

4 Fluvial ecology

4.1 Introduction

The term ‘fluvial ecology’ refers to the relationships between aquatic organisms and environments associated with rivers or streams. It has long been known that river channel morphology has a strong influence on riparian plant and animal communities. Hence, changes to the form and function of rivers invariably have knock-on effects on ecology.

Some of these changes are brought about by natural processes such as drought and flood. However, others are a direct result of human intervention, specifically those activities identified in this guide relating to reducing flood risk, or associated with water resources or hydropower schemes.

This chapter highlights the inextricable link between channel form and ecology. It identifies general design principles and engineering approaches that avoid substantial deviation from the natural ecological state or, if this is not feasible, that minimise ecological damage and identify options for mitigation.

It is important to recognise that, while engineering works in the aquatic environment inevitably pose potential risks to the fluvial ecology, sympathetically designed schemes can also offer opportunities for ecological enhancement and biodiversity gain. The key to realising these benefits is early identification of the opportunities for enhancement, so that these can be factored into the design from the start, rather than added later.

4.1.1 Role of river morphology

After water quality, river morphology is arguably the main driver influencing aquatic ecology in fluvial environments. This has long been recognised in fisheries ecology, where gradient and stream order have been used to classify river reaches in terms of the fish populations they hold (for example, *Huet's Classification*; Huet, 1949).

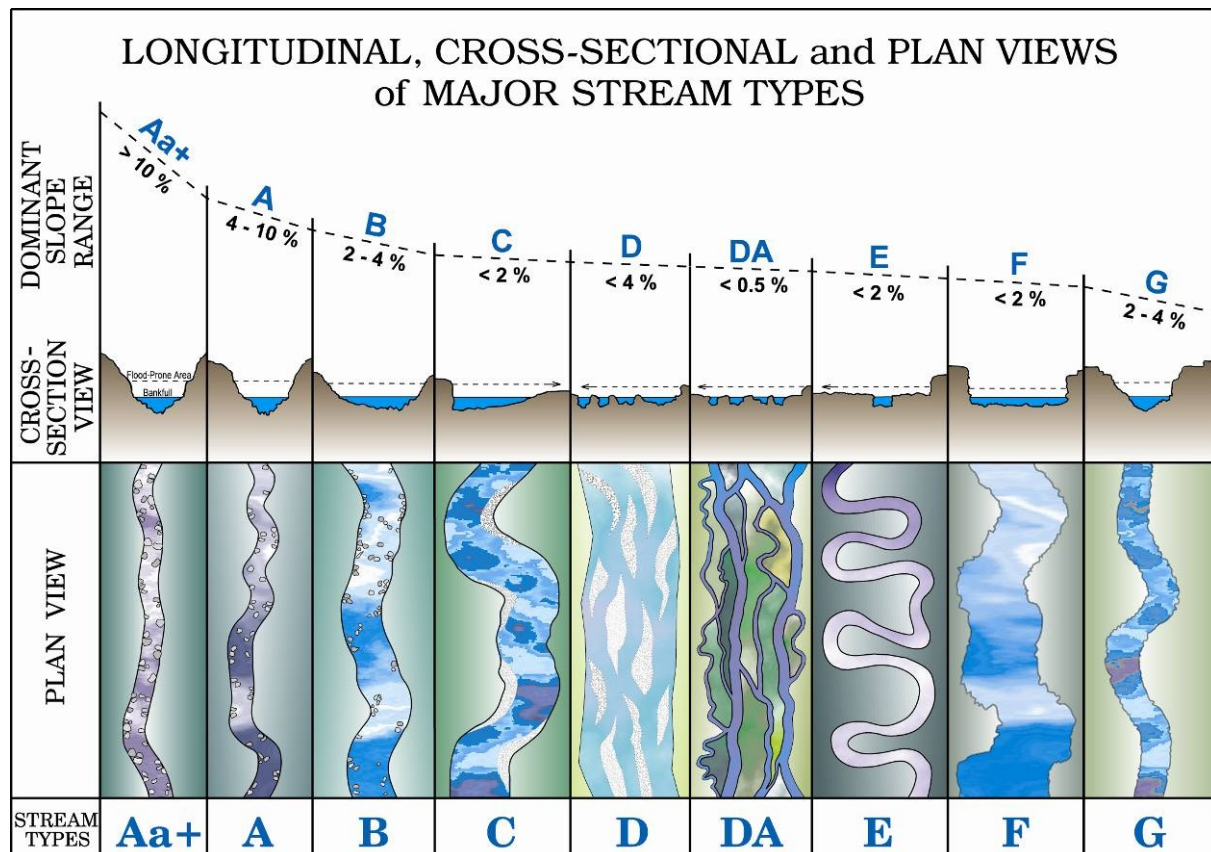
High gradient upland reaches (low stream order) are typically favoured habitats of salmonids (for example, trout and salmon), whereas the shallow gradient of lowland reaches (high stream order) are preferred by cyprinid fish (such as roach and bream). Other faunal communities (such as macroinvertebrates) vary considerably with changes in stream order. Similarly, considerable variation in aquatic flora can be observed with bryophytes tending to dominate low stream order, high gradient reaches and with a general shift to higher plants (such as crowfoots and pondweeds) in high stream order, lower gradient reaches.

Streams can be classified in many ways, with approaches often differing between countries. Although Water Framework Directive (WFD) typologies based on altitude, size and geology have been used in the UK, there has been recent development work to try out different methods. An example of this is Mimas, a national data centre based at the University of Manchester (SNIFFER, 2006), which is supported by the Joint Information Systems Committee and the Economic and Social Research Council. One approach to river typology is based on geomorphology and has been taken further by Rosgen (1994), who identified up to nine different stream types, with the broad differences resulting in contrasting habitats for aquatic ecology (see [Figure 4.1](#)).

River morphology defines these habitats, not only in terms of discharge (flow), velocity and depth of water, but also in the way that these physical parameters influence erosion, deposition, sediment size and sediment transport. These in turn influence the substrates available for algae, invertebrates and aquatic plant (macrophyte) colonisation. The latter have a profound influence on aquatic ecology in

terms of habitat creation or ‘niche’ availability. Put simply ‘if the niche isn’t there, the beasts won’t colonise’. This applies to fish, invertebrates and water plants, and to the terrestrial animals and birds that depend on them.

Figure 4.1 Broad level stream classification delineation showing longitudinal, cross sectional and plan views of major stream types



(Rosgen, 1996, reprinted with permission from Wildland Hydrology)

- Aa+ Very steep, deeply entrenched, low width/depth ratio and laterally contained
- A Steep, entrenched, cascading with step/pool streams
- B Moderately entrenched, moderate gradient, riffle-dominated channel
- C Low gradient, meandering, point-bar, riffle/pool with broad floodplains
- D Braided channel with longitudinal and *transverse bars* – very wide with eroding banks
- DA Multiple channels, narrow and deep, with extensive well-vegetated floodplains and *wetlands*
- E Low gradient, meandering riffle/pool stream with low width/depth ratio, high meander width ratio
- F Entrenched meandering riffle/pool channel on low gradients with high width/depth ratio
- G Entrenched 'gully' step/pool and low width/depth ratio on moderate gradients

4.1.2 Importance of ‘connectivity’

A river can be defined as a channel or corridor taking precipitation-derived water down a gradient towards the sea. With this in mind, the concept of ‘physical’ longitudinal connectivity is easy to grasp, as most of the water that initially starts off in the upper catchment ultimately ends up in the sea. However, river-borne sediments usually make an equivalent – albeit slower – seaward journey. Again, this has a profound influence on habitat availability and quality, as sediment forms a key component of many river habitats.

Many aquatic organisms make riverine migrations, either actively or by drifting with the current. Indeed, the lifecycle of some aquatic organisms relies on the use of different parts of the river system during specific life stages. In addition, the lifecycle of a number of migratory fish species (salmon and eel, for example) involves moving between riverine and marine environments. Consequently, the ‘ecological’ connectivity between reaches is of fundamental importance. Artificial barriers to longitudinal connectivity (for example, obstructions such as weirs) can have a devastating effect on aquatic ecology, removing species from a river section, or indeed catchment, with immediate effect. Similarly, natural barriers such as densely vegetated channels can act as a constraint to the movement of organisms within a watercourse.

Lateral connectivity is the connection of the river channel to adjacent wetlands, fringe habitats and riparian land. Adjacent wetlands serve a variety of important functions, not least by holding up floodwaters in natural flood retention areas or acting as simple ‘land sponges’. Although subject to some debate and considerable continuing research, such wetlands are thought to ‘smooth’ the ascending and descending limbs of the hydrograph and reduce flood peaks.

In addition to such hydraulic functions, lateral connectivity is also extremely important for aquatic ecology, with natural wetlands providing a vital habitat for many aquatic organisms. For example, ponds and wetlands adjacent to, and connected to, rivers provide fish species with areas of refuge that are important during periods of high flow.

The ideal scenario for such wetlands and offline habitats is for them to be connected permanently to the main river channel, as this facilitates colonisation by fish, plants and invertebrates. Additionally, they typically provide still-water conditions in which different aquatic and riparian plants (such as marginal reed-beds) can flourish. In turn, these support diverse invertebrate communities and offer a spawning medium and structural refuge for some fish species.

Wetlands also add considerable ecological value to the river ecosystem by providing an ideal habitat for wading birds and waterfowl, amphibians and aquatic mammals such as water voles. Indeed these wetlands are now regarded as nationally rare habitats in their own right and their substantial conservation value is promoted by organisations such as the Association of Rivers Trusts (<http://www.associationofriverstrusts.org.uk>) and Pond Conservation: The Water Habitats Trust (<http://www.pondconservation.org.uk>).

4.2 Learning from the past

Historically, the focus of fluvial design for flood risk management and water resources was rarely on ecological considerations. Diverse river features such as meanders, gravel shoals, pool sequences and even riparian vegetation, have all been considered a hindrance to the effective and efficient transport of water. However, the attitudes and values of society have changed dramatically over recent years, and the importance of conserving and enhancing fluvial ecology – while achieving other objectives such as effective flood conveyance – is now fully acknowledged.

Many riverine features of ecological value slow down the transport of water through the drainage system, causing backing up and hence higher water levels upstream, and an associated increase in flood risk. Removal of these features allows water to pass more quickly through the system and this was frequently undertaken to reduce flood risk upstream. Unfortunately, this practice often increases the flood risk downstream as floodwaters can arrive at bottlenecks more rapidly. In addition, such habitat complexities are essential requirements for aquatic ecological diversity and the consequence of over-engineered river channels can be an ecologically barren watercourse with little connection to the wider environment in which it lies.

Numerous opportunities are available to maintain natural habitat complexity and to retain the aquatic diversity of watercourses. Retention of the ecological diversity provided by riverine habitats is a key

requirement of general flood risk management practices. This requirement is emphasised in the Government’s *Making space for water* strategy (Defra, 2005), with such interests being balanced at the river basin level with WFD objectives, river basin management plans (RBMPs) and catchment flood management plans (CFMPs). When considering the selection of appropriate management practices, it is important to consider the stream classification (as described in Section 4.1.1) and the expected ecological communities at particular sites.

An extreme example of the ecological contrast resulting from different engineering and management practices has been observed in two rivers at Heathrow Airport. Known as the ‘twin rivers’, these channels have now been re-routed as part of the Terminal 5 development. Studies carried out prior to the diversion demonstrated the ecological consequences of different management practices (Box 4.1). The two channels had been heavily engineered in some parts (with culverts running under the runways) and left in a more natural condition in others, but essentially contained the same water in terms of quality and biochemistry. They therefore provided an ideal opportunity to assess the influence of physical habitat structure on riverine ecology.

Box 4.1 Ecological consequences of different management practices on the ‘twin rivers’, Heathrow Airport

Downstream
Open concrete channel

Upstream
Vegetated channel

In this concrete-lined reach, the fish biomass was less than 10 g/m².

In this more natural channel reach, without the concrete lining, the fish biomass was greater than 50 g/m². This section also supported a far greater diversity and abundance of aquatic invertebrates and macrophytes than the heavily engineered sections. The associated risk was that the vegetation would impede water movement and thus encourage sediment deposition, which would further reduce the channel cross section and increase flood risk.

The concrete trapezoidal channels, though very efficient in terms of water transport, could be considered relatively barren in terms of aquatic ecology; they supported a relatively low biomass of

fish compared with the adjacent river sections with more natural features. The ecological differences between the over-engineered concrete river channel and the more natural habitats immediately upstream were even more startling when it is considered that the rivers were actually 500-year-old artificial sluice-fed distributaries of the River Colne. In other words, well-constructed, ‘naturalised’ artificial river channels can perform perfectly well in terms of aquatic ecology with an appropriate diversity of in-stream habitat while still achieving the primary design objective of moving water from one place to another.

Similar effects to those observed in over-engineered channels can be seen in heavily dredged rivers, where riparian habitat (gravels, cobbles, sands, silts and vegetation) is removed from the channel. Once again, a lack of in-stream habitat resulting from channel-wide dredging has a detrimental impact on aquatic ecology. This not only applies to the width of the channel, but also to the affected reach. As a consequence, immigration routes for aquatic colonists may be constrained in a way not dissimilar to the removal of hedgerows and equivalent terrestrial wildlife corridors. In addition, the organisms found in these heavily dredged channels are likely to have migrated there from more natural areas elsewhere in the system. These organisms could therefore be considered transient features, being unable to complete their lifecycles in such a degraded habitat.

Vegetation removal is a common management practice to maintain channel capacity. Retaining some vegetation is important for all components of aquatic communities, so clearing only part of a vegetated channel is an ecologically sensitive management approach which provides a compromise between ecological considerations and water transport requirements.

Further examples of less ecologically sensitive engineering practices are evident in some water resources schemes, where longitudinal channel connectivity can easily be lost, for example by failing to provide adequate provision for fish passage. Historically, facilitation of fish passage has been considered most important for salmonids due to their economic importance. More recent research has demonstrated that non-salmonid species also migrate extensively on both a daily and seasonal basis. Fish passage requirements for non-salmonid fish can often be very different to those required by salmonids and this needs to be considered when designing fishpass facilities.

It is also important to understand the effect of river structures (bridge supports, dams, weirs, etc) on channel substrate dynamics. Weir structures can retain coarser substrates such as gravels, while bridge supports can modify substrate deposition and erosion within the channel. This in turn can have major consequences for the distribution of habitats.

A further consideration is that heated effluents entering watercourses (such as cooling water return from power stations) has the potential to impact aquatic ecology; differences in the temperature and volume of these effluents determine the extent of the zone of potential impact. Thermal variation within the aquatic environment can result in community change, particularly for species at the edge of their geographical thermal range. In addition, heated effluents could exacerbate the potential impacts of climate change on aquatic communities and could favour the proliferation of species tolerant of elevated temperatures.

4.3 The legislative framework

Many of the positive changes referred to earlier have come about in response to increased environmental awareness. UK and European environmental legislation has been a major driver influencing our approach to aquatic ecology and the impacts of fluvial design and construction. For example, when designing and determining construction methods for the proposed ‘Mersey Gateway’ bridge across the upper Mersey estuary, legislation required full consideration to be given to the effects of changes in hydrology, piling noise, sedimentation, release of pollutants and other potential impacts on algae, invertebrates, fish and marine mammals (APEM, 2008). There are dozens of similar examples from around the UK.

4.3.1 UK legislation

Salmon and Freshwater Fisheries Act

The Salmon and Freshwater Fisheries Act 1975 (SAFFA) is a complicated piece of legislation aimed at the protection of freshwater fish, with a particularly strong focus on salmon and trout. There are many activities that could constitute an offence under SAFFA including direct mortality, barriers to migration and degradation of habitats.

Fish passage is also a major issue. In the future, it is likely that fish passage facilities will need to be designed to accommodate all fish species and life stages, with nature-like bypass channels being the most appropriate solution currently available. Further information is available on the Defra website: <http://www.defra.gov.uk/marine/freshwater/sffrev.htm>.

Wildlife and Countryside Act

The Wildlife and Countryside Act 1981 allows for the designation of Sites of Special Scientific Interest (SSSIs) due to features of conservation interest related to flora, fauna, physiography or geology. The Act makes it an offence to kill, injure, take, possess or trade in many wild animal species and to pick, uproot, possess or trade in a number of wild plants. Measures are outlined to prevent the establishment of non-native species that could adversely affect native wildlife.

Natural Environment and Rural Communities Act

The Natural Environment and Rural Communities Act 2006 (NERC) created Natural England as a new integrated agency to promote the natural environment and established a Commission for Rural Communities, which operates as a national rural adviser. The Act is designed to help achieve a rich and diverse natural environment and thriving rural communities by facilitating the implementation of environmental government policy.

Water Resources Act

The Water Resources Act 1991 (WRA) sets out Environment Agency responsibilities in terms of water resource management and issues including flood defence and water pollution. Under the Act there is strict regulation of discharges to rivers, lakes, estuaries and groundwaters. It also aims to ensure polluters cover the costs associated with pollution incidents.

4.3.2 European legislation

Strategic Environmental Assessment Directive

The SEA Directive (2001/42/EC) is designed to ensure that the environmental outcomes of particular plans, programmes and policies are identified and assessed during their preparation and before their adoption. For example, where there is a risk of flooding, the SEA Directive should ensure that the environmental impacts of all possible options for addressing that problem are taken into consideration before a preferred solution is decided. The Directive has been transposed into UK law since 2004.

Environmental Impact Assessment Directive

The environmental impact assessment (EIA) process is well established. The main aim of EIA is to allow specialists to identify and assess the potential impacts of an individual plan or project. This is followed by the identification of appropriate mitigation or compensation measures for any impacts expected to have a significant environmental effect in order to reduce any residual environmental change to an acceptable level.

Water Framework Directive

The Water Framework Directive (WFD) (2000/60/EC) is arguably the most significant piece of new legislation for fluvial engineers. One of its main aims is to ensure that inland and coastal waters attain ‘good ecological status’ by 2015. It is not yet clear precisely what action will be required by Member States to fulfil their obligations under the WFD.

The Directive’s demand that hydromorphological features are managed to protect the ecology has important implications for fluvial schemes. Water bodies of any status are not be allowed to deteriorate, so the design of in-channel works must ensure that any changes to channel morphology do not result in a decline in ecological status. Deterioration is permitted only under certain strict conditions, for instance where a scheme is of overriding public interest and all reasonable mitigation has taken place.

Water bodies that are already extensively physically altered are designated by the WFD as ‘heavily modified’. Such water bodies are required to achieve ‘good ecological potential’ (GEP). Achieving GEP currently depends on the extent to which all possible mitigation measures have been implemented, though this may change in future river basin planning rounds.

There is little doubt that sympathetic design and implementation of both routine management and rehabilitation will be the only way to achieve the ecological ‘status’ or ‘potential’ necessary to meet the requirements of the WFD. Consequently, the WFD should bring about a step change in fluvial design, with river and coastal engineers requiring a greater environmental awareness and an understanding of the legal requirements for the design and implementation of projects of all scales.

Habitats Directive

Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora (otherwise known as the Habitats Directive) is intended to help maintain biodiversity by defining a common framework for the conservation of wild plants, animals and habitats through the designation of Special Areas of Conservation (SACs). These areas are designated based on the presence of particular habitats or species that are either rare or declining in the EU.

Any development that is likely to have an impact on a SAC or another type of European protected site (for example, Special Protection Areas – see below) requires the completion of an ‘appropriate assessment’ to determine the potential impacts of the proposal on a site’s conservation objectives. The Directive also requires consideration of issues such as ‘imperative reasons of overriding public interest’ (IROPI) when assessing proposals that may have an impact on European protected sites.

Birds Directive

The Directive on the conservation of wild birds (79/409/EEC) (known as the Birds Directive) requires Member States to take a number of measures to protect wild bird species, their sites and habitats through the designation of Special Protection Areas (SPAs).

Natura 2000 network

SACs and SPAs together form a European ecological network of protected sites known as Natura 2000. The Habitats Directive states that it must be demonstrated that any activity carried out at a Natura 2000 designated site will not affect the integrity of that site. It also requires the prevention of any impact on site integrity through the employment of measures to mitigate and compensate for the effects of the activity. For example, in terms of river management, a development could result in the release of fine sediment which could adversely affect bullhead, shad, salmon, freshwater pearl mussel and floating water-plantain (example species for which an SAC can be designated). Any activity that could potentially affect a SAC or a SPA requires an assessment of whether it is likely to have a significant impact on the integrity of the site with reference to the features for which it was designated and its conservation objectives.

Ramsar Convention

Wetlands of international importance are designated under the Ramsar Convention as Ramsar sites. Because they are designated primarily due their importance for water birds, many Ramsar sites are also classified as SPAs under the Birds Directive.

4.4 Environmentally sensitive design

What then can be done within the new legislative framework to safeguard aquatic ecology while still achieving the fundamental objectives of flood defence or water resource management?

The guiding principles for promoting natural diversity of aquatic ecology in fluvial design are:

- all work should mimic and work with nature and natural processes rather than against them;
- maximise channel diversity (providing this is in keeping with what would be natural);
- maintain lateral and longitudinal connectivity.

But perhaps a better starting point is a general plea applicable to all fluvial design schemes, and that is to retain existing channel diversity and connectivity, and avoid the need for restoration. While this is not always possible, the need to incorporate guiding principles into fluvial design must be considered a high priority, with emphasis on protecting and restoring aquatic habitats. It is essential that sympathetic and innovative design – incorporating mitigation and compensation measures where appropriate – provides the basis for fluvial engineering in the future.

4.4.1 Channel diversity

There are many well-established design techniques that are appropriate to enhance channel diversity. These are reviewed in detail in the following publications:

- *Methods for the restoration of fisheries habitat. Salmon* (Hendry and Cragg-Hine, 1997);
- *Habitat rehabilitation for inland fisheries. Global review of the effectiveness and guidance for rehabilitation of freshwater ecosystems* (Roni *et al*, 2005);
- *Channels and challenges. Enhancing salmonid rivers* (O’Grady, 2006).

O’Grady (2006) provides a series of excellent examples of successful techniques used in stream restoration in Ireland over the past 20 years where a long-term programme of habitat restoration in many hundreds of kilometres of arterial drainage has demonstrated the effectiveness of the techniques, resulting in improvements in the diversity and production of aquatic flora, macroinvertebrate fauna and fish stocks, while maintaining drainage and minimising flood risk. Arterial drainage engineering works in the 1960s and 1970s were extremely detrimental for aquatic ecology (particularly for fish populations). O’Grady utilised detailed surveyors’ drawings of stream bed level, composition and habitat types (pool/riffle sequences) prior to the arterial drainage in the 1960s and 1970s to recreate habitat features at a lower level within the channel than they were originally. He consequently maintained the drainage and flood relief function of the channel while achieving spectacular improvements in biodiversity, especially fish stocks.

Examples of the techniques used, which can be incorporated into in-stream fluvial design to create channel diversity, are given by Hendry and Cragg-Hine (1997) and important techniques are illustrated in [Figures 4.2 to 4.7](#). All these structures also require adequate protection against bank erosion and the ability to be bypassed by fish. Appropriate restoration measures vary in relation to the type of river being considered (see [Section 4.1.1](#)).



Figure 4.2 In-stream structure – vortex stone weir

Benefits

Flow is deflected around rocks and directed towards centre of channel.
Creation of vortices in water and increased range of flow speeds.
Creation of scour pool immediately downstream of weir.
Increased habitat diversity.

Risks

Must ensure that stones remain in place during flood flows.
A stone apron is required in a channel with steeper gradients and high energy flows.
Vortex rocks should rest on layer of footer rocks with top elevation at existing bed level.
Rock elevation at the centre of the weir should be at or near bed level to permit fish passage at low flows.



Figure 4.3 In-stream structure – a log 'notch' weir

Benefits

Creation of pool immediately downstream of the weir.
Increased habitat diversity for aquatic flora and fauna.

Risks

Requires sturdy anchoring system to prevent collapse of log weir if undercutting occurs.



Figure 4.4 In-stream channel deflectors constricting low flow

Benefits

When channel has been widened artificially, this increases water velocity in stream centre and promotes pool formation, enhancing diversity.
Minimal impact on conveyance.

Risks

Can cause erosion problems if not executed properly.



Figure 4.5 In-stream boulders creating hydraulic diversity

Benefits

Presence increases heterogeneity of available flow due to slack water behind boulders.
Creation of ecological niche for invertebrates and refuge area for fish.

Risks

Too many boulders can increase erosion within local sections of the channel.
Careful thought is required before placement.



Figure 4.6 Bank protection

Fencing to exclude grazers and maintain bank stability.

Benefits

Exclusion of livestock prevents removal of riparian vegetation by grazing and trampling. This vegetation is important for invertebrates, bird life, amphibians and aquatic mammals.
Increases bank stability.

Risks

Placement is important. If it is too close to the bank and within high energy river systems, then successive flood events can remove fences.
Requires maintenance to be effective in the long term.

It is therefore recommended that:

- fencing is set back from the channel;
- occasional light grazing is allowed to prevent the establishment of tall rank vegetation.





Figure 4.7 Soft-engineered bank restoration

Log revetment and Christmas trees to trap silt.

Benefits

Log revetment stabilises bank.

Tree tops dissipate water energy, reducing bank erosion.

Tree tops encourage sediment deposition, which is subsequently vegetated, providing riparian habitat beneficial for aquatic and bankside ecology.

Risks

The main requirement is for the materials to remain anchored in place following the restoration.

Once the stabilisation period of newly deposited sediment is complete, risks are minimal. But if revetments and Christmas tree tops are dislodged before the end of the stabilisation period, the built-up silt can be dispersed downstream in large quantities causing siltation of downstream habitats.

Similarly, any trees washed away can result in channel blockage.



Weed cutting

Extensive macrophyte overgrowth of waterways can lead to a decrease in channel diversity. One management option to resolve this issue is the use of weed cutting techniques.

From an ecological perspective, there is conflicting evidence in the literature with regard to the precise proportions of cut and retained vegetation. The majority of studies show that conveyance is improved when cutting a central channel while leaving a percentage of marginal vegetation; where possible, marginal vegetation should be cut in a ‘meandering’ pattern.

With respect to weed cutting for flood maintenance, the following recommendations are made by Williams (2003):

- Cut 75% of channel width on an annual or biannual basis.
- Alternate the banks from which the cut is made so that the 25% left uncut does not gradually accumulate sediment and revert to land (terrestrialisation).

The Environment Agency may have locally applicable guidelines on the maximum extent to which vegetation can cut back, so it is important to consult the local area office before commencing weed clearance. In all cases, marginal vegetation that acts not only as a wildlife refuge but also as a source of bank stability should be left untouched.

As for dredging, the slow and noisy process involved may allow fish to escape (reducing the likelihood of direct impact between the fish and dredge) though, if fluvial habitats such as riffles are removed, these will probably be permanently lost.

In over-widened channels, it is often necessary to leave the uncut section in the same place each year to allow sedimentation to occur and promote natural narrowing of the channel. This enhances habitat diversity and reduces the need for ongoing intervention.

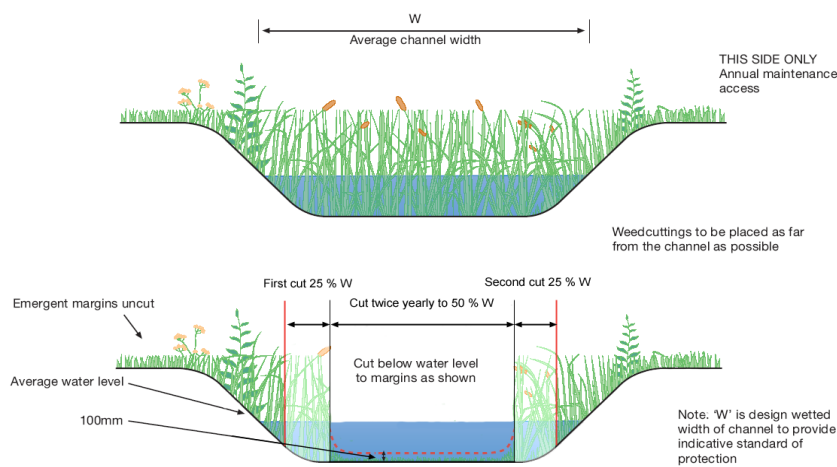


Figure 4.8 Weed cutting regime for enhanced biodiversity

Benefits

Improves the conveyance of water within channels overgrown with macrophytes. The amount removed needs to be managed carefully.

Risks

Involves removal of in-stream habitat. Some organisms can be removed from the waterway during the cutting process.

Source: Williams (2003)

4.4.2 Lateral and longitudinal connectivity

The standard for assessing river quality set by the European Committee for Standardisation (CEN) in 2004 and subsequently adopted in the UK (BS EN 14614; BSI, 2004) is based primarily on hydromorphology. It has a specific section on how longitudinal connectivity is affected by artificial structures while considering other features such as the structure of aquatic vegetation.

Access and ability to move along river reaches is an important consideration for aquatic mammals such as otter and water vole, as well as fish and invertebrates such as crayfish. For example, underpasses and ledges (under bridges and within culverts) can facilitate the movement of aquatic mammals. Disruptions to longitudinal connectivity have the potential to influence the distribution of any macroinvertebrate and macrophyte species reliant on currents to transport key lifestages.

In terms of fish, longitudinal connectivity is vital for salmonids and non-salmonids (including eel) as well as for conservation species, such as lamprey and shad, that have no conventional fishery value. Appropriate fishpass design to facilitate unhindered movement of all species and life stages is now an essential prerequisite of fluvial design for weirs, sluices and other potential obstructions, with nature-like bypass channels being favoured over engineered solutions. The Environment Agency's *Fish pass manual* (Armstrong *et al*, 2004) examines fish passage and connectivity, and includes references to other important sources. Some of the design criteria identified in this publication are in fact statutory requirements.

It is vital that design engineers appreciate that fish passage is a year-round requirement, with different life stages of different species migrating at different times of year, all with distinct flow and migration needs. For example, elvers (young eels) and spring salmon (a component of salmon stock under threat) migrate at the same time of year but have very different migration requirements, resulting in the need for completely different fish passage solutions.

Lateral connectivity is also now regarded as an essential feature of river systems, not only for aquatic ecology but also for flood defence. In the latter case, storage of water on the floodplain reduces peak flows in the channel downstream, thereby reducing the need for flood defences. Pioneering work in this area has been undertaken by the Environment Agency, with the development of off-river supplementation units (ORSUs) – most notably in Nottinghamshire with the connection of gravel pits

to the River Trent, a river subject to substantial removal of natural features over previous decades. Linfield (1985) provides detail of the design and success of a similar approach for lowland rivers in eastern England, with respect to non-salmonid fish populations; it is widely accepted that the broader biodiversity benefits extend to invertebrates, amphibians, water plants, mammal and birds. More recent developments along this theme require water bodies to be permanently connected to the main river channel to optimise connectivity (see Figure 4.9). Further details on stillwater habitat creation and restoration relevant to ORSUs are given by Hendry *et al* (2001).

Lateral connectivity can be engineered in this formal way by constructing backwaters with active connections to the watercourse or by allowing a degree of naturalisation to occur via intervention. Such intervention can be as simple as blocking drainage ditches or land drains, and allowing wetlands to regenerate within designated areas of the catchment. These areas are purported to act as hydraulic sponges while allowing substantial biodiversity benefits and extremely effective carbon sequestration.



Figure 4.9 Permanently connected backwater

Benefits

Permanently connected backwaters offer a wide range of ecological benefits. They can increase the range of habitat types available, thereby increasing local floral and faunal diversity. They also provide valuable resting and feeding areas for fish throughout the year and offer ideal habitat for juveniles of a number of fish species. In addition, as these backwaters are permanently connected to the main watercourse, they can be reached year-round by organisms which may benefit from the relatively stable environment they provide.

Risks

Reasonably large areas of land are required for these backwater areas and ongoing maintenance may be necessary to prevent siltation. In addition, permanently connected backwaters can encourage the establishment of invasive species. The presence of these backwaters could, depending on their position in relation to the main stem, influence geomorphological processes within the main channel.

4.5 Invasive species

An issue of increasing concern is the presence and competitive dominance of unwanted invasive species in many UK watercourses. It is imperative that:

- engineering works do not facilitate or promote the movement of invasive species from an aquatic or riparian habitat in which they are present to one in which they are absent, for example by opening up new channels for colonisation;
- all efforts are made to ensure that these species are contained where they are already established.

Invasive floral species in riverine habitats include riparian vegetation such as Himalayan balsam, Japanese knotweed and giant hogweed, and aquatic species such as floating pennywort. Signal crayfish and Chinese mitten crabs are highly invasive invertebrates and, in terms of fish, sunbleak, topmouth gudgeon, zander and wels catfish can be found in watercourses and water bodies throughout the UK (see Figure 4.10).

More information on the most important invasive species is provided in factsheets found on the Environment Agency website (<http://www.environment-agency.gov.uk/homeandleisure/wildlife/31350.aspx>).

An audit of non-native species in England from 2005 is available on the GB non-native species secretariat website (<http://www.nonnativespecies.org>).

The *Invasive non-native species framework strategy for Great Britain* (Defra et al, 2008) was launched by Defra, the Scottish Government and Welsh Assembly Government in May 2008.

Figure 4.10 Invasive species found in and adjacent to aquatic habitats in the UK



Himalayan balsam (with characteristic pink flowers)



Japanese knotweed



Himalayan balsam (flower)



Japanese knotweed (leaves)



Floating pennywort



Signal crayfish



Topmouth gudgeon



Chinese mitten crab

4.6 The need for monitoring

Fluvial design for aquatic ecology should be guided by the principles of riverine habitat restoration. Although the effectiveness of stream restoration techniques has been the subject of some debate over the years, it has long been accepted in North America and Ireland that substantial aquatic ecological benefits accrue from appropriate deployment of the techniques available. Roni (2005) provides an extensive review of the effectiveness of stream restoration techniques in North America while O’Grady (2006) describes the success of a range of techniques used in Ireland.

Because the discipline of habitat restoration is still in its infancy within the UK, specific information on ‘what works where’ is still thin on the ground. In order to justify the principles identified here (quantifying the benefit), both pre-scheme and post-scheme monitoring are strongly advocated.

Roni (2005) provides examples of the nature and extent of various monitoring programmes for a variety of scheme designs. In all cases, it is essential to establish the statistical basis for the monitoring programme, so that confidence in the statistical power of results (and hence the success of the scheme) can be justified. As the processes affecting fluvial ecology vary seasonally, it is also important that the monitoring of these features is targeted at appropriate seasons (see Table 4.1).

Table 4.1 Monitoring seasons for selected fluvial ecology features

Feature	Monitoring season			
	Spring	Summer	Autumn	Winter
Algae	✓	✓	✓	✓
Diatoms	✓	✓	✓	
Macroinvertebrates	✓	✓	✓	
White-clawed crayfish	✓	✓	✓	
Freshwater pearl mussel	✓	✓	✓	
Macrophytes		✓	✓	
Bryophytes		✓	✓	
Lamprey	✓	✓	✓	✓
Fish – salmonids		✓	✓	
Fish – non-salmonids	✓	✓	✓	✓
Water vole	✓	✓	✓	
Otter	✓	✓	✓	

4.6 Conclusions

Incorporating aquatic ecological considerations into fluvial design is no longer optional. Indeed, with the implementation of the WFD, ever more stringent ecological requirements are likely not only for future schemes but also for structures already built.

The primary design objectives are:

- to maximise fluvial ‘naturalness’ and ‘natural’ diversity within the context of the prevailing stream type;
- the maintenance of longitudinal and lateral connectivity for all species and habitats.

To repeat the well-worn maxim, ‘if it ain’t broke, don’t fix it’, that is a plea for the avoidance of in-stream works unless absolutely necessary.

Finally, wherever possible, utilise soft engineering techniques and follow the advice of Dr Martin O’Grady, who has spent that last 20 years restoring over-engineered river channels in Ireland: ‘don’t knock it – nudge it’.

Key references

Rosgen, D (1994). A classification of natural rivers. *Catena*, Vol 22, pp 169–199.

Rosgen identified a requirement for more detailed quantitative measures to be applied to river classification techniques and developed a hierarchical river channel classification system. He describes river channels based on the relationship of the river to its valley and/or landform features, gradient, the ratio of width to depth, landform sinuosity and substrate type. In applying the classification system, Rosgen highlights the use of this technique in river restoration and the enhancement of fluvial habitats, and summarises potential management implications.

O’Grady, M F (2006). *Channels and challenges. The enhancement of salmonid rivers*, Irish Freshwater Fisheries Ecology and Management Series: Number 4. Central Fisheries Board, Dublin.

This is a training manual designed to be easily understood by the layman which outlines a number of management options for rivers. The manual first indicates the importance of baseline surveys to understand natural riverine communities and how changes in plant and invertebrate communities can indicate environmental change (such as variation in water quality). The key attributes of healthy rivers for salmonid fish and other fauna and flora are then discussed and examples of damaged riverine habitats and loss of ecological features are provided. Numerous physical management options for different issues likely to be encountered in the riparian zone and in-stream are then described, with diagrams and images indicating the particular measures in operation. Overall this is a very well illustrated and useful guide covering a wide range of options for river management.

Roni P, Hanson, K, Beechie, T, Pess, G, Pollock, M and Bartley D M (2005). *Habitat rehabilitation for inland fisheries. Global review of the effectiveness and guidance for rehabilitation of freshwater ecosystems*, FAO Fisheries Technical Paper 484. FAO. Available from: <ftp://ftp.fao.org/docrep/fao/008/a0039e/a0039e00.pdf>.

This comprehensive review brings together information from around the world, assesses the effectiveness of different rehabilitation techniques for aquatic habitats, and provides information for individuals involved in the research and management of these environments. The review includes discussion of the application of techniques in relation to road and riparian rehabilitation, floodplain connectivity, dam removal, flood flow conveyance, in-stream habitat structures, lakes habitat enhancement and nutrient enrichment. Emphasis is placed on the effectiveness of different techniques in restoring natural features and physical habitats, and increasing diversity and production. Shortcomings of different techniques are addressed and advice is provided for the planning of rehabilitation projects and associated monitoring. This review is an invaluable source of data and information,

providing a broad overview of the effectiveness of various rehabilitation techniques and the consequences for aquatic ecosystems.

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