember that sediment transport is far from a precise science and results from these methods should always be treated with caution, however, understanding the nature and quantity of the sediment will give an indication of what is likely to move and under what flow conditions. When carrying out the topographic surveys, estimate the extent of material trapped behind the weir and hence calculate its volume.

The other important issue is contamination and this should be considered within any project; samples of material from behind the weir should be collected, and geochemical analyses undertaken, to ascertain the extent and type of any contamination.

5.2.5 River restoration

Weir removal on its own clearly represents an element of restoration. However, in some situations (especially in highly modified, high energy systems) an element of bed and bank protection may be necessary to prevent unacceptable levels of lateral or longitudinal erosion. Options such as installing large wood deflectors may help to hold upstream sections in place and mitigate against unacceptable levels of erosion upstream whilst at the same time providing habitat features.

5.2.6 Project cost

One of the most important considerations is the overall cost of the project. Removing a weir is often perceived to be prohibitively expensive; however, a cost-benefit analysis will help demonstrate the benefit of full removal as opposed to ongoing maintenance or the introduction of a fish pass, for example. Accurate measurements of the weir must be made to work out how much spoil needs to be removed, since this is likely to be the most costly part of the exercise. Costs for spoil removal vary considerably between sites based on ease of access and geographical location. The cost of disposal of any sediment will depend on the level of any contamination. The benefits of the schemes will depend on the objectives of the project and may include ecological benefits, reduced maintenance and improved passage.

5.2.7 Project appraisal

If time and resources have been spent assessing the suitability of removing/lowering a weir, it is a wasted opportunity if the project is not appraised. Appraisal is the most effective way to demonstrate the success of a project. The RRC and partners have developed guidelines on setting SMART objectives and developing an evidence base for a project (RRC 2011), but a useful hypothetical example for weir removal is given in Figure 5.1. It is recommended that formal monitoring is included in removal plans and budgets, but this does not need to be detailed.

Evidence collection must be systematic rather than ad hoc as is currently done. This does not necessarily require expensive monitoring equipment, but rather a focus on what you wish to understand about the weir removal (setting of specific and measurable objectives) and the formation of an appropriate monitoring regime which, in some cases, may be a simple set of fixed-point photographs along the river where there may have been concerns about fine sediment deposition for example. In the meantime, best practice case studies are useful benchmarks. One of the key elements currently lacking is evidence on the impact of removing small weirs on surrounding banks, bed and sediment movements. Analysis should help to increase the evidence base and encourage future projects.

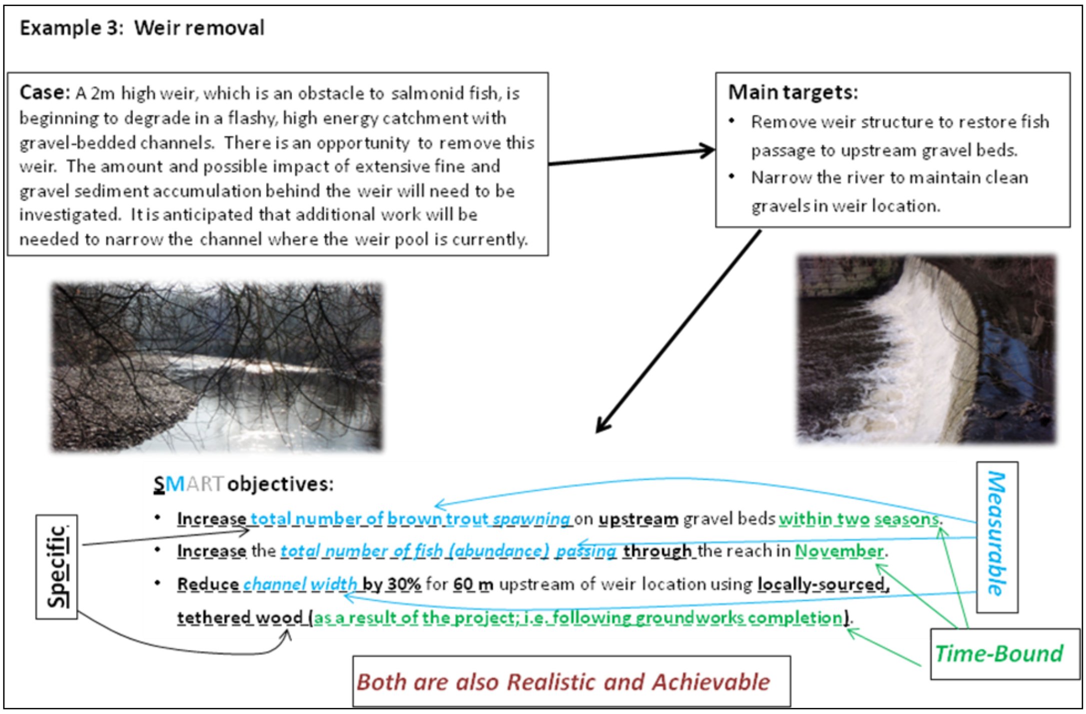


Figure 5.1: Monitoring weir removal example.

References

AMERICAN RIVERS, FRIENDS OF THE EARTH AND TROUT UNLIMITED, 1999. *Dam removal success stories. Restoring rivers through selective removal of dams that don't make sense*. 176pp.

AMERICAN RIVERS, 2005.*The ecology of dam removal: A summary of benefits and impacts*, 1-10.

BABBITT, B., 2002. What goes up, may come down. *Bioscience*, 52, 656-658.

BEDNAREK, A.T., 2001. Un-damming rivers: A review of the ecological impacts of dam removal. *Environmental Management*, 27, 803-814.

BRUFAO, P., 2006. La demolicion de presas y otrasobrashidraulicasebEspana. Quercus, 241. Cited in: De Leaniz, C.G., 2008. Weir removal in salmonid streams: implications, challenges and practicalities. *Hydrobiologia*, 609, 83-96.

BUNN, S.E. AND ARTHINGTON, A.H., 2002. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. *Environmental Management*, 30 (4), 492-507.

CITY OF LONDON, 2005. *Class Environmental Assessment Report, Dingman Creek Weir Removal, Canada*. 43pp.

CENTRE FOR EVIDENCE BASED CONSERVATION (CEBC), 2009. *Guidelines for Systematic Reviews in Conservation and Environmental Management*. Bangor University, 71pp. http://www.environmentalevidence.org/Documents/Guidelines.pdf [Accessed 29th October 2010].

DEDECKER, A.P., GOETHALS, P.L.M., D'HEYGERE, T. AND PAUW, N.D., 2006. Development of an in-stream migration model for *Gammarusplex* L. (Crustacea, Amphipoda) as a tool in river restoration management. *Aquatic Ecology*, 40, 249-261.

DEFRA/ENVIRONMENT AGENCY, 2003. *River Weirs – Good Practice Guide*. Defra/Environment Agency Flood and Coastal Defence R&D Programme. R&D Publication W5B-023/HQP, 137pp.

DE LEANIZ, C.G., 2008. Weir removal in salmonid streams: implications, challenges and practicalities. *Hydrobiologia*, 609, 83-96.

DE LA FUENTE, J. AND ARAUJO, J.M. 2001. Mejora de la accesibilidad en pequenosazudes.Cited in: De Leaniz, C.G., 2008. Weir removal in salmonid streams: implications, challenges and practicalities. *Hydrobiologia*, 609, 83-96.

DENNIS, I.A., MACKLIN, M.G., COULTHARD, T.J. and BREWER, P.A. (2003) The impact of the October/November 2000 floods on contaminant metal dispersal in the River Swale catchment, North Yorkshire, UK. *Hydrological Processes* **17,** 1641-1657.

DOYLE, M.W., STANLEY, E.H. AND HARBOR, J.M., 2002. Geomorphic analogies for assessing probable channel response to dam removal. *Journal of the American Water Resources Association*, 38 (6), 1567-1579.

DOYLE, M.W., STANLEY, E.H., HARBOR, J.M. AND GRANT, G.S., 2003. Dam removal in the United States: Emerging needs for Science and Policy. *EOS Transactions, American Geophysical Union*, 84, 29-33.

ENVIRONMENT AGENCY, 2008. *Flood defence consent requirements: dams and weirs. Operational instruction 226_03*. 5pp.

ENVIRONMENT AGENCY, 2009. *Removal of impounding works and revocation of licences. Operational instruction 88_07*. 13pp.

ENVIRONMENT AGENCY, 2010. *Mapping hydropower opportunities and sensitivities in England and Wales.* Technical Report, 74pp.

FAO/DVWK, 2002*. Fish passes – Design, dimensions and monitoring*. Rome, FAO, 119p.

FRINGS, R.M.. VAEßEN, S.C.K., GROß, H., ROGER, S., SCHUTTRUMPF, H. and HOLLERT, H. 2013 A fish-passable barrier to stop the invasion of non-indigenous crayfish. *Biological Conservation*, 159, 521-529.

GREGORY, S., LI, H. AND LI, J., 2002. The conceptual basis for ecological responses to dam removal. *Bioscience*, 52, 713-723.

GRAF, W.L., 2002. *Dam Removal Research. Status and Prospects*. The Heinz Center, Washington, 165pp.

HART, D.D., JOHNSON, T.E., BUSHAW-NEWTON, K.L, HORWITZ, R.J., BEDNAREK, A.T., CHARLES, D.F., KREEGER, D.A. AND VELINSKY, D.J., 2002. Dam removal: Challenges and opportunities for ecological research and river restoration. *Bioscience*, 52, 669-681.

HART, D.D. AND POFF, N.L., 2002. A special section on dam removal and river restoration. *Bioscience*, 52, 669-681.

HEINZ CENTER, 2002. *Dam Removal. Science and Decision Making*. The Heinz Center, Washington, 236pp.

HILL, M.J., LONG, E.A. AND HARDIN, S., 1993. Effects of dam removal on Dead Lake, Chipola River, Florida. Apalachicola River Watershed Investigations, Florida Game and Fresh Water Fish Commission. Cited in: Bednarek, A.T. 2001. Un-damming rivers: A review of the ecological impacts of dam removal. *Environmental Management*, 27, 803-814.

HJORTH, P., 2001. *Operation, Monitoring and Decommissioning of Dams.* World Commission on Dams. Thematic Review IV.5.

JOHNSON, S.E. AND GRABER, B.E., 2002. Enlisting the social sciences in decisions about dam removal. *Bioscience*, 52, 731-738.

KEMP, P.S., RUSSON, I.J., WATERSON, B., O'HANLEY, J.R. AND PESS, G.R., 2008. *Recommendations for a "coarse-resolution rapid-assessment" methodology to assess barriers to fish migration and associated prioritization tools.* Stirling, Scottish Environment Protection Agency (SEPA), 143pp.

KEMP, P.S. AND O'HANLEY, J.R., 2010. Procedures for evaluating and prioritising the removal of fish passage barriers: a synthesis. *Fisheries Management and Ecology*, 17, 297-322.

LARINIER, M., 2001. Environmental issues, dams and fish migration. In: Marmulla, G. (editor), *FAO Fisheries Technical Paper 419. Dams, Fish and Fisheries. Opportunities, Challenges and Conflict Resolution.* FAO, Rome, 45-89.

LONGSTAFF, T., 2010. *An assessment of barriers to fish passage in the Upper River Lee.* A report on a placement with the Environment Agency in fulfilment of the requirements of the MSc in Aquatic Resource Management of King's College London, 156pp.

MACKLIN, M.G. (1996) Fluxes and storage of sediment-associated heavy metals in floodplain systems: assessment and river basin management issues at a time of rapid environmental change. In: Anderson, M.G., Walling, D.E. and Bates, P.D. (editors) *Floodplain processes.* John Wiley and Sons, Chichester, pp. 441-460.

MAGILLIGAN, F.J. AND NISLOW, K.H., 2005. Changes in hydrologic regime by dams. *Geomorphology*, 71, 61-78.

NILSSON, C.C., REIDY, A., DYNESIUS, M. AND REVENGA, C., 2005. Fragmentation and flow regulation of the world's large river systems. *Science*, 308, 405-408.

PIZZUTO, J., 2002. Effects of dam removal on river form and process. *Bioscience*, 52, 683-691.

RIVER RESTORATION CENTRE (RRC), 2006. *Notes on options for habitat enhancement of the river Browney, Langley Park following a site visit (May 2006).* 14pp.

RIVER RESTORATION CENTRE (RRC), 2009. *Restoring houting passage article* (RR News, Issue 34, 2009, 1-3) [Online] www.therrc.co.uk/newsletters/rrn_34.pdf

RIVER RESTORATION CENTRE (RRC), 2010a. *Practical River Appraisal Guidance for Monitoring Options (PRAGMO) Shopham Loop Case Study.* RRC, 2010.

RIVER RESTORATION CENTRE (RRC), 2010b. *Practical River Appraisal Guidance for Monitoring Options (PRAGMO).* [Online] www.therrc.co.uk/rrc_pragmo.php.

RIVER RESTORATION CENTRE (RRC), 2011. *Practical River Restoration Appraisal Guidance for Monitoring Options (PRAGMO)* [Online] http://www.therrc.co.uk/rrc_pragmo.php

ROBERTSON, C.T., 2005. *Conservation of endangered Atlantic salmon in Maine.* PhD thesis, Department of Zoology, University of Toronto, Canada. Cited in: De Leaniz, C.G., 2008. Weir removal in salmonid streams: implications, challenges and practicalities. *Hydrobiologia*, 609, 83-96.

SHAW, E., LERNER, D. AND LANGE, E., 2010. Where weirs were: A look at the benefits of weir removal. RRC Annual Conference Proceedings, 9pp.

SHAW, J., SKINNER, K., HUMPHREYS, A. AND SEWELL, R. 2011. In-stream barriers assessment – A multidisciplinary approach. Proceedings paper for the RRC 2011 Annual Conference. 10pp.

STANLEY, E.H., LUEBKE, M.A., DOYLE, M.W. AND MARSHALL, D.W., 2002. Short-term changes in channel form and micro-invertebrate communities following low-head dam removal. *Journal of the North American Benthological Society*, 21, 172-187.

TILT, B., BRAUN., Y., HE, D., 2009. Social impacts of large dam projects: A comparison of international case studies and implications for best practice. *Journal of Environmental Management*, 90, 249-257.

TULLOS, D., TILT.B. AND LIERMANN, C.R., 2009. Editorial, Introduction to the special issue: Understanding and linking the biophysical, socioeconomic and geopolitical effects of dams. *Journal of Environmental Management*, 90, 203-207.

WATERHOUSE, E.K., 2004. *A detailed and critical analysis of the Kirkstall Valley Park white-water canoe course proposals.* A report to Leeds City Council. MSc Thesis, University of Leeds.

WIK, S.J., 1995. Reservoir drawdown: Case study in flow changes to potentially improve fisheries. *Journal of Energy Engineering*, 121 (2), 89-96.

Bibliography

These titles are particularly useful bibliographic sources, representing the core foundation of information relating not only to weir removal, but also to the potential benefits of reinstating/keeping weirs for hydropower and alternatives to weir removal such as fish bypass channels and constructed passes, which are not within the remit of this report.

AMERICAN RIVERS, FRIENDS OF THE EARTH AND TROUT UNLIMITED, 1999. *Dam removal success stories. Restoring rivers through selective removal of dams that don't make sense.* 176pp.

DEFRA/ENVIRONMENT AGENCY, 2003. *River Weirs – Good Practice Guide*. Defra/Environment Agency Flood and Coastal Defence R&D Programme. R&D Publication W5B-023/HQP, 137pp.

ENVIRONMENT AGENCY, 2010. *Mapping hydropower opportunities and sensitivities in England and Wales*. Technical Report, 74pp.

FAO/DVWK, 2002. *Fish passes – Design, dimensions and monitoring*. Rome, FAO, 119p.

GRAF, W.L., 2002. *Dam Removal Research. Status and Prospects*. The Heinz Center, Washington, 165pp.

HEINZ CENTER, 2002. *Dam Removal. Science and Decision Making*. The Heinz Center, Washington, 236pp.

RRC, 2002.*Manual of Techniques*. Arca Press Ltd.

Appendix A - Online survey

The list of projects entered online by survey respondents

River Darent Restoration Project at Lullingstone
River Beult SSSI Restoration Project
Tal-y-fan Wier removal
Arborfield
Plough Lane
Butterhill Mill
Weir Road
North Manchester Rivers Restoration Project
PhD Project: Application of the Ecosystem Service to Aid Weir Management Decision Making
Colnbrook FAS
Poyle Weir Removal
Hartham Weir
Mersey Life Little Bollington Fish Pass
Lambourn at Woodspeen/Hunts Green
Lambourn at Newbury
Kennet at Avington
Wye and Usk Foundation Project
Heatley Fish Pass Project
Padiham Weir
Skelton Beck weir modification
Easeneye Weir
Bonesgate River Restoration

Survey also filled in (where possible) for Case Study B: Collapse of Thorverton Mill weir on the River Exe as there were no specific on-the-ground weir works to appraise. This was done retrospectively as it was identified as a good example of weir collapse in addition to the other three chosen (see Appendix B).

Benefits of weir removal

Improved fish passage
Naturalization of river
Improved fish passage
Improved connectivity
Permanent solution
Local awareness of issues and good examples
Weir removal. Primary benefit the increased connectivity of the river benefitting some fish species
Long length of river improved
Working with partners on a project
Restoring river continuity for all species, sediment and habitats
The reach aims to provide an example of weir removal restoring chalk stream habitat
Restore flow regime upstream and downstream and get sediments moving more naturally
More natural channel, with associated habitat improvements
Naturalised flow velocities - habitat benefits
Fish passage
Enhance fish stocks (sea trout)
Reduce flood risk
Reduced impoundment/sediment deposition
Naturalisation of flow
Essential to WFD objectives
Other departments assistance, ie. fisheries and flood defence worked together
Fish pass installation: Alternative to weir removal that also improves connectivity but still retains the benefits associated with the weirs existence, eg. As a resource for canoeists
Improved connectivity
Increased local awareness of the river and fish
Direct improvement in habitat quality at weir site
The project kick-started natural processes in this reach of the river
Remove blockage to fish
Reduced maintenance (desilting and weed-cutting)
Fish passage
Channel connectivity
Remove poaching hot-spot
Removal of maintenance liability
Reduced flood risk
Fish stocks
Improvements in recreational/angling/visual interest
Weir removal: Personal opinion that there often is an aesthetic improvement in the river goes from looking like a canal to a dynamic system. My subjective opinion and needs research to see if this is a more generic opinion.
Encourage deposition/erosion and habitat creation
Removal of obstruction to fish passage
Ranunculus growth

Difficulties of weir removal

Determining ownership
Landowner agreement
Ensuring contractors achieve your aims
Lack of examples and methodology to do such works in more urban catchments
Conflict with hydropower plans
Physical constraints, ie. access of large plant to banks
Weir removal; Lack of understanding about the overall ecological impact. Removal often assumed to be of benefit.
Silt management
Detail design and project management by technical staff
External acceptance of the project from local peoples, angling groups
Benefits are limited by a much bigger weirs immediately upstream
Cost or machinery and removal of masonry
Local resident like the sound of water over the weir!
Landowner approval/agreement
Politics
Unknowns in regards to geomorphology impacts of high energy watercourses ie. Movement of sediment, bed lowering etc
Timescales for completion
Fish passage improvements: the vast cost of fish passes considering the shere numbers of weirs in catchments such that of the Don (>200)
Erosion (bed and bank) control
Very public space, public opinion may differ from projects objectives
Cost of large weir removal/modification
Had to convince the angling club, so the design of the scheme was a compromise: we left parts of the weir still in place so that they could be sandbagged back up again if their were future problems with flow
Access in some cases
Technical design
Cultural/fisheries interests
Funding
Benefits or not in regards to flood risk issues
Archaeological interests
Lack of catchment wide data on the distribution and dimensions of weirs making it difficult to plan strategically
Expertise on the design of fish passes
Due to nature of concrete bed and banks notching may be more appropriate in some cases than full removal
Approvals/budgets

Appendix B - Case studies

The case studies in this appendix are intended to illustrate a range of weir removal and lowering projects and an instance of weir collapse that bring out many of the lessons incorporated into this report.

A – River Calder, Padiham Weir – deconstruction of a weir and the installation of a rock ramp style pass to improve fish passage.

B – River Exe, Thorverton Mill Weir – weir collapse increased the rate of active geomorphic change, and sediment movement has become an issue requiring continual action.

C – River Lambourn SSSI – removal of a number of impounding structures, and river restoration techniques, have improved the naturalness and ecology of the river.

D – River Loddon, Arborfield – nature-like bypass and weir lowering project to create new natural channels around obstructions and provide an example to inform future work.

CASE STUDY A: Deconstruction of Padiham Weir on the River Calder

Pre-deconstruction

The River Calder is a major tributary of the River Ribble and it has recently experienced thriving coarse fish populations attributed to water quality improvements and strategic fish restocking. There are salmon and sea trout populations below the weir and anecdotal evidence that both species attempt to pass the weir. The River Calder above Padiham weir is heavily urbanised. Around 30 weirs were identified by the Environment Agency and the Ribble Catchment Conservation Trust (RCCT) through the 2005 strategy, River Calder Fish Migration Project, which identified the location of these and prioritised them in terms of those which require modification. Many constructed for industrial purposes in the past are now redundant. Padiham Weir is one of the lower most and significant barriers to fish migration, and altering the weir was identified as essential for the success of the project. Figure A.1 is a photograph of Padiham Weir prior to the deconstruction project.

The Padiham weir deconstruction project is one in a long line of plans to improve the hydromorphology of the reach and to improve fish passage, as well as improve the naturalness and ecology of the river. The geology of the River Calder river valley at Padiham weir is characterised by slow permeable, seasonally and naturally wet, acid loams and clayey floodplain soils.

Figure A.1: Prior to the deconstruction project, January 2008.

Water Framework Directive catchment context

The River Calder aims to achieve good ecological and chemical status by 2027, and being designated as heavily modified means that its current overall potential can only be moderate. A summary of this information is provided in Table A.1 (Defra/Environment Agency, 2009). Mitigation measures which have been identified are also included, but none are currently in place.

Table A.1: Waterbody status and objectives

Waterbody ID	GB112071065490
Waterbody name	River Calder
UK grid reference	SD 82832 35072

Current overall potential	Moderate
Status objective(s)	Good ecological and chemical status by 2027
Protected area designation	Freshwater Fish Directive, Nitrates Directive and the Urban Waste Water Treatment Directive
Hydromophological designation	Heavily modified
Reason for designation	Flood protection, urbanisation, water regulation (impoundment release)
Ecological status	Moderate (uncertain - WoE)
Chemical status	Fail (quite certain)
Biological elements	Fish: Poor (very certain)
	Invertebrates: Good
	Phytobenthos: Moderate (very certain)
Mitigation measures	
Educate landowners on sensitive management (urbanisation)	Not in place
Ensure that the thermal regime in waters downstream of the impounding works is consistent with good status conditions	Not in place
Ensure that good status of dissolved oxygen levels is being achieved downstream of the impounding works	Not in place
Provide flows to move sediment downstream	Not in place
Ensure there is an appropriate baseline flow regime downstream of the impoundment	Not in place
Maintain sediment management regime to avoid degradation of the natural habitat characteristics of the downstream river	Not in place
Re-engineer the river where the flow regime cannot be modified	Not in place

Aims and objectives

The primary objectives of the project have been to:

- improve passage without the use of an artificially constructed pass;
- improve fish stocks.

Secondary objectives aimed to:

- increase in-stream diversity;

- naturalise the flow regime;
- introduce a pool-riffle sequence and a rock cascade;
- additionally benefit eel and elver passage;
- create spawning habitat for salmon and trout;
- stabilise sediment transport.

This was to be achieved by reducing the height of the existing weir by a maximum of 1.4m and by installing three new bed check weirs each at a height of 300m downstream.

Baseline studies

Ten years in the planning, the Padiham weir project presented a major challenge to all parties involved in finding a workable and sustainable long-term solution. Proposals on how to alter the impoundment included a pool-and-traverse scheme, a fish pass and even a white-water canoe course but due to lack of funds, local opposition and concerns over contaminated sediment, each project failed to materialise. Following surveying and an investigative report (Environment Agency, 2010), it was decided that the weir could and indeed should be partially deconstructed. This allowed the RCCT and the Environment Agency to focus their attention on targeting further impounding obstructions upstream on the Calder, and Pendle Water, which has good water quality and habitat for salmonids.

Flood risk assessment

The River Calder presents a significant flood risk to Padiham, Barrowford and Blackburn as demonstrated by events in 2000 and 2002, which affected tens of residential and commercial properties in these areas (Environment Agency, 2009). The Ribble Catchment Flood Management Plan recognises the need for the Environment Agency to follow up previous studies investigating the feasibility of flood risk management measures, particularly in areas of restricted flows (Environment Agency, 2009). These include areas affected by culverts and weirs.

The FCRM team were consulted during the initial design reviews and the whole concept of the bed checks and partial removal of the weir was developed jointly by the Area team, National Capital Programme Management Service (NCPMS) and the National Engineering and Environmental Consultancy Agreement (NEECA). A visual inspection was carried out by consultants to assess the flood risk implications of deconstructing the weir. These predicted a likely improvement in flood risk for at least one business due to elimination of the weir backwater effect approximately 500m upstream of the weir.

Other benefits of reducing the weir and raising the downstream bed level were to reduce loading on the existing piles/banks. The sheet piles downstream of the weir were in poor condition and several were severely corroded at water level. By raising the bed level this effectively reduced the height of ground retained by the piles and reduced the associated load. Leaving the 'ends' of the weir intact provided ongoing support to the wing walls effectively providing a buttress to the existing sheet pile walls at the edge of the river.

Modification of structures

The Ribble Catchment Conservation Trust led the work to open up a further fifth of the Ribble catchment to salmon, trout, grayling and eel for the first time in many years. Above Padiham four more weirs were addressed. A large weir on the main stem Calder at Montford was removed by the Trust in March 2010. On Pendle Water at Barrowford, two small weirs were made more passable by installing check weirs, and a technical fish pass was installed on a larger weir that could not be removed for cultural reasons. Padiham weir was deconstructed gradually to ensure that safety was not compromised and to see the impact of the works at varying stages. Figure A.2 (before) and Figure A.3 (during and near completion) show the progression of the project. Reducing the weir’s presence has dramatically reduced the backwater effect on the flow by up to a quarter of a mile. In a practical sense, the weir has been removed and fish have free passage through the reach. There were multiple reports of adult salmon and sea trout in the River Calder above Padiham during the winter of 2010-11.


Figure A.2: Padiham Weir prior to removal. Left – looking across the river from the left bank. Right – looking at the structure from downstream (March 2010).

Photographs courtesy of: Jack Spees, the director of the Ribble Trust


Figure A.3: Padiham deconstruction. Left – during removal (April 2010). Right - nearing completion (May 2010).

Photographs courtesy of: Jack Spees, the director of the Ribble Trust

Monitoring

The amount of available documentation (Table A.2) makes Padiham Weir a valuable site to appraise the impact of a project of this nature on the hydromorphology and biology of the stream. This information was collected through the online survey (Chapter 2.3).

Table A.2: Available documentation

	No	Yes	Yes (output available)	Planned	Unknown
Job specification	X				
Stated objectives			X		
Topographic survey			X		
Pre-project data					X

Photos pre-works			X		
Hydromorphological assessment		X			
Habitat survey	X		X		
Water quality data		X			
Post-project data		X			
Fisheries survey			X		
Invertebrates survey			X		
Macrophytes survey			X		
Photos post-works			X		

Hydromorphological and biological impacts

Table A.3 and A.4 describe the impact of the weir deconstruction works on the hydromorphological and biological aspects of the River Calder for the Padiham reach. This information was collected through the online survey (Chapter 2.3). Please note that ‘not applicable’ is stated if that particular aspect was not identified as a direct objective of the scheme.

Table A.3: Hydromorphological impact

	Negative	Negligible	Beneficial	Extremely positive	Not applicable
Reach profile			X		
Sediment transport			X		
Water level			X		
Flood risk			X		
Water quality					X
Flow regime			X		
Backwater effect					X
Navigation					X

Table A.4: Biological impact

	Negative	Negligible	Beneficial	Extremely positive	Not applicable
Floodplain ecology		X			
In-stream diversity			X		
Fish stocks					X

Fish passage				X	
Elver/eel passage				X	
Fry refuge habitats					X
Spawning habitats				X	
Phytoplankton					X

Conclusions

As the deconstruction works have only recently finished (mid-2010), it is currently unclear how effective the project will be hydromorphologically as it takes time for the river to adapt to its new conditions. There have been two bankfull flow events since the weir was removed, and the channel through the work area has remained stable. Short-term hydromorphological and ecological objectives appear to have been achieved. A number of additional benefits have also been realised. One good example is the social side of river restoration where at a local school, Hameldon Community College, the children had the opportunity to learn about migratory fish and how to prepare a report.

Lessons learnt

Padiham weir removal has been one of the Ribble Catchment Conservation Trust's greatest success stories, where fish of all species and ages are now able to pass the weir in all flow conditions. The increased number of fish in the upper reaches should in turn lead to a greater variety of wildlife such as kingfishers and otters, creating a much more ecologically diverse and sustainable ecosystem. Greater investment from fishing clubs/riparian owners is anticipated, with a knock-on effect for the local community in terms of a much more attractive environmental asset in which to fish, walk and bird spot.

References

- Defra/Environment Agency (2009). *Water for life and livelihoods: River Basin Management Plan North West River Basin District.* Accessed online www.environment-agency.gov.uk/research/**planning**/33106.aspx 20 August 2010.
- Environment Agency (2009). *Ribble Catchment Flood Management Plan Summary Report.* December 2009.
- Environment Agency (2010). *Determination report. Padiham weir*. 16pp.

Bibliography

Ribble Catchment Conservation Trust: Padiham Weir. Accessed online 20 August 2010. http://www.ribbletrust.org.uk/education/padiham-weir/

River Restoration Centre, 2010.Calder Improvement Project, Case Study Series. Accessed online 27 October 2010. http://www.therrc.co.uk/rrc_case_studies1.php?csid=61

Reviewed by Kyle Young (Environment Agency, North West Region)

CASE STUDY B: Collapse of Thorverton Mill weir on the River Exe

Pre-collapse and current issue

The River Exe drains a catchment area of approximately 600km² upstream of the Thorverton gauging station weir and the geology is predominantly Devonian sandstones and Carboniferous Culm measures while the land use is a mixture of moor land, forestry and agriculture with a few small urban areas. The Environment Agency gauging station at Thorverton was built in 1956, the measuring weir being added in 1973. This was constructed principally for two reasons. Firstly, to determine the timing and volume of upstream reservoir water release to maintain an adequate level of low flow discharge in the River Exe ($3.16m^3s^{-1}$) and secondly, to act as a flood warning within the catchment downstream of the weir (Halcrow, 2010). The gauging station is an important hydrometric monitoring site; however, for many years the quality of the stage-discharge relationship data appears to have been adversely affected by active in-channel sedimentation processes.

Following the collapse of Thorverton Mill weir, 300m upstream of the gauging station weir, in 1999, large gravel deposition meant that existing stage-discharge relationships no longer applied. Prior to the breach, the Thorverton Mill weir pool used to cause ponding approximately 500m upstream, reducing local velocity and storing bed material. Two disused railway bridge footings used to be submerged by the ponded water, but post-collapse, these were exposed causing a split flow which directed at a rapidly eroding river bank (Figure B.1). The effects of the increased velocities were noticed at least 400m upstream at Up Exe Mill (RRC, 2008). Nearly 5,500 tonnes of gravel has been dredged in the last twenty years, with a notable increase in the quantity since the 1999 collapse (Table B.1). However, a more sustainable approach is needed in the long-term.

Figure B.1: An eroding river bank in the Thorverton Mill reach; photograph taken at low flow (©Halcrow, 2010).

Table B.1: Gravel removal at the gauging station weir (Halcrow, 2010).

Date	**Observation**	**Mass of gravel removed (tonnes)**
1990/91	Gravel removed	100
August 2002	Shoal visible at weir	-

September 2003	Shoal removed	800
July 2004	Shoal removed/scraped to right bank side	300
January 2005	Shoal visible at weir	-
August 2005	Shoal removed	1,000
August 2006	No shoal	-
December 2006	Shoal visible at weir	-
June 2007	Shoal removed	600
November 2007	No shoal	-
December 2007	Shoal visible at weir	-
July 2008	Shoal removed	2000
September 2008	Shoal visible at weir	-
January 2009	Shoal visible at weir and larger than previous	-
June 2009	Shoal regraded and gravel moved upstream	600

Water Framework Directive catchment context

The River Exe at Thorverton is classified in the waterbody ID GB108045015050 (Exe) and a summary of the current status and objectives are summarised in Table B.2. The objective is to achieve good ecological status and good overall status by 2027, and good chemical status by 2015 (Defra/Environment Agency, 2009).

Table B.2: Waterbody status and objectives

Waterbody ID	GB106039023220
Waterbody name	Exe
UK grid reference	SU 94960 20424
Current overall status	Moderate
Status objective (overall)	Good by 2027
Status objective(s)	Good ecological status by 2027, good chemical status by 2015
Protected area designation	Drinking Water Protected Area, Freshwater Fish Directive, Nitrates Directive
Hydromophological designation	Not designated A/HMWB
Ecological status	Moderate (uncertain - WoE)
Chemical status	Good
Biological elements	Invertebrates: High Macrophytes: Good

	Phytobenthos: Moderate (very certain)
	Fish: Not assessed
Hydromorphological supporting conditions	Quantity and dynamics of flow: Does not support good (uncertain)
	Morphology: Supports good
Mitigation measures	Not stated

Baseline studies

The aim of a series of geomorphic investigations (Babtie, Brown and Root (BBR), 2004; Halcrow, 2010) has been to appraise the condition of the reach in the context of the wider river corridor in order to understand the current dynamics, and to determine the best approach and business case for managing sediment in the long term. Halcrow (2010) was commissioned following the advice of BBR (2004) which stated that it may take a number of years to decide whether the rate of sediment transfer remains as high in the medium term (five years) following collapse, or whether it is simply a short-term geomorphic response.

In summary, the reports suggest that bank erosion along the wider river corridor is neither a severe issue nor is it contributing to the significant sediment load; it is instead episodic transfers of sediment from in-channel bars, which have formed at long-standing depositional locations both upstream and downstream of the gauging station weir, which are the main inputs of coarse sediment (Figure B.2). However, it is unclear from hydrological records whether sediment transfer is the product of multiple low-magnitude high-frequency events, or the consequence of fewer high-magnitude low-frequency events (Halcrow, 2010). While the sediment is reused positively to repair riverbed spawning areas upstream, with the remainder provided to local riparian landowners, the current situation means that the site requires frequent and active maintenance.

While the long profile of the River Exe is 0.003m m^{-1} (typical for a lowland meandering channel), the step-drops in the bed profile due to weirs and a dismantled railway pillar within the Thorverton reach cause significant discontinuity, which has led to much of the instability and high geomorphic activity (Halcrow, 2010). When grade controls are lost (the collapsed weir in 1999), channel hydraulics change significantly and flows become faster and more turbulent. Sediment that would have previously accumulated behind the Thorverton Mill weir has moved downstream as the river adjusts to the post-collapse geomorphic conditions. Where grade controls remain downstream, sediment accumulation has increased causing a local reduction in bed gradient. Sediment supply and storage areas indicate how sediment dynamics may continue to alter over time, and mapping these is critical to establishing the balance of the fluvial system.

Flood risk assessment

No flood risk assessment was carried out following the collapse of the Thorverton Mill weir, however, an assessment would be required if any work is undertaken in future.

Figure B.2: In-stream bar and flow dynamics; photograph taken at high flow (December 2009 ©Halcrow, 2010).

Monitoring

The documentation on the site/reach (Table B.3) shows how much information has been collated to assess the weir collapse and its implications on the hydromorphological, ecological and biological state of the watercourse. This information was collected through the online survey (Chapter 2.3). Many of the ecological aspects are included within routine monitoring for the River Exe. The work that the Environment Agency has done in relation to this breach has been carried out with a view to protecting the downstream gauging station rather than because of a direct interest in the weir breach or a restoration scheme. As such, columns for post-project data and post-project photos are absent in the table below as the work has been responsive to the issue at hand.

Table B.3: Available documentation at Thorverton weir.

	No	Yes	Yes (output available)	Planned	Unknown
Job specification			X		
Stated objectives			X		
Topographic survey			X		
Pre-project data			X		
Photos pre-works			X		
Hydromorphological assessment			X		
Habitat survey			X*		
Water quality data			X		
Post-project data	N/A				
Fisheries survey			X		

Invertebrates survey			X		
Macrophytes survey			X		
Photos post-works	N/A				

* ERS invertebrate surveys on shingle banks below weir breach.

Hydromorphological and biological impacts

The hydromorphological and biological impacts of any action taken to deal with the active sedimentation are unclear. In due course, however, it will be interesting to see which of the proposals is taken forward, and whether any will lead to more stability in the long-term.

Conclusions

Halcrow (2010) identified a method for appraising all possible options and formulating the best action (Figure B.3). For the weir breach at Thorverton Mill, this led to the formulation of three possible options:

1. Do nothing – assume that all sediment management works at the existing gauging station will cease, and that no capital works will be undertaken. This is likely to result in a degradation of both the stage-discharge data accuracy and gauging station serviceability.

2. Do the minimum – continue the current maintenance regime; this scenario assumes that current levels of gravel extraction are continued.

3. Capital works – reinstate a multithread channel adjacent to Up Exe Mill to create a dynamic sediment sink which will also modify flow patterns to reduce right bank erosion. This would involve the trial planting of vegetation on the channel bed, to assess the viability in stabilising existing sediment sources. This would offer environmental improvements, in addition to aiding the management of sediment within the channel.

While the appraisal mechanism ranks the options in a preferred order, an element of cost-benefit and expert judgement should also play a role, and at the time of this report going to print, it was still undecided which option would be chosen. The key point to take from this is that by addressing a weir-related concern holistically, the best approach is most likely to be determined following this or a similar process.

For the Thorverton situation, it is likely that until funding, Environment Agency priorities and enthusiasm from all parties can be agreed on, and gravel will continue to be managed at the gauging station. It is a very expensive problem to solve and a cross-departmental approach within the Environment Agency plus engagement and agreement with other partners, parties and private landowners is required.

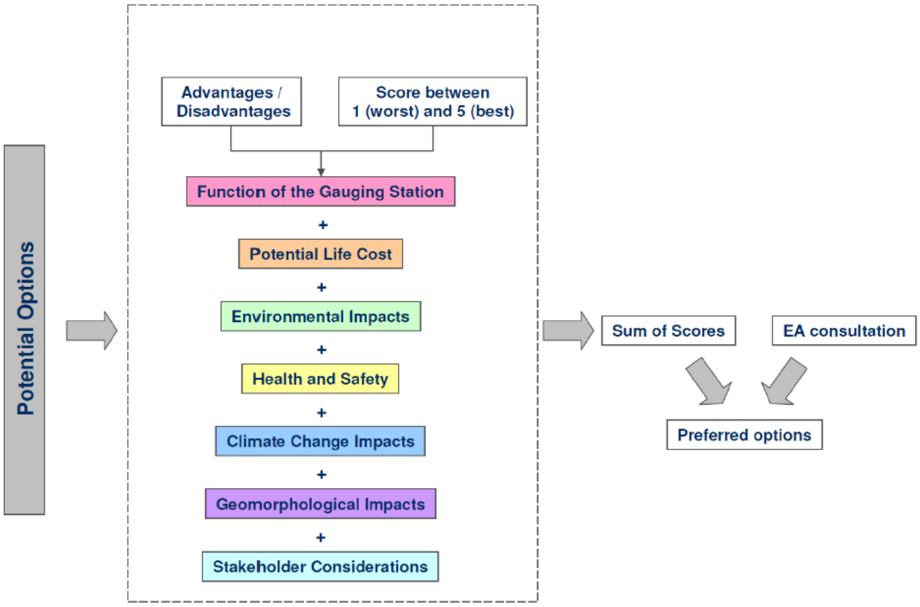


Figure B.3: Options appraisal methodology (Halcrow, 2010).

Lessons learnt

The weir breach has led to significant gravel deposition at the gauging station after every major spate, which must then be removed to ensure accuracy of the gauging station. This is both expensive and unsustainable. There are problems with a lack of knowledge of ownership of historic structures, and opinions on removal vary. Some owners are keen to reinstate the structure, while the Environment Agency may be keen to take advantage of the benefits of the breach: improved fish migration, more natural flows and better management of, for example, the Wimbleball Reservoir fisheries bank upstream of Thorverton. Bed material, mainly gravels, taken to reinstate spawning areas in the headwaters of the Exe has been another positive impact.

Major shifts in the erosion patterns upstream of the weir have caused problems for landowners, and have led to Flood Defence Consent applications to try to control the river to return to a similar regime (as prior to the breach), and it can be difficult explaining to landowners why this is not something that is recommended from a biodiversity/conservation perspective.

References

Babtie, Brown and Root, 2004. River Exe at Thorverton Gauging Station: Geomorphological Assessment. *B*WA 00014127, Revision R03, August 2004.

Defra/Environment Agency, 2009. *Water for life and livelihoods: River Basin Management Plan South West River Basin District.* Accessed online on 10/3/2011.

Halcrow, 2010. *Environment Agency Thorverton Gauging Station Sedimentation Issues Report*. September 2010.

RRC, 2008. Mill Weir Breach on the River Exe. *River Restoration News*. p6.

Reviewed by Tim Shipton (Environment Agency, South West Region)

Pre-restoration

The River Lambourn is designated as a Site of Special Scientific Interest (SSSI) and Special Area of Conservation (SAC) for its characteristic chalk stream features, species-rich and diverse in-stream flora, abundant aquatic invertebrates, and mixed stock fishery. However, it has been classified by Natural England as in unfavourable condition. One of the main causes for this is the presence of large structures, especially in the lower units of the river from Hunts Green, down to its confluence with the Kennet at Newbury.

These structures have severely impounded the river, slowed down velocities and led to significant siltation and the over-wide and over-deep conditions found. The river has also been subject to significant land drainage and flood defence engineering operations in the past. As a result of this the river habitat was very poor, with the loss of characteristic aquatic macrophytes – especially *Ranunculus* species. Populations of wild fish were also poor. In Newbury, movement of fish from the River Kennet was impossible due to the impoundment and associated weirs in the grounds of the Newbury Manor Hotel (Figure C.1). The structure at Woodspeen was also a total blockage to fish movement.

Figure C.1: A structure at the Newbury Manor Hotel (left) and at Woodspeen (right).

Water Framework Directive catchment context

The two projects highlighted in this case study, the Hunts Green to Woodspeen restoration (SU 436698) and the Newbury Manor Hotel projects (SU 487674), are both reaches within water body ID GB106039023220, Lambourn (Source to Newbury). A summary of the current status and objectives are summarised in Table C.1. The overarching objective of this specific water body is to achieve 'good' overall status by 2015.

Table C.1: Waterbody status and objectives

Waterbody ID	GB106039023220
Waterbody name	Lambourn (Source to Newbury)
UK grid reference	SU 35058 77015
Current overall status	Moderate
Status objective (overall)	Good by 2015

Status objective(s)	Good ecological and chemical status by 2015
Protected area designation	Freshwater Fish Directive, Natura 2000 (Habitat and/or Birds Directive), Nitrates Directive
Hydromophological designation	Not designated A/HMWB
Ecological status	Moderate (uncertain - WoE)
Chemical status	Good
Biological elements	Fish: Moderate (very certain) – Good by 2015 Invertebrates: High – High by 2015 Macrophytes: Moderate (uncertain) – Good by 2015
Hydromorphological supporting conditions	Quantity and dynamics of flow: Supports good Morphology: Supports good
Mitigation measures	Not stated

Aims and objectives

Huntsgreen to Woodspeen reach:

- Remove the major structure at Woodspeen that was impounding the river upstream for approximately one kilometre. This would significantly drop levels upstream and increase the gradient and therefore the water velocities.
- Substantially narrow the river upstream of the structure to maximise the benefits of removal, and use locally sourced gravel to raise the bed and return a good quality gravel substrate to the river. *Ranunculus* growth, in-stream diversity and fish cover are expected to develop when the stream naturalises following restoration. The estate intends to stop stocking fish and ultimately become a 100 per cent wild trout fishery.
- Access for angling is an important component and consideration of the project.

Newbury Manor Hotel reach:

- Significantly drop the impoundments in the grounds of Newbury Manor Hotel (immediately upstream of the confluence with the River Kennet) to lower depths and increase velocities upstream.
- Achieve fish passage in this reach for the first time in decades.
- Natural regeneration of the reach for a year, prior to restoration works upstream of the hotel involving river narrowing and raising of the bed.

Baseline studies

As part of the UK Government's Public Service Agreements targets for recovering status on SSSI rivers, a review of the Water Level Management Plans of the River Kennet and Lambourn was undertaken. The review identified all of the structures causing significant impacts on the rivers and the actions necessary to remove them. This ranged from major changes in operation, to removal or bypass. River restoration in the upstream channel would also be an important aspect to restore a more natural flow regime.

Modification of structures

At Woodspeen, the structure was evidently causing a significant impoundment effect for almost a kilometre upstream. The flow upstream was largely static and vegetation had settled on the surface of the water, making it appear much more like a pond than a chalk stream. Immediately following removal, the depth of the water lowered and an increased velocity led to an increase in flow diversity. As Figure C.2 shows, the visible change is dramatic and this illustrates why restoration work was necessary to restore the channel upstream and why natural recovery was not possible in this case, especially with a private landowner of the adjacent gardens at the heart of this project.

Figure C.2: Upstream of the Woodspeen structure before (left) and following removal (right).

Figure C.3: The Woodspeen structure during (left) and following removal (right).

At Newbury, the weir in Figure C.4 and the side spill upstream were both lowered by 0.5m, with the latter being transformed into a pool and traverse fish pass (Figure C.5). Two side gates were also altered and a rotting penstock was replaced with a new penstock and a Larinier fish pass. As with Woodspeen, this has significantly improved velocities upstream (data evidence) and fish numbers have improved, demonstrating that the passes have worked. Restoration works followed a year later to allow natural geomorphic adjustment following the removal of structures.

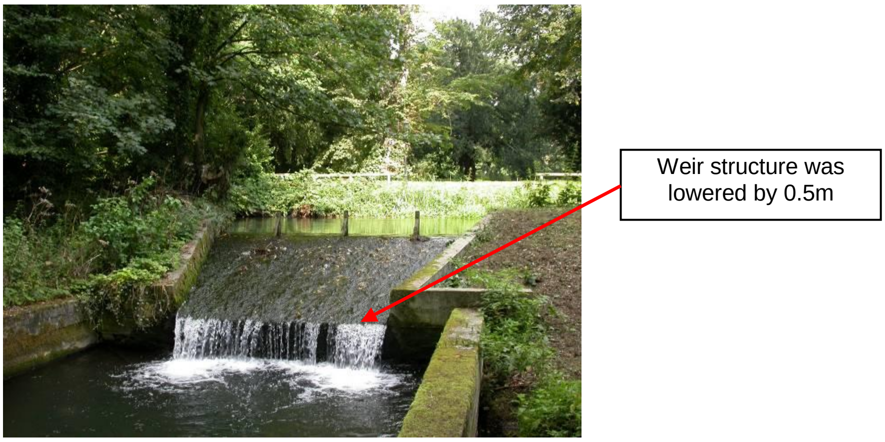


Figure C.4: One of the structures in the grounds of Newbury Manor Hotel before weir lowering.

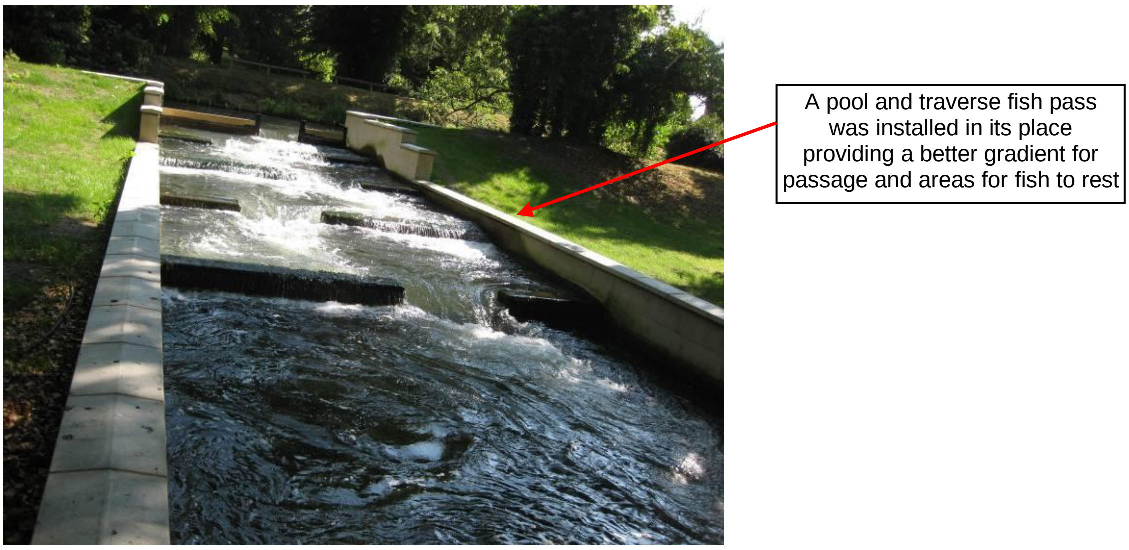


Figure C.5: Following lowering, and the installation of a pool and traverse fish pass.

River restoration

In both projects, river restoration was a key component in ensuring the rehabilitation of the Lambourn to its former state. The works that were undertaken in Newbury aimed to build on the first phase works – the lowering of weirs and provision of fish passage, and were carried out following the modification of structures. The project at Newbury was given longer to naturally recover.

In the case of Woodspeen, restoration works started shortly after the structure was removed due to the dramatic visual change in the stream. This was requested by the landowner. The river was narrowed using a combination of techniques. Coir matting was folded over posts that were strategically positioned in the stream and these were backfilled with material gained from regrading the banks. Silt from the riverbed was reused in this instance and plant material was eventually transplanted from the original river margins onto the new margins. Increased velocities mean that the gravel bed is now self-cleansing, *Ranunculus* has returned and fish populations are healthy. Naturally re-vegetating woody mattress was installed in an interspersed manner upstream and substantial amounts of gravel were used to raise the bed. These works collaboratively reconnected the river with its floodplain and improvements have been seen along the whole reach.

Upstream of the Newbury Manor Hotel, in phase two of the project, brushwood mattress and large woody debris was used to encourage meandering and diversity in stream features. Native Kennet gravels were imported in a variety of sizes considered suitable in terms of substrate composition (O'Grady, 2006) and velocity (Wild Trout Trust, 2006) to optimise spawning conditions for trout and grayling. Larger bottom gravels were overlaid with a natural dressing substrate to give a clean gravel appearance. Tree cover was cut back to increase light for *Ranunculus* and this was recycled for reuse. The brushwood mattresses were filled using material sourced at site. Whole trees were used for the large woody debris, which were driven into the bank and post and wired in place (Figure C.6).

Flood risk assessment

The flood risk associated with both projects was assessed using hydraulic models that had already been created for the river. In both cases the effects of the work were assessed as being insignificant both upstream and downstream. In lowland watercourses, the likelihood of increasing flood risk by lowering or removing in-stream structures is small.

At Woodspeen, the depth in the channel upstream of the structure was reduced by over a metre. The structure was a constant risk during high flows, as it blocked up regularly putting Woodspeen House at risk of flooding. The riverbanks upstream were elevated due to deposition of historic dredging material on the river margins. This reduced the inundation frequency of the water meadows and the lateral connectivity of the river to the floodplain in all but the largest of rainfall events. The physical restoration works lowered these banks, re-connecting the floodplain and providing important floodplain storage.

In Newbury, the lowering of the structures in the grounds of the hotel lowered the river levels by approximately 75cm. The works to the structures improved conveyance under the A4 road bridge at the bottom of the reach, which was the chief blockage under high flows. Upstream, the raising of the bed and narrowing using the brushwood mattresses, meant that much of this improvement to flood risk was removed. However, overall it is likely that there is a minor net improvement to flood risk.

Figure C.6: Large woody debris installed at 45º to improve flow diversity.

Monitoring

The extent of available documentation to assess the impact of the structure removal and the restoration scheme at Woodspeen and the Newbury Manor Hotel is shown in Table C.2 and C.3 respectively. This information was collected through the online survey (Chapter 2.3). While the available documentation may appear lacking, the sites are relatively well monitored compared to other weir lowering/removal projects. Therefore, both represent good examples showing the qualitative success of the schemes, even if quantitative data is not available.

Table C.2: Available documentation at Woodspeen/Hunts Green.

	No	Yes	Yes (output available)	Planned	Unknown
Job specification			X		
Stated objectives			X		
Topographic survey	X				
Pre-project data	X				
Photos pre-works			X		
Hydromorphological assessment			X		
Habitat survey	X				
Water quality data	X				
Post-project data	X				
Fisheries survey	X				
Invertebrates survey	X				
Macrophytes survey	X				
Photos post-works			X		

Table C.3: Available documentation at the Newbury Manor Hotel.

	No	Yes	Yes (output available)	Planned	Unknown
Job specification			X		
Stated objectives			X		
Topographic survey	X				
Pre-project data	X				
Photos pre-works			X		
Hydromorphological assessment			X		
Habitat survey	X				

Water quality data	X				
Post-project data	X				
Fisheries survey			X		
Invertebrates survey	X				
Macrophytes survey	X				
Photos post-works			X		

Hydromorphological and biological impacts

The following tables describe the impact of the schemes on the hydromorphological and biological aspects of the River Lambourn at Woodspeen/Hunts Green (Tables C.4 and C.6), and the Newbury Manor Hotel (Tables C.5 and C.7). This information was collected through the online survey (Chapter 2.3). Please note that 'not applicable' is stated if that particular aspect was not identified as a direct objective of the scheme.

Table C.4: Hydromorphological impact at Woodspeen/Hunts Green.

	Negative	Negligible	Beneficial	Extremely positive	Not applicable
Reach profile				X	
Sediment transport				X	
Water level				X	
Flood risk			X		
Water quality				X	
Flow regime				X	
Backwater effect				X	
Navigation					X

Table C.5: Hydromorphological impact at the Newbury Manor Hotel.

	Negative	Negligible	Beneficial	Extremely positive	Not applicable
Reach profile				X	
Sediment Transport				X	
Water Level			X		
Flood Risk		X			
Water Quality			X		X
Flow Regime			X		
Backwater Effect				X	

Navigation					X

Table C.6: Biological impact at Woodspeen/Hunts Green.

	Negative	Negligible	Beneficial	Extremely positive	Not applicable
Floodplain ecology			X		
In-stream diversity				X	
Fish stocks				X	
Fish passage				X	
Elver/eel passage					X
Fry refuge habitats			X		
Spawning habitats				X	
Phytoplankton					X
Macrophytes				X	
Phytobenthos				X	
Benthic invertebrates			X		

Table C.7: Biological impact at the Newbury Manor Hotel.

	Negative	Negligible	Beneficial	Extremely positive	Not applicable
Floodplain ecology					X
In-stream diversity			X		
Fish stocks			X		
Fish passage			X		
Elver/eel passage					X
Fry refuge habitats			X		
Spawning habitats				X	
Phytoplankton					X
Macrophytes			X		
Phytobenthos			X		
Benthic invertebrates			X		

Conclusions

Based on expert opinion alone, both projects have been extremely successful in meeting hydromorphological and biological targets. The structural removal or lowering of impoundments combined with follow-up river restoration has had a beneficial impact on the stream condition, illustrating the effectiveness of structural removal/lowering. Not only has it improved stream connectivity and passage, the enhancement work has also improved the wider condition of the channel's geomorphology and ecology.

The Huntsgreen to Woodspeen project has been tremendously successful and the river keeper on reporting increased fish numbers believes that stocking may not be necessary beyond 2010. The in-stream habitat has been remarkably restored and counts of redds in 2009 were very good. *Ranunculus* growth has developed in areas where it had not been observed before and the re-establishment of naturalised flow velocities through enhancement has optimised habitat benefits. The river Lambourn has been reconnected to its floodplain with the associated benefits for a variety of wetland species, and the borrow pits left following the removal of gravels are to be reshaped and included in an estate wetland scheme.

At the Newbury Manor Hotel, both phases complement each other in not only improving re-connectivity and fish passage but also through river restoration, restoring the natural river regime and habitat condition. Fish surveys are being carried out annually, and over time, will aim to demonstrate the true extent of the works.

Lessons learnt

The difficulties encountered were found to be securing landowner approval/agreement, technical design and approval and budgetary constraints; three issues that were commonly identified by others involved in projects. While a project manager needs sufficient resources and expertise to run a project of this scale and the project may have to be split into multiple phases to achieve this, he or she must also have a good working relationship with local landowners and other groups with a vested interest in the project. While the range of monitoring documentation isn't extensive due to resource availability, the series of pre-, during and post-project photographs demonstrate the development of both reaches after the removal of the structure, and following river restoration.

At Woodspeen in particular, the river keeper's observations have provided an extremely useful anecdotal account. Where time and resources are constrained, fixed point photography and observation combined with expert judgement can provide a useful insight for project appraisal and may be sufficient. In future, there should be more focus on setting SMART objectives which would retrospectively have offered a more detailed quantitative assessment of the success of the techniques applied, and as such would help build a more detailed evidence base beyond observation.

References

- Defra/Environment Agency, 2009. *Water for life and livelihoods: River Basin Management Plan Thames River Basin District*. Accessed online www.environment-agency.gov.uk/.../**thames**_swmi_cons_1953946.pdf on 25 August 2010.

- O'Grady, M., 2006. Channels & Challenges. Enhancing Salmonid Rivers, Irish Freshwater Fisheries Ecology & Management Series: Number 4, Central Fisheries Board, Dublin, Ireland.

- Wild Trout Trust, 2006. *The Wild Trout Survival Guide*. Habitat and fishery management guidelines produced by the Wild Trout Trust.

Reviewed by Paul St Pierre (Environment Agency, Thames Region)

CASE STUDY D: Nature-like bypass and weir lowering on the River Loddon at Arborfield

Pre-restoration

The River Loddon rises within the urban area of Basingstoke and flows into the River Thames near the village of Wargrave. The river in total is 28 miles or 45 kilometres in length draining an area of approximately 1,036km. Upstream of the Arborfield site, the River Blackwater joins the Loddon close to Swallowfield, which adds substantially to its flow. While chalk underlies parts of the upper of the catchment area, at Arborfield the surface geologies consist of Reading Beds and London Clay.

Prior to restoration, a series of flow control structures (weirs and sluices) impounded upstream water levels and habitat for approximately four kilometres in length (Dennis, Martyn and Clough, 2008) leading to slower, deeper and more uniform flow conditions. The channel displayed restrained morphological diversity with associated impacts on biological conditions.

Phosphate levels are high in a number of rivers in the region, including the River Blackwater, and high levels of nutrients can lead to excessive plant growth, in turn impacting upon the stream biodiversity. Sources of nutrients in this catchment include effluent from sewage treatment works and agricultural pollution (Environment Agency, 2010). An illustration of the reach's location and proposed rehabilitation work areas is shown in Figure D.1.

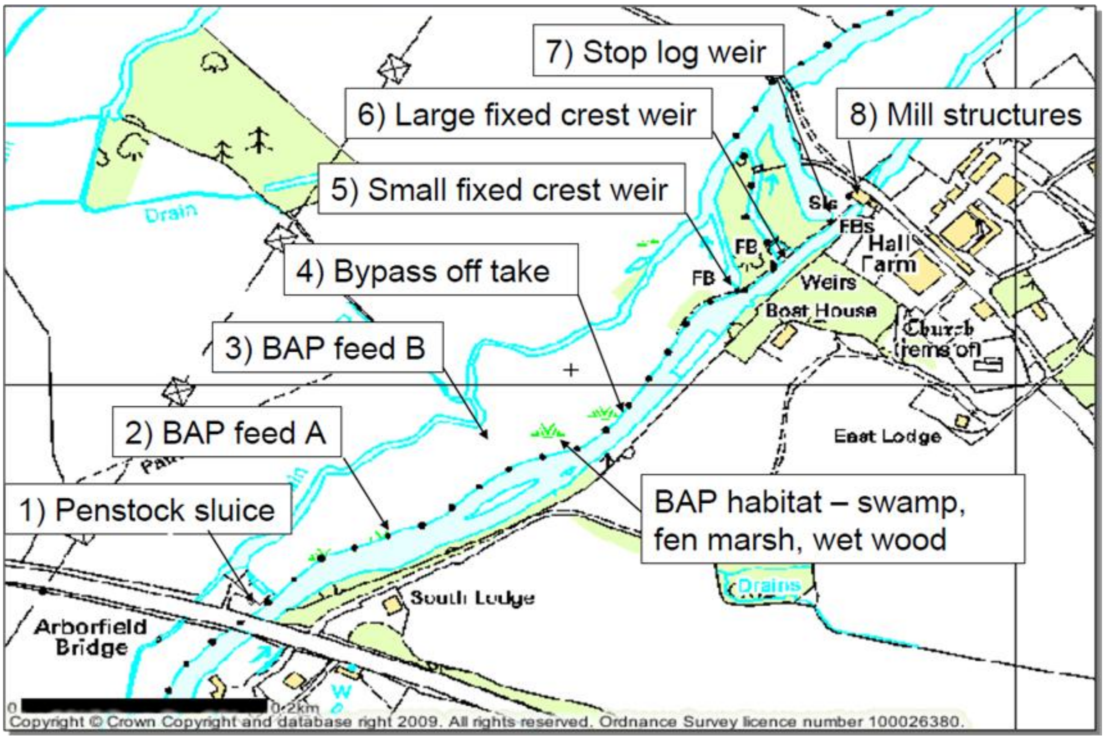


Figure D.1: Location of the Arborfield restoration reach and proposed rehabilitation work areas.

Water Framework Directive catchment context

Arborfield is located within water body GB106039023160 Loddon (Swallowfield to River Thames confluence). The current overall status of the water body is moderate. The objectives for the waterbody are to achieve good ecological and chemical status by 2027; justification for not achieving good status in the one supporting element which is not currently good, phosphate, is that it is disproportionately expensive to do so (Defra/Environment Agency, 2009). A summary of the waterbody condition and status objectives are provided in Table D.1. The hydromorphological designation is that this water body is not heavily modified and the target is to reach Good Ecological Status by 2027. The reasons for failure include physical habitat degradation effluent amongst others.

Table D.1: Waterbody status and objectives

Waterbody ID	GB106039023160
Waterbody name	Loddon (Swallowfield to River Thames confluence)
UK grid reference	SU 77347 71890 (Arborfield site is SU 74845 68159)
Current overall status	Moderate
Status objective (overall)	Good by 2027
Status objective(s)	Good ecological and chemical status by 2027
Protected area designation	Freshwater Fish Directive, Nitrates Directive
Hydromophological designation	Not designated
Ecological status	Moderate (very certain)
Chemical status	Fail (uncertain)
Biological elements	Fish: Moderate (very certain) – Good by 2015
	Invertebrates: High
Hydromorphological supporting conditions	Quantity and dynamics of flow: Supports good
	Morphology: Supports good
Mitigation measures	Not stated

Aims and objectives

The Arborfield Nature-like Bypass and Weir project aims and objectives are provided in Table D.2. The project was first suggested in 1992 but it has taken a further 19 years to finally complete the project works (Table D.3).

Table D.2: Aims and objectives

	Aim	Objective
1	Allow free fish passage	Construct naturalistic bypass channel
2	Improve WFD fish status from moderate to good	Create 100m length of gravel spawning ground and provide fish passage around longstanding barrier
3	Restore impounded habitat	Lower weirs to restore flow and two shallow gravel riffles
4	Create Biodiversity Action Plan habitats	Construct two wet feeds and create over 1ha of BAP habitat

5	Provide case study	Monitor before and after work and report on findings
6	Put people and communities at the heart of what we do	Engage key stakeholders ensuring excellent communication
7	Improve site health and safety	Reduce frequency of footpath flooding and improve access, create bypass and formalise wet habitat feeds
8	Reduce local flood risk	Lower/modify four out of five weirs to reduce breaching

Table D.3: Timeline of the Arborfield site

Arborfield Timeline	
1997	Pre-feasibility
2003	Weir boards removed and put back
2007	Principle partnership agreement
2008	Initial outline design, emergency weir work
2009	Defra funding
2010	Detailed design and Thames Water Weir Work
2010-11	Construction of 200m nature-like bypass channel and BAP feeds

Baseline studies

During the design of the restoration scheme, a variety of in-stream surveys, river habitat mapping, fish, invertebrate and plant surveys, river corridor surveys and spot flow measurements were carried out by the Environment Agency and APEM consultants to appraise the site conditions prior to works commencing. The reach was unsafe to access partly due to bank breaching. BAP habitat incorporating a mosaic of swamp, fen, marsh and wet woodland was deteriorating as a result of emergency work to lower water levels, with a detrimental impact on fish spawning and nursery grounds. The River Loddon is reportedly known to have shoals of bream, chub, roach, dace and very large specimen barbel. Spawning grounds for certain WFD failing fish species (dace, roach, chub and barbel) were limited in this area to immediately downstream of the up and downstream weirs. It was predicted that weir works undertaken by Thames Water, which owns the immediate site, would increase accessible riffle habitat in the upstream reach from one major spawning ground to two or as many as four. In 2008 and 2010, chub spawning activity was observed on one of these riffles since water levels were lowered.

Flood risk assessment

An assessment carried out using the latest version of the Lower Loddon TUFLOW-ESTRY model (referred to hereafter as the 'Existing Lower Loddon Model') was delivered to the Environment Agency in January 2009 and described in the 'Lower Loddon Flood Modelling Update'.

The work considers the following incremental changes to the existing hydraulic model:

- Updates to the existing model to incorporate more accurate information available on the Hall Farm complex since production of the catchment scale model and recent changes to weir levels through emergency works.
- Incorporation of the proposed Thames Water works to notch two weirs and the impact this has on flood levels.

- Incorporation of the proposed bypass channel and the impact on flood levels. Discussion as to the effect of this impact, and presentation of model results.

Summary of Bypass Channel Findings:

When considered as a 'complete scheme' including the Thames Water works at the Hall Farm complex, the proposed fish pass results in a general reduction in in-channel modelled flood levels in and around the Hall Farm complex.

This reduction in peak flood level is most strongly experienced upstream of the fish pass itself and on the main Loddon channel upstream of Hall Farm. This is because a new flow path is being provided by the fish pass channel, which does not otherwise exist apart from when levels exceed the bank levels on the left bank leading up to the Hall Farm complex.

The impact on in-channel flood levels reduces as flood magnitude increases. This is because the fish pass channel has only a modest capacity in comparison to the flood flows predicted for more extreme flood events, and flows for these events tend to wash through and bypass the structures and banks of the Hall Farm complex.

The above statements are true when assessing the impact of the fish pass in isolation. When comparing against flood levels predicted in the Thames Water works model, the magnitude of change is slightly reduced for all scenarios, however, and a very minor increase (5mm) is predicted for a 1 in 5 year event downstream of the Hall Farm complex.

The effect of the fish pass channel on floodplain levels is not as straightforward, with minor impacts seen, both raising and lowering flood levels upstream and downstream of the Hall Farm complex. The magnitude of these changes is small, and a number of them occur in areas that are either remote or hydraulically disconnected from the changes occurring at the Hall Farm complex. On this basis, such impacts cannot accurately represent the hydraulics of the proposed changes, and are assumed to be shown as a result of normal model instability and variability. It is to be expected that a large catchment model of this size displays some degree of instability when dealing with significant flood flows. Furthermore, the changes made to the model to facilitate the representation of the proposed fish pass channel alter the model in such a way, by editing the main in-channel cross sections, as to influence this variability.

There are limited potential 'receptors' of flooding that could be affected by any increase in flood risk arising as a result of the proposed works. A small group of properties on the northern side of Arborfield Road, which are currently predicted to be surrounded by the flood extents for all events, were considered in this assessment. By interrogating the output from the hydraulic model, it has been shown that the proposed works result in a very minor decrease in peak flood level for all events considered. It should be noted however that these reductions are all less than 10mm. Despite this, the Environment Agency may choose to obtain surveyed threshold data for this small group of properties for comparison against modelled levels.

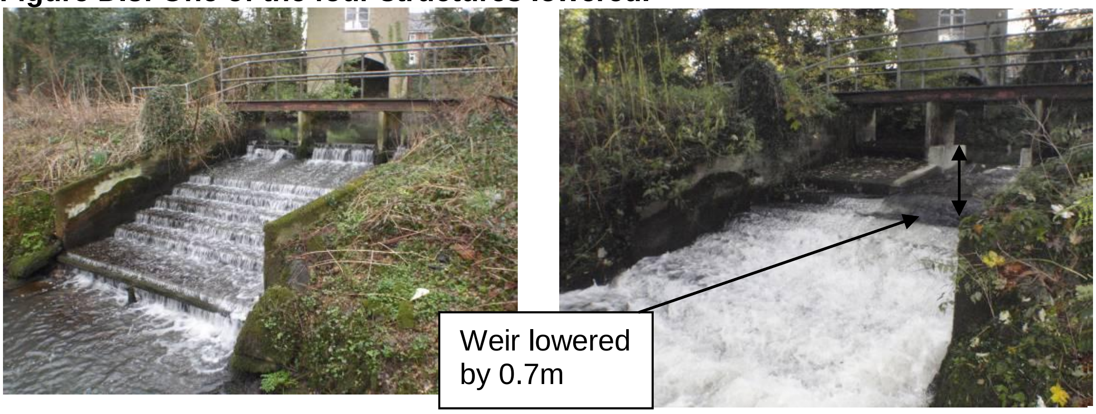
Figure D.2: before and after weir lowering – new run/riffle 2.9km upstream of the weirs used by spawning chub (inset).

Modification of structures

The Arborfield structures presently constitute the greatest barrier to fish migration in the Loddon catchment. The complex consists of five main structures of weirs and sluices. Fish pass solutions have been constructed on other barriers along the River Loddon over the last 20 years; these are believed to permit fish passage for a number of species under at least some flow conditions. However, allowing free passage at Arborfield would remove the last major obstacle to fish, particularly sea-trout, migrating to the upper Loddon chalk reaches and to the Blackwater and Whitewater. It will also improve coarse fish access to important spawning areas upstream of Arborfield.

In 2010, Thames Water carried out weir lowering and repair work to four out of five structures to lower upstream water levels by 0.7m (Figure D.3), reduce bank breaching and the frequency of water overtopping the perched upstream bank. This has improved safe access whilst restoring flows to approximately 4km of previously impounded habitat upstream.

Figure D.3: One of the four structures lowered.



River restoration

In addition to weir works, the Environment Agency, Cain Bio Engineering and Atkins have finished building a nature-like fish and wildlife bypass channel. The completion for this project phase is the end of 2011. This has created 200m of new channel connecting up and downstream of the weirs. The bypass will deliver free migration status and create 80m of new gravel fish spawning ground (run/riffle habitat and nursery habitats) to help reach good ecological status under the WFD.

The bypass forms two parts to deal with a head loss of 1m. In the top 50m, a pool riffle fish pass has been constructed with a 0.6m drop (Figure D.4). This involves an inlet structure, seven drops and six pools (0.03-0.1m per drop) within an embankment designed to protect most flows. The embankment (max 0.8m) tails off to ground levels at 50m and 80m for the right and left hand bank respectively.

Figure D.4: Before and after pool riffle pass and inlet.

Construction improvements further downstream to shallow the bed, allow channel adjustment and improve connectivity in the 150m nature-like bypass have reduced the head loss from 0.9m to 0.6m in the first 50m. This should lead to improved passability from the shallower gradient and enhanced connectivity to the wet woodland (Figure D.5). Within this 50m section, on site construction has changed the gradient compared to the detailed design from 1:56 to 1:83. The average flow velocity is between 0.25 -0.36ms^{-1}in the pools at Q95 and Q20 respectively.

For the remainder of the 150m nature-like pass (0.4m drop), the average gradient is approximately 1:215 and the average velocity in channel at Q95 has been estimated to be 0.42$m\ s^{-1}$, and at 0.65ms^{-1} at Q20. The assumed Manning's n (0.075) provided significant scope for in-channel habitat features including tree roots, coarse and large woody debris. Existing fallen trees including large fallen willow were carefully hand dug around to retain valuable wildlife habitat (photo D.5) and to work with natural erosion processes.

Figure D.5: Woody debris and in-channel habitat features.

A mosaic of habitats indicative of local reference conditions were constructed including in-stream vegetated islands, backwaters, sheer cliff, ledges and an embankment bay. Figure D.6 illustrates online flowing pond, vegetated island, woody debris and potential fish spawning run.

Figure D.6 Mosaic of habitats in the nature like bypass channel.

Monitoring

A wealth of project appraisal surveys (Table D.4) and documentation (Table D.5) makes Arborfield a valuable resource to assess the impact of weir lowering on the hydromorphology and biology of the stream following works. The information in Table D.5 was collected through the online survey (Chapter 2.3). Initial post-project back pack electrofishing survey was completed in under 1/3rd o the channel and revealed over 100 fish of seven species including chub, gudgeon, perch, stone loach and bullhead.

Table D.4: A list of Arborfield project surveys, reports and appraisal documents.

1987 – 2010 Project Appraisal	
1987 - 2008	Fisheries surveys, Environment Agency
2004	River Corridor Survey, Angela Walker
2005	Spot flow measurements, Environment Agency
2007	Long surveys, cross sections, Environment Agency
2007	Invertebrate surveys, Environment Agency Ecological Appraisal and APEM
2007	Plant surveys, Environment Agency Ecological Appraisal and APEM
2007	Aerial photos five cm resolution, APEM
2007	River Corridor Surveys, APEM
2007	Phase 1 Woodland Habitat Mapping, Angela Walker
2008	River Habitat Mapping and Predicted Habitat Change, APEM
2008	Water level data up and downstream of weirs
2008	Arborleigh match catch data for 1997 to 2007
2008	Thames Water emergency work
2008	Spot flow measurements after emergency work, Environment Agency
2008	Targeted Environment Agency fisheries surveys up and downstream of the weirs
2009	Spawning ground assessment, Environment Agency
2009	Report on large woody debris, Vaughan Lewis (WAEC)
2009	Protected species surveys, Atkins
2009	Fixed point photography pre/post Thames Water emergency works
2010	Bathymetry and sediment sampling, APEM

2010	Thames Water weir lowering
2010	Impact of large woody debris on flow and hydromorphology (MSc)

Table D.5: Available documentation.

	No	Yes	Yes (output available)	Planned	Unknown
Job specification		X			
Stated objectives			X		
Topographic survey			X		
Pre-project data			X		
Photos pre-works			X		
Hydromorphological assessment			X		
Habitat survey			X		
Water quality data					X
Post-project data				X	
Fisheries survey			X		
Invertebrates survey			X		
Macrophytes survey			X		
Photos post-works			X		

Hydromorphological and biological impacts

The following tables, collected through the online survey (Chapter 2.3), describe the impact of the schemes on the hydromorphological and biological aspects of the River Loddon for the Arborfield reach (Tables D.6 and D.7). Please note that 'not applicable' is stated if that particular aspect was not identified as a direct objective of the scheme.

Table D.6: Hydromorphological impact

	Negative	Negligible	Beneficial	Extremely positive	Not applicable
Reach profile			X		
Sediment transport			X		
Water level			X		
Flood risk			X		
Water quality					X
Flow regime type/ hydromoprhology				X	

Backwater effect				X	
Navigation					X

Table D.7: Biological impact.

	Negative	Negligible	Beneficial	Extremely positive	Not applicable
Floodplain ecology					X
In-stream diversity			X		
Fish stocks			X		
Fish passage				X	
Elver/eel passage			X		
Fry refuge habitats			X		
Spawning habitats				X	
Phytoplankton					X
Macrophytes					X
Phytobenthos					X
Benthic invertebrates					X

Conclusions

Aspects of the scheme including the bypass channel were in construction as this report was finalised; however, it is clear that following weir works, the outlined objectives have been achieved from a hydromorphological perspective. Geomorphic alteration is likely to occur in the short-medium term as the channel adjusts to its new conditions, and ecological development will take a considerable length of time. A more detailed explanation for flow, morphology and biology outcomes is provided below.

1) Flow restoration (3&4 hydromorph)
From initial observation, weir lowering has resulted in the restoration of flows throughout a 4km stretch of the River Loddon and on the River Blackwater approximately 400m upstream of the confluence of the two rivers. This restoration may be accounted for by high points in the bed level over the long section (riffle habitat). The bed morphology now appears to dictate upstream stage (level) at low flow. Before weirs were lowered, the impact of the Arborfield impoundment extended upstream to a shallow section downstream of the next upstream impoundment at Sheepbridge (4.9km). Since weir lowering took place, there are now three riffle locations upstream of the weirs that impact on upstream water levels at low flow. The distances of these riffles upstream of the weirs are 30m, 700m, and 2900m. Fisheries habitat mapping undertaken prior to weir lowering provides predicted changes following different weir lowering scenarios. Comparison of before and after changes will quantify the effect on pool, riffle, run, glide and eddy habitats.

2) Morphology
In the reach between Sheepbridge and Arborfield weirs, three riffles have occurred as a direct result of lowering of the impoundments. On two occasions since lowering was completed, chub were observed spawning on the riffle furthest upstream near the middle of the reach. Successful

hatching and recruitment has yet to be determined but it shows a promising sign for improving flowing water fish communities in this water body.

3) Biology
The 2008 baseline fisheries survey highlights good fish populations in diverse flowing water habitats associated with sections downstream of weirs (Sheepbridge and Arborfield) and in the Arborfield Millstream. Poor to moderate fish populations surveyed upstream of the weirs may indicate inefficient electro-fishing due to depth, but also points towards a lower biomass, density and diversity of fish species associated with impounded habitats. This is supported by angling catches in the stretch.

A number of additional benefits were realised during the life of the project including:

- working with local communities
- safer site access
- reducing and controlling upstream breaching
- creating Biodiversity Action Plans (BAP)
- improving fishing experience.

Financial support has been awarded from local and national sources to ensure a robust and repeatable dataset with which future comparison can be made and it will be of great interest to see how closely the finished scheme matches up with reports that have predicted, for example, how existing habitats and flow types will change.

Lessons learnt

1) Planning permission
This can take a long time for certain types of weir projects and should not be underestimated. Much of the monitoring has happened by chance, and this project illustrates the types of data that can be collected if a project start time is delayed or put back for whatever reason. Collecting data can also be an excellent way to overcome or query any foreseen issues or debates within the design of the project – and by working with students from Reading and Cranfield University, studies have helped improve understanding of what may happen following the works.

2) Designing and building – weir lowering and bypass
We engaged consultants on the Environment Agency Framework to deliver hydraulic modelling and detailed design for the nature like bypass channel. A good end product was delivered, but an opportunity remains for better understanding of environmental outputs required to deliver high quality restoration measures in light of WFD objectives. We should be setting the environmental targets for projects and design engineering requirements to achieve the solution. The result was an over-engineered design for the bypass channel project element that lacked a mosaic of ecological niches.

Time and cost savings are possible with improved communication between ecologists and engineers to bridge gaps in uncertainty and deliver high quality designs requiring little if any revision. Design liability is key. Therefore, future recommended options are 1) ensure contractors commissioned to design and/or build engage with ecologists earlier in the process. This may have avoided design liability issues (that have since been overcome) with the changes made and produced a detailed design in shorter time/cost. 2) Avoid being too prescriptive with detailed design for natural channel restoration. Set restoration targets (e.g. 100m of riffle run habitat) and leave scope for on site changes by experienced staff to avoid cost and time associated with designing and refining the end product to great detail.

3) Upstream water level reduction and mitigation
Weir removal or lowering projects should account for upstream changes to wetted width and depth via lowered water levels. This is to avoid ecological deterioration possible during short to medium term habitat adaptation. This issue of dropping water levels is the major concern of angling clubs involved with the Arborfield project.

Management measures should be employed to ensure variation in wetted width and depth, especially at historically dredged sites. These measures include retention of woody debris in various forms, narrowing and re-profiling to create a pool, riffle, run and glide sequence. This type of habitat restoration may be required to ensure the quality and quantity of ecological niches are maintained and improved. If mitigation is not used, adaptive morphological changes may take a long time to occur at the expense of the fishery/ecology especially if woody debris is removed during routine maintenance.

At Arborfield, the channel upstream of the weir structures was too wide for the new water level. Large, stable fallen trees provide a simple low cost solution to morphological adaptation on the basis they are assessed for flood risk on an individual/cumulative basis. Securing fallen trees on this stretch can double the water depth, due to bed erosion and offer significantly greater refuge for fish amongst other wildlife. Cumulatively, these habitats should increase the carrying capacity of the reach and achieve good ecological status for the failing fish element.

An MSc thesis was carried out to assess the impact of large woody debris on flood risk. This concluded that weirs were the key influence on upstream stage prior to lowering, followed by bed morphology and vegetation as a whole. The contribution of large woody debris to overall channel roughness is relatively small and as such is unlikely to cause significant flood risk.

4) Communication

Managing expectations with weir removal projects is key and requires consistent and regular communication with partners. The main issue raised during planning and construction relates to decreasing upstream water levels and effects on the fishery. Separation of perceived and actual problems is important to help determine if any management is required upstream of the weir to be lowered/removed.

5) Way forward

The nature like bypass is due to be completed by the end of 2011 and repeat monitoring will commence after completion of the works. This will assess progress against the objectives set to improve the ecological status of the water body and provide free fish passage.

A full analysis is planned during 2011 to 2012 covering:

- fisheries – surveys, catches, spawning and nursery, passage
- invertebrates – airlift and kick samples
- plants - MTR
- hydromorphology – geomorphological and bathymetric assessment, long and cross sections, habitat mapping, aerial photos, large woody debris
- levels – before and after.

6) Recommendations

- Environmental surveys for environmental projects. In the future it will become increasingly important to deliver projects at lower cost. It is therefore essential that the resource spent on environmental surveys is proportionate to the level of risk of negative impacts. Where the risk is likely to be low, finance could be saved by allowing experienced staff to assess the impacts without extensive surveys at high cost ,which may be unlikely to be repeated in future.
- Do communicate even when nothing is happening.
- Ensure consistent management advice to up- and downstream landowners, especially with regard to management of large woody debris.
- Managing woody debris can be a simple low cost technique to restore upstream habitats post weir lowering/removal.
- Ensure a robust ‘no surprises’ plan from project inception to exit to ensure no negative ecological or partnership effects.
- Design build may provide improved opportunities for continuity and save time/money.
- Plan projects for construction to avoid winter months.

References

Clough, S.C, Dennis, P and Martyn, D., 2008. *Predicting the consequences of weir removal for freshwater fish habitats. (unpublished)*

Defra/Environment Agency, 2009. *Water for life and livelihoods: River Basin Management Plan Thames River Basin District.* Accessed online www.environment-agency.gov.uk/.../**thames**_swmi_cons_1953946.pdf 12 August 2010.

Environment Agency, 2010. *Application for planning permission: Arborfield nature-like fish and wildlife bypass channel*. 21pp.

Martyn, D., 2010. Arborfield Nature-Like Bypass and Weirs Project Presentation, presented at the IFM Fish Lowland Passage Conference, March 2010.

Reviewed by Dominic Martyn (Environment Agency, Thames Region)

Appendix C - Glossary

Denil fish pass – A type of fish pass that uses a series of symmetrical close-spaced baffles in a channel to redirect the flow of water, allowing fish to swim around the barrier. It was developed in 1909 by Belgian scientist G. Denil and has since been adjusted and adapted. It is has become one of the most common fish passes used.

Eurytopic – A species or organism able to adapt to a wide range of environmental conditions.

Exotic species – Non-native plants or animals that have been introduced in areas where they do not naturally occur. These are introduced largely through human action either accidentally, or intentionally for agricultural or ornamental/aesthetic purposes. They may sometimes out-compete native species by reproducing faster, and thriving in the absence of natural predators.

Lentic – The ecology of natural communities relating to or living in still waters (for example lakes or ponds).

Lotic – The ecology of natural communities relating to or living in flowing waters (for example riverine environments).

Rheophilic – A species or organism that prefers to live in fast-moving waters.

We are The Environment Agency. It's our job to look after your environment and make it **a better place** – for you, and for future generations.

Your environment is the air you breathe, the water you drink and the ground you walk on. Working with business, Government and society as a whole, we are making your environment cleaner and healthier.

The Environment Agency. Out there, making your environment a better place.

Published by:

Environment Agency
Horizon House
Deanery Road
Bristol
BS1 5AH
Tel: 0870 8506506
Email: enquiries@environment-agency.gov.uk
www.environment-agency.gov.uk

Would you like to find out more about us, or about your environment?

Then call us on
08708 506 506* (Mon-Fri 8-6)

email
enquiries@environment-agency.gov.uk

or visit our website
www.environment-agency.gov.uk

incident hotline 0800 80 70 60 (24hrs)
floodline 0845 988 1188

* Approximate call costs: 8p plus 6p per minute (standard landline). Please note charges will vary across telephone providers

Environment first: This publication is printed on recycled paper.