River Weirs – Good Practice Guide

Guide - Section A

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Statement of Use
This guide is for all parties who have an interest in the construction, operation and maintenance, refurbishment or demolition of river weirs. Its aim is to make them aware of the wide range of issues that are relevant in planning and implementing such works, and by doing so, to ensure that mistakes are avoided and potential benefits are maximised.

Keywords
Weirs, Guidance, Best Practice, Safety, Recreation, Fisheries, Engineering, Environment

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FOREWORD

This guide has been produced following consultation with a wide range of interested parties, both within the Environment Agency, and in other organisations. Taking account of the multitude of views expressed has been a balancing act, which aptly reflects the process that is required when planning and implementing works on weirs. No solution will fully satisfy the desires of all parties, but hopefully, through consultation, all parties will accept that the end product is appropriate and worthwhile.

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Photographs

Many of the above provided photographs that have been used in the Guide. Individual credits for photographs have not generally been provided in the Guide.

EXECUTIVE SUMMARY

This guide aims to provide advice and guidance to all parties engaged in the planning, design, construction and improvement of weirs, so as to ensure that mistakes are avoided and opportunities are not missed. It is also relevant to those involved in operation and maintenance.

The guide does not attempt to be a technical treatise. It is what it says on the cover – a guide to good practice, with the aim of pointing the reader in the right direction and warning of pitfalls on the way.

The guide is divided into two main sections. Section A is intended to give a quick overview of the subject for the reader, or for someone who does not need to delve into the detail. Section B provides more comprehensive guidance, but stops short of textbook detail. The Appendices include a large section on case studies, well illustrated with photographs, which are mainly intended to give the reader ideas of what can be achieved.

For readers in a hurry, there is (in Appendix B) a checklist that indicates all the issues that need to be considered in the process of planning works on weirs.

Finally, for those who only have time to read this page, the following list summarises the key issues to be considered:

- Early consultation with all stakeholders will ensure that all views are considered, and no decisions are taken without considering their impact.
- Weirs must be robust structures in order to withstand the hydraulic forces to which they are subjected - but they do not necessarily have to appear so.
- Weirs can be dangerous – considering the safety of all parties from the outset will help to reduce the risk of accidents.
- Weirs create a barrier across the river that can adversely affect wildlife (especially fish) and recreation. Appropriate design can ensure that the adverse impacts are minimised or eliminated, or even turned into a benefit.
- No new weir should be constructed without first investigating if there is an alternative that will achieve the designer's objective without compromising other interests.
- No existing weir should be demolished without first considering all the impacts that might follow, including geomorphological, hydraulic, social, amenity, historic, ecological and environmental.
- When planning any repair or rehabilitation works on weirs, the opportunity should be taken to consider how the weir might be improved in terms of, for example, fish migration, hydraulic performance, appearance, and recreational use.

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GLOSSARY

Note – if a word used in the explanation is itself defined in the Glossary, then it is generally in italics.

Abutments	The walls that flank the edge of a *weir* or other *hydraulic structure*, and which support the river *banks* on each side of the *weir*.
Backwater effects	Effects that flow conditions in one location have on flow conditions farther upstream (in particular, the *water level* upstream of a *weir* in low flow conditions).
Bank	The edge of a river or stream. Note that left and right refer to the river viewed looking downstream.
Bank protection	Works to protect a *bank* from *erosion* or undermining by *scour*.
Broad-crested weir	*Weir* with a *crest* section of significant thickness measured in the direction of *flow*. For accurate flow gauging, the thickness should normally not be less than about three times the upstream *head* of water above the *weir crest*.
Canoe	Kayak or other similar vessel.
Channel	Natural or man-made open *watercourse* that contains and conveys water.
Control structure	Device constructed in a *channel* or between water bodies, used to control the *flow* passing the device and/or the *water level* on either side of the device. Many control structures have movable gates. A *weir* is an example of a simple control structure.
Crest (of weir)	Top part of *weir*. The level of the crest, its length and its cross-sectional shape determine the *discharge* (flow) characteristics of the weir.
Crump weir	A form of *weir* with a precise triangular profile often used for discharge monitoring (after E S Crump, who defined the characteristics of this shape of *weir*).
Cumec	Cubic metres per second (m^3/s). A measure of rate of *flow*.
Discharge	*Flow* rate expressed in volume per unit time (typically cubic metres per second or m^3/s). In this guide the word "*flow*" is used to mean flow rate or *discharge*. (NB the letter Q is universally accepted as the symbol for discharge. Q_{95}, for example, indicates the *flow* in a river that could be expected, on the basis of statistical analysis, to be equalled or exceeded for 95% of the time).
Discharge intensity	*Discharge* per unit length of *weir* (see also unit discharge).
Duckbill weir	A weir with a *crest* that forms a U-shape on plan, such that the crest length is much longer than the width of the river. Similar to a *horseshoe weir*. The long *crest* gives lower variations in upstream *water level* for changing *flow* conditions, but note that this effect may not apply to flood conditions when the *weir* is drowned.
Drowning	In the context of *weir* hydraulics, a *weir* is said to be drowned (or drowned out) when the downstream *water level* rises to the point where it begins to affect *flow* over the *weir*.
Erosion	Process by which material forming the bed or *banks* of channel is removed by the action of flowing water or waves.

Fish pass A device provided to allow fish to migrate over or round a *weir* that would otherwise obstruct the movement of fish.

Flood bank Embankment, usually earthen, built to prevent or control the extent of flooding.

Flow Flow rate or *discharge*.

Freeboard Height of the top of a bank, *flood bank*, or structure above the level of the water surface. Freeboard is provided as a safety margin above the maximum design *water level* to allow for uncertainties.

Glacis The downstream sloping face of a *weir*, between the *weir crest* and the *stilling basin*.

Head (of water) The height of *water level* above a datum (such as the weir crest). Note, there are more technically precise definitions of head, making the distinction between static head, velocity head and total head – refer to a hydraulics text book for details.

Head loss The drop in *water level* across a weir or other *hydraulic structure.*

Horseshoe weir See *duckbill weir*.

Hydraulic jump Abrupt rise in *water level* when *flow* changes from a *supercritical* to a *subcritical* state, with associated dissipation of energy. Hydraulic jumps are a feature of *weir* structures and are characterised by very turbulent flow and surface waves.

Hydraulic structure Structure used to control or convey *flow*; or structure built in a position where it may affect, or be affected by, *flow*.

Invert level Level of the lowest point in a natural or artificial *channel*.

Labyrinth weir A *weir* with an elongated *crest* length achieved by corrugating the *crest* in plan view (in effect, multiple *duckbill weirs*).

Main river Certain *watercourses* are designated as "main river". These are shown on a statutory map. The Environment Agency generally has an enhanced supervisory duty for such *watercourses*. However, the act of "enmaining" does not place any specific obligation on the Agency to exercise its permissive powers.

Modular flow Condition in which *flow* is able to discharge freely over a *weir*, resulting in a unique relationship between *flow* rate and upstream *water level* (modular flow occurs when the *weir* is not *drowned*).

Non-modular flow Condition in which *flow* is not able to discharge freely over a weir, with the downstream *water level* influencing the upstream level (i.e. *drowned flow*).

Nappe The jet of water passing over a weir *crest* and plunging into the *stilling basin*. Term normally only applied where the jet is not in contact with the *weir* structure (i.e. there is an air gap between the underside of the nappe and the downstream face of the *weir*).

Ordinary watercourse A *watercourse* that is not designated as a *main river*.

Rating curve A plot of *water level* against *flow* rate for a *channel*, *weir* or other *hydraulic structure* (also called a stage-discharge curve). *Weirs* with fixed *crests* generally have non-varying rating curves provided the *flow* over the *weir* is *modular*. Rating curves for natural *channels* may vary with time due to changes in *channel* geometry or to seasonal growth of vegetation.

Regulator *Hydraulic structure* for controlling *water levels* or division of *flow*.

Scour *Erosion* resulting from the shear forces associated with flowing water or wave action.

Sediment Erodible material forming bed or *banks* of channel, which may be eroded or deposited depending on the prevailing *flow* conditions.

Sharp-crested weir *Weir* with a *crest* section of small thickness measured in the direction of *flow*. For accurate *flow* gauging, the *crest* is normally chamfered with the horizontal tip having a thickness of the order of 1-2 mm. Such structures are not normally used as permanent weirs in rivers and streams, but are used for measuring flow in the laboratory and small channels.

Side weir *Weir* installed in a *channel* to divert part of the approach *flow* into a separate spill *channel*.

Siltation The deposition of *sediment*.

Sluice (or sluice gate) Gate that is moved (usually vertically) between guides to control the rate of *flow* or upstream *water level*.

Stage Elevation of water surface relative to an established datum.

Stilling basin Energy dissipator comprising a basin in which a *hydraulic jump* occurs. The turbulent water downstream of a *weir* should be contained within the *stilling basin* to avoid *erosion* to the river bed and *banks* downstream.

Subcritical flow *Flow* in a *channel* at less than critical velocity. Flow in the lower reaches of rivers and streams is generally subcritical.

Supercritical flow *Flow* in a *channel* at greater than critical velocity. Supercritical flow is rapid, high-energy flow, often seen on the *glacis* of a weir, or in the steep upper reaches of a river or stream.

Tailwater level *Water level* downstream of a *hydraulic structure*.

Tilting gate A steel gate hinged at the bottom such that it can be raised or lowered to act as a *weir* with a variable *crest* level. Can be operated by hydraulic rams or cables.

Transverse weir *Weir* installed across the width of a *channel* – usually the *crest* line of the *weir* is set at right angles to the longitudinal centreline of the upstream *channel*, with the *flow* passing over the *weir* being discharged into the downstream reach of the *channel*.

Unit discharge *Discharge* per unit length of weir.

Water level The level of the water surface.

Watercourse A river, stream, or drain in which water flows for some or all of the time.

Waterway *Channel* used, previously used, or intended for the passage of vessels.

Weir An artificial obstruction in any *watercourse* that results in increased water surface level upstream for some, if not all flow 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*.

Wingwall A wall on a *weir* or other *hydraulic structure* that ties the structure into the river *bank*. Wingwalls extend from the *weir abutments* into the river *bank*. They can be at right angles to the flow, or at 45^0 or other appropriate angle, and may also be curved

.

1. SECTION A – OVERVIEW

1.1 Introduction to this Guide

This document is intended to provide authoritative guidance to all parties who have an interest in the construction, refurbishment, or demolition of weirs in England and Wales. It also addresses the issues of importance to those responsible for the operation and maintenance of such weirs. Its overriding aim is to make all parties aware of the wide range of issues that are of importance in planning and implementing such works, and by doing so, to ensure that mistakes are avoided and potential benefits are maximised.

Although the guide is comprehensive in its coverage of the issues, it does not attempt to replace standard textbooks on the underlying theory and practice. References to such documents are presented in Appendix A.

Fundamental to the guide is its examination of the weir from all perspectives, including (but not limited to) hydrology, hydraulic engineering, landscape, ecology, fisheries, archaeology, recreation, amenity, and safety. Although the guide is directed principally at Environment Agency personnel, it is intended to be a useful source document for anyone involved in weir projects.

The structure of the guide has been deliberately arranged to avoid division into sections relating to the Environment Agency "functions", as this was considered likely to promote "thinking in boxes". Instead the guide is divided into a small number of major sections that address the main areas of interest, and includes cross-references to other sections wherever appropriate. Nor has the guide been divided into the three major options of new construction, rehabilitation, and decommissioning (except in section 1.4 of this overview), because many of the issues are common to two if not all three, and such division would have therefore led to repetition.

The guide is therefore divided into two major parts. This first part comprises an overview of the subject, and is intended as a quick guide to all the issues. The second part contains the detailed guidance in three main sections, followed by appendices containing supporting information and case studies.

It is important to note that no decision regarding a weir (either existing or proposed) should be made without full consideration of all the issues and impacts. This guide provides an insight into all of these, and will enable the reader to assess these in relation to the project being considered, and to identify any potential conflicts of interest between the various parties.

1.2 Scope

The guide addresses the issues relating to weirs in England and Wales, but is applicable (with care) to weirs worldwide.

In the context of this guide, a weir is defined as an artificial obstruction in any watercourse that results in increased water surface level upstream for some, if not all flow conditions. As such, all weirs are characterised by a drop in water level in the

watercourse, from the elevated upstream level to the natural downstream level, although this drop may disappear in flood conditions.
The guide does not explicitly address the subject of gated weirs, although much of the content is applicable to such structures. Gated structures are briefly discussed in Section 2.3.12.

The guide covers all forms of construction from informal rock weirs to concrete and steel sheet pile engineered structures. It covers weirs of all ages and functions, in watercourses of all sizes. In particular, the guide addresses the issues that are of relevance to the:

- Construction of new weirs, either as a replacement for an existing structure, or as an entirely new structure
- Rehabilitation of existing structures, from minor repairs to complete re-engineering, either to maintain existing function, or to meet new requirements
- Decommissioning of a weir.

1.3 Value, function and impact of weirs

1.3.1 Introduction

Regardless of the function, ownership, age or condition, it must be remembered that weirs are engineering structures that have to operate in demanding environments. New weirs and rehabilitation works to old weirs must therefore be designed by qualified and appropriately experienced engineers. In engineering terms the design of a weir must satisfy three fundamental requirements:

- Hydraulic performance – the weir must provide the desired hydraulic performance throughout the full range of flow conditions, from low summer flow to flood.
- Structural integrity – the weir must be able to resist the onerous hydraulic and structural loading throughout its design life, without the need for excessive maintenance expenditure
- Health and safety requirements – the weir must not pose any avoidable and unacceptable health and safety risks to members of the public or operational staff, both during construction and for the completed structure (see Section 2.1 for detailed guidance on safety issues)

However, in addition to the basic need to get the engineering right, there is a parallel need to take into account the environmental impact of the weir, both during construction and throughout its design life. In this context, the environmental impact must be considered in its broadest sense, and will include, *inter alia*, issues of:

- Archaeology
- Conservation and heritage
- Fish migration
- Flora and fauna
- Land drainage and flood defence
- Landscape and ecology
- Navigation

- Recreation and amenity
- Sedimentation and erosion
- Water resources and water quality

In addition, there may be legal and/or planning issues to address (see Section 2.2).

It must also be appreciated that many of the weirs on our rivers, streams and canals are historic structures, and merit the same sort of status that is commonly afforded to historic bridges. Weirs in the urban environment can act as a focus for regeneration, and renewed interest in our rivers.

Figure 1.1 Crown Point Weir

Crown Point weir on the River Aire in Leeds is located in an area of renewal and development. The weir is diagonal to the flow to maximise the crest length and thereby reduce water level variation upstream. Note the new riverside walk on the right of the picture, and the historic bridge in the background (photograph courtesy of British Waterways).

1.3.2 Stakeholders

A key issue for weir design, construction, operation, maintenance and decommissioning is the diverse range of stakeholders that can influence decisions on, or be affected by weirs. It is therefore important that anyone involved in a weir project is aware of the full range of issues, appreciates the views of all stakeholders, and understands how these interact and constrain the decisions made during the life-cycle of the weir (see Case Study M for a good example of stakeholder involvement). This guide therefore presents these issues and constraints and sets out the advantages and disadvantages to the stakeholders. In this way interested parties in each function will be better prepared to appreciate the issues that affect their colleagues in other functions.

In the Environment Agency the stakeholders include staff with interests covering:

- Conservation and ecology
- Development control
- Environmental protection (water quality)
- Estates and legal
- Fisheries
- Flood defence – planning, regulation, design, construction, operation and maintenance
- Flood forecasting and warning
- Health and safety
- Navigation and recreation
- Water resources

Other interested parties include:

- British Canoe Union
- British Waterways, navigation trusts and other navigation interests
- English Heritage
- English Nature (or the Countryside Council for Wales)
- Local angling clubs
- Local conservation bodies
- Local interest groups (Wildlife Trusts, ornithology societies etc.)
- Local planning authorities
- Local residents and landowners
- National Federation of Anglers
- Riparian owners
- Water Companies

With such a wide range of potential interests in works on weirs, it is easy to see that there is significant potential for conflict, particularly in terms of the potential negative impacts. Early consultation with all relevant parties will help to identify such conflicting interests, and thereby assist in resolving them before they materialise (see Case Study A).

1.3.3 Function of weirs

Weirs are usually provided for one of four fundamental reasons:

- Water level management
- Flow (discharge) measurement
- Environmental enhancement
- Channel stabilisation

Weirs are also occasionally constructed for fish counting purposes (see Case Study G).

Many of the weirs on rivers in England and Wales were constructed before the 20th Century, for the first of the above four reasons, most notably in connection with navigation and water supply to mills, as well as for the creation of water meadows. Many of these weirs no longer serve their original function, in particular those associated with water mills. In such cases, the pros and cons of leaving the weir in place are likely to be examined, and it is valid to consider decommissioning of the weir. However, it is important that each case is considered on its merits. In some circumstances decommissioning of a weir may result in loss of amenity, ecological value, heritage, or recreational use. In other situations decommissioning a weir may be beneficial to the ecology of the river, with few if any other negative impacts.

(i) Water level management

Most of the weirs in England and Wales have been constructed with the primary aim of water level management. The impoundment of water is clearly a central function of weirs as by their very nature they raise water levels relative to downstream conditions. Increased water levels may be required to provide sufficient draft for navigation, to permit the diversion or abstraction of water, or to provide a source of power. Many of the older weirs in England and Wales were constructed in connection with water mills (see Case Studies E and M) and navigation improvements. In cases where a river reach serves a navigation requirement, the increase in water levels is often accompanied by the need for controllability of level to ensure that canal banks are not overtopped, and that headroom under bridges is maintained. This is often achieved by the construction of a weir with a long crest (see Figure 1.1), such that water level variation is small in response to changing flow conditions (the alternative is to have a gated weir that will allow regulation of water level). Side weirs are frequently used for water level management in navigable waterways (Section 2.3.7). Weirs are also used to divert water into off-stream reservoirs or diversion channels, for flood defence purposes or as part of a water supply scheme. In providing raised water levels weirs may also be allowing the continued use of a reach of a river for recreation and amenity. Weirs are also used to maintain groundwater levels (the weirs on the recently completed Jubilee River, a flood diversion channel for the Thames, were provided for this purpose – see Figure 2.32).

Figure 1.2 Tilting gate weir at Tewkesbury

A former mill weir at Tewkesbury now replaced by a tilting gate allowing precise control of upstream water level. Note that works of this nature can readily blend in with an attractive landscape. The weir is on the right of the picture, and is indistinguishable from a conventional weir.

(ii) Flow measurement

Weirs also form the backbone of the national hydrometric system, which provides accurate discharge information to facilitate development planning, flood forecasting, planning and development of flood alleviation schemes, and water resources regulation. Although any weir can be used to provide information on flow rates, weirs not specifically designed with this in mind are likely to provide only approximate data. In the last fifty years or so, a large number of weirs have been constructed with the sole purpose of monitoring flow conditions in rivers, mostly (until recently) aimed at low to moderate flow conditions, and not high flood flows. Flow gauging weirs permit engineers and hydrometrists to calculate the discharge in a river reach, monitor it over time and, if real time monitoring is available, to issue flood warnings and to adjust flood control structures in response to changing conditions

Figure 1.3 Gauging weir at Horncastle

A modern discharge monitoring weir of the flat-vee type. This type of weir is often favoured for its accuracy of flow measurement and suitability for both low and high flows. It is one of the best weirs for sediment conveyance, but tends to make fish migration difficult. Note that it is possible to create an attractive gauging weir that sits well in its surroundings.

(iii) Environmental enhancement

By raising water levels weirs may offer the opportunity to create wetland and conservation habitats as well as enhance rivers and their surrounding areas. However, the very fact that the weir creates a barrier in the river may be detrimental to nature conservation, so it is important that all potential impacts are assessed before a decision is made.

Specific advantages of weirs include the prevention of the river channel drying out upstream of the weir, and increased aeration of the river water as it cascades over the weir crest (but see Section 2.4.7). These can help to develop a rich and diverse environment for both aquatic and terrestrial species. Weirs also open up options for improving low flow conditions by keeping water depths greater than they otherwise would be (see Case Study K), and providing opportunities for water meadows and landscaping. As such, weirs may form an important component of a Water Level Management Plan (WLMP).

Weirs also have a significant impact on the amenity value of rivers, creating or enabling opportunities for enhanced use of the river.

However, care needs to be exercised because the presence of a weir can constitute a barrier in the watercourse thereby preventing the migration of fish upstream and downstream, thus limiting their access to suitable spawning sites as well as reducing the overall biological value of a fishery. Indeed, it can be argued that the ponded water upstream of a weir creates a more homogeneous environment, with lower biodiversity than a natural river. Thus it is not uncommon for weirs to be removed in order to return the channel to a more natural status.

Figure 1.4 Thorney Weir

Not all weirs can be designed to enhance the visual environment as much as this graceful structure with its arching form and matching elegant footbridge, but even a little extra thought at the planning and design stages can yield significant environmental benefits. Note that this weir has two fish passes, one on either flank.

(iv) Channel stabilisation

In reaches of river where the channel gradient is steep, and where erosion is an issue, the increased water depths caused by impounding will slacken water surface slopes, reduce and regulate velocities and help to control erosion. Such weirs are much more common in southern Europe than they are in England and Wales. In this context, weirs are also provided in a reach of channel that has been shortened, so that the gradient in the stream can be maintained at a stable value. Weirs can also be used to create a silt trap, thereby preventing or reducing siltation downstream. For such use it must be remembered that the effectiveness of the weir will depend on regular removal of the trapped silt, and this will require safe and easy access to the weir for suitable plant and equipment.

Figure 1.5 Cripsey Brook

The creation of a riffle in a small urban brook can look quite stark immediately after construction, despite the use of natural materials (rock). However, as the second photograph (taken one year later) shows, such works soon blend into the environment.

1.3.4 Impact of weirs

The primary impact of a weir on the river, and indeed its primary function, is the raising of upstream water level above the natural level. Table 1.1 summarises some of the secondary impacts, both positive and negative, that weirs can have on the environment in which they are located. The table is not intended to be a comprehensive guide to impacts.

Figure 1.6 illustrates the way in which a weir raises water level in a river or stream.

Figure 1.6 Impact of a weir on water level

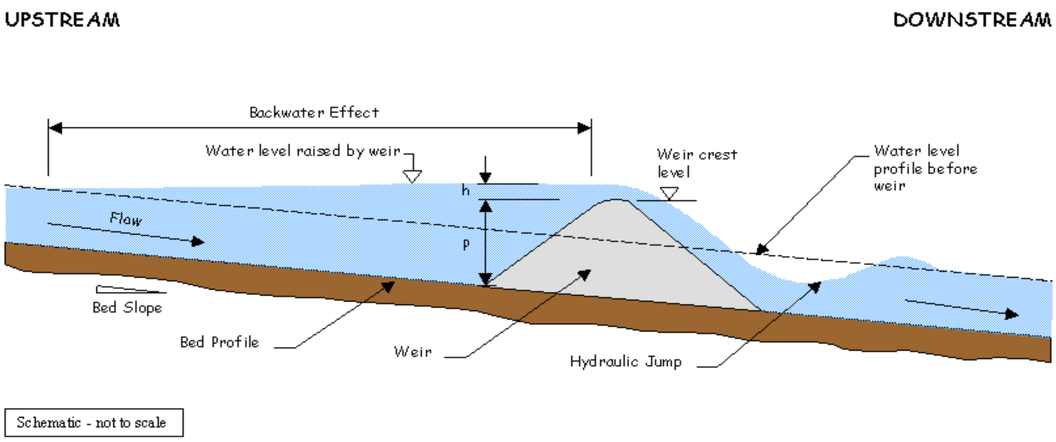


Table 1.1 Positive and negative secondary impacts of weirs

Secondary Impact	Potential Negative Impacts	Potential Positive Impacts
Increased depth upstream	Increased flood risk. Loss of marginal vegetation. Loss of *ranunculus* vegetation. Increased risk of death by drowning. Reduced biodiversity. Raised groundwater level may have negative impacts (such as restricted drainage).	Visual appearance. Improved amenity. Improved navigation. Improvement to some fisheries. Raised groundwater level may have positive impacts (such as improved wetland).
Drop in water level at weir	Barrier to fish migration. Noise. Barrier to navigation.	Amenity value. Ability to measure flow accurately. Potential for power generation.
Reduction of water velocity upstream	Algal blooms. Loss of some angling opportunities.	Safer navigation (except that the weir itself may be a hazard).
Turbulent flow downstream	Bank and bed erosion. Dangerous conditions for canoeists and swimmers.	Visual appearance. Aeration of water. Attractive conditions for canoeists.
Physical barrier across the river	Trapping of debris. Siltation of channel upstream. Fish migration inhibited.	Opportunity to create a crossing point.

The impacts outlined in Table 1.1 only consider the impact of an established weir and do not address the impact of its construction, refurbishment or de-commissioning, the processes associated with which may have both short and long-term impacts. Prior to any works being implemented, an appropriate level of environmental assessment must be conducted. Through the process of environmental assessment, any design/construction/operation issues can be identified and addressed, and any potential negative impacts eliminated or mitigated, at little or no extra cost. (Note. In general, works on weirs come under the EIA (Land Drainage Improvement) Regulations 1999. SI1999 No1783 would apply, and therefore an Environmental Impact Assessment would be required. This will generally apply to rehabilitation and demolition as well as to new works).

It is clear from the above that weirs have a number of functions and many potential impacts, both positive and negative. It is important that these are considered carefully in the planning stages of any project that includes any works to an existing weir (rehabilitation or demolition), or the construction of a new weir.

1.3.5 Types of Weir

Weirs come in a wide range of shapes, forms and sizes, with the choice of type normally driven by the fundamental purpose of the weir. The most commonly encountered types of weir are illustrated in Figures 1.7a and 1.7b. Whereas some indication of the pros and cons of each type are given in these two figures, it is inappropriate to go into detail, because these vary depending on the function and setting of the weir, and on the interests of the person making the assessment. For example, the Crump section flat-vee weir is favoured by hydrometrists because of the accuracy and range of flow measurement, but is disliked by fisheries officers because it can present a barrier to fish migration. More detailed guidance is given in Part 2 of this guide.

Figure 1.7a Weir types – cross sections

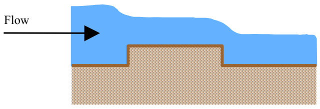
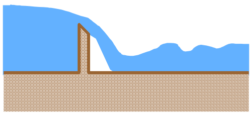
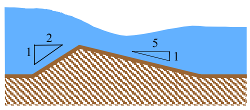
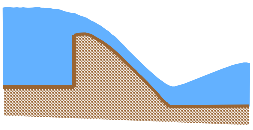
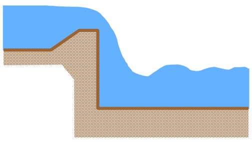
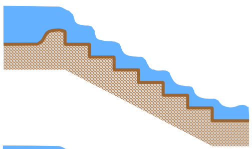
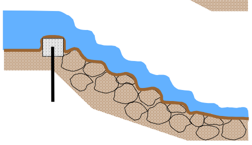
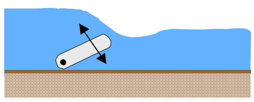
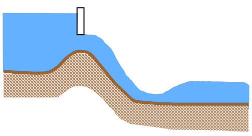
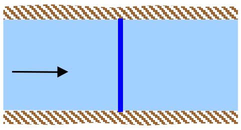
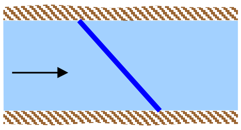
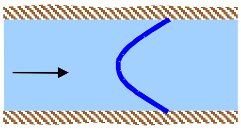
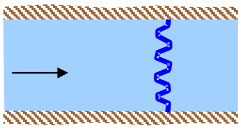
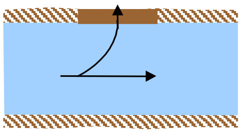
	Broad Crested	Most weirs in rivers are effectively broad crested, although with many variations in shape.
	Sharp Crested	Not commonly used in rivers and not covered by this guide.
	Crump	A special type of broad-crested weir used for discharge measurements
	Ogee	Crest profile conforms to prescribed curve for hydraulic efficiency. Commonly used for dam spillways
	Straight Drop	Not recommended for canoeists or fish
	Stepped	Forms a cascade for low flows
	Dumped stone or rock	Designed to act as a riffle or a cascade
	Tilting	Added versatility (also referred to as a bottom-hinged gate)
	Gated	Not covered in detail by this guide The addition of gates to a weir increases the operational flexibility for water level and flow control.

Figure 1.7b Weir types – plans and elevations

Plan

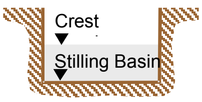
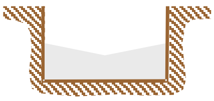
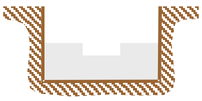
	Orthogonal	Weir spans channel at right angles to flow
	Diagonal[1]	Weir spans channel at an angle - gives increased length of crest
	Curved[2]	Length of weir crest increased. Visually attractive (see core photograph). Also referred to as a Duckbill Weir.
	Labyrinth [2]	Length of weir crest increased. Useful for water level regulation in artificial channels not subject to high flood flows.
	Side Weir	Used to control water level in navigable waterways, and to divert flood flows.

Notes.

1. Diagonal weirs create more complex hydraulic conditions downstream. Stilling basin design is more difficult

2. Curved and Labyrinth weirs give increased weir crest length and hence less water level variation upstream for low to moderate flows. In high flows, the weir will tend to act as an Orthogonal weir.

Elevation (viewed from

	Horizontal	Crest level is constant across the weir. This is the most common type of weir.
	Shallow Vee or Flat Vee	Used for discharge measurement for accuracy across a wide range of flows
	Compound	Low flow section for improved discharge measurement or amenity, and improved fish passage.

1.4 Key decision issues

The following sections provide, by way of brief introductions, an overview of the most pertinent issues concerning the construction, rehabilitation and decommissioning of weirs. To assist, some of the environmental impacts associated with constructing or decommissioning weirs have been tabulated and a brief action or opportunity included. Opportunities may be considered either as mitigation measures to offset an impact, or simply as environmental stewardship actions aimed to bring permanent improvements to an area. When considering the design and construction of a weir it should be possible to separate impacts into short-term construction impacts and long-term operation impacts, both of which may require provision for differing mitigation measures, or simply pre-planning well in advance. Clearly the severity of an impact will vary according to the setting in which the weir is located, and some impact types (e.g. archaeological) do not always apply. Land-use impacts may be negligible in urban environments, but severe in agricultural areas; conversely noise during construction and operation in towns may be a serious consideration, but may be of little significance in a rural setting.

It should be noted that the Water Act 1989 imposes wide-ranging requirements with respect to the protection and enhancement of established amenity and recreation in the water environment. The construction, rehabilitation and demolition of weirs present considerable opportunities in this respect.

1.4.1 Construction of a new weir

(i) Environmental Issues

There are numerous and diverse environmental impacts associated with the construction of a weir from new. These are covered in more detail in Section 2.4, but Table 1.2 gives an indication of issues typically investigated during environmental assessment for which consultation with statutory and non-statutory consultees is required. In examining environmental issues, it is important to consider both short-term impacts (which are likely to arise during the progress of the works and subsequent months) and the longer-term impacts that will be a feature of the years following completion of the project.

Table 1.2 Generic environmental issues

Impact on	Illustrative Impacts	Potential Opportunities (not necessarily in direct response to the illustrative impacts)
Landscape	Impact on a "micro" scale to the river channel during construction and operation. "Macro" scale impact to landscape of the floodplain during construction and operation.	Use of local building materials. Re-contouring of immediate surrounds and planting with indigenous trees to screen weir and to create new wildlife habitats.
Land use	Loss of agricultural productivity during works. Changes to soil moisture of surrounding land leading to alterations in land-use practices.	Purchase of areas of riparian land for creation of backwaters, ponds and wetland habitat.
Ecology	Loss of submerged, emerged and bank-side vegetation, and loss of associated animal and invertebrate communities Disturbance to nesting birds.	Creation of varied flows upstream and downstream suitable for colonisation by a wide range of plant species. Provide additional nesting habitats
Social	Visual and aesthetic impacts. Noise during and after construction	Landscaping, screening, provision of river crossing point and basic amenities such as a picnic area.
Archaeology and Heritage	Disturbance to drowned or buried artefacts.	Interpretation boards detailing heritage.
Recreation and Amenity	Reduced angling and navigation value of the river.	Construction of fishing piers, canoe landing stage and white-water 'play' area. Provision of access for the disabled.

(ii) Engineering issues

A thorough knowledge of the chosen site is fundamental to the successful implementation of a new weir. In particular, those responsible for planning and designing a new weir will need to have:

- Topographic survey of the site. This should include full width cross sections of the river at the site and upstream and downstream of it, as well as a survey of the adjacent floodplain. The survey should pick up all relevant features including any existing river structures, buildings, major trees, access ways, etc.
- Soils/geological information from available maps and, depending on the scale of the project, boreholes and test pits. This information will allow safe and appropriate design of foundations, cut-offs and erosion protection measures.
- River flow and level data. These data are essential for the hydraulic design of the weir and for planning the construction works. Flow and level data are also required for the consideration of fish pass requirements.

- Details of land ownership, rights of way, and any rights of use of the watercourse. Note that there may be informal or unauthorised use of watercourses, and it will be important to identify such use in the interest of public safety.
- Details of the locations of any service ducts (water and gas mains, sewers, power cables, telecommunications cables)
- Information on any commercial or recreational use of the watercourse.
- Details of available access routes for construction, operation and maintenance
- An understanding of the likely operation and maintenance requirements for the type of structure envisaged.
- Awareness of any nature conservation designations, protected species or habitats that might be adversely affected by the works
- Information on land use that might be affected by the works (e.g. impact of changed groundwater levels)

A list of stakeholders should be drawn up at an early stage in the project planning process, and contacts established. Consultation with the stakeholders will allow a range of issues to be discussed including appropriate timing of the construction works, restrictions on the type of materials used, likelihood of vandalism (during and after construction), space for site compound, preferred access routes, and health and safety issues.

1.4.2 Rehabilitation of an Existing Weir

The rehabilitation of a weir should provide opportunities to improve on the original design and to include mitigation measures that may not have been considered before, or that in hindsight would have been appropriate. Such measures might include the construction of a fish pass (see Case Study A) and/or the provision of better conditions for canoeists (see Case Study H). The impacts of rehabilitating a weir are likely to be the same as or very similar to those for constructing from new, but there are likely also to be additional impacts such as removal of material from the original weir, which may require partial demolition. For certain fish and birds, temporary works causing disturbance and stress may result in species seeking habitats elsewhere, thereby temporarily or permanently reducing the biodiversity of the reach.

Rehabilitating should allow previous experience and knowledge of the behaviour of the particular reach of river to be used beneficially. For instance, previous uncertainties may have lead to over-engineering and the use of inappropriate materials. Opportunities may present themselves that allow aesthetics to be improved. For example, rehabilitation may allow the use of a natural stone coping to complement the surrounding landscape or architecture.

The rehabilitation of an existing weir, especially one on the site of historic significance, offers the opportunity for archaeological exploration. This has been the case in the medieval Irish town of Kilkenny where the construction of flood alleviation works has been preceded by a major archaeological investigation.

Figure 1.8 Rehabilitation potential

Rehabilitation of a weir such as this offers considerable opportunities for environmental enhancement, as well as improved safety.

1.4.3 Decommissioning Weirs

In this section, the decommissioning of weirs includes lowering the weir crest and "notching" of the crest to the extent that such works can have a significant impact on the water environment.

(i) Environmental issues

Once more, environmental issues may be divided into short-term and long-term. Furthermore, any assessment should consider the strategic as well as the local impacts of weir removal. It should be appreciated early on that by removing a weir, habitat and species that have become established are likely to find the new conditions unfavourable for their continued existence. On the other hand, in the longer term, removal of a weir may have a positive impact on the reach of river in question.

Weirs in urban areas may be heavily engineered and designed for the purpose of regulating water level or diverting flows, often with negligible impact on the character of the river reach. In contrast, the diversity of changes to the characteristics of rural river reaches associated with the effects of weirs may be considerable. However, **approaching decommissioning with the sole thought that it must be a good thing "because the river is being returned to normal" is unacceptable**. Although the removal of a weir is likely to increase diversity in the river in the long term, it may result in the reach upstream and/or downstream of a weir exhibiting signs of biological degradation, such as low species diversity and colonisation by invasive plants. Table 1.3 presents briefly a few of the environmental issues that should be considered during the decommissioning of weirs. Note that it is important to think of the environment in its broadest sense, including issues of social and cultural heritage, when considering the removal of a weir.

If total demolition of a weir is unacceptable, then consideration should be given to lowering the weir. This may, for example, improve conditions for fish migration and reduce flood level upstream, whilst avoiding the total loss of an amenity or historic structure.

Table 1.3 Decommissioning weirs - environmental issues

Impact on	**Illustrative Impacts**	**Potential Opportunities** (not necessarily in direct response to the illustrative impacts)
Landscape	Removal of a feature that may have reduced the uniformity of a valley both at the micro and macro landscape scale.	Landscaping, planting schemes and habitat creation to provide discontinuities in the landscape.
Land use	Alteration of the groundwater regime of the riparian zone upstream.	Excavation of backwaters for wetland habitat.
Ecology	Reduction in the extent of the wetted perimeter, increased flow velocities, changes to sediment deposition and erosion.	Increased diversity through, for example the creation of varied marginal habitats, including backwaters, embayments etc.
Social	Permanent loss of a visual amenity.	Creation of a different visual amenity, for example a pool and riffle sequence
Archaeology and Heritage	Possible direct loss of riverine archaeology or function of an associated structure (e.g. mill-race).	Preservation of mill-race as open water (at a lower level) and wetland habitat.
Recreation and Amenity	Alterations to species mix of fishery.	In-stream structures such as groynes to vary flow, create visual features as well as varied territory for fish and canoeists. Provision of facilities for disabled anglers.
Geomorphology	Erosion of deposited sediments in the river bed.	Stabilisation of the river bed by the introduction of gravel and rock that will resist erosion and create a more varied habitat.

(ii) Engineering issues

The most important "engineering" issue to investigate as part of any plan to remove or lower a weir structure is the impact on the stability of the river channel. Removal of a weir has the immediate impact of steepening the water surface slope, with inevitable increase in the velocity of flow. The impact may be less at high flows, but there will nevertheless be a response from the channel, which could take place over a short period of time, or could take much longer to occur. At worst this could result in erosion of the bed of the channel, undermining of river walls and banks, and damage to other infrastructure (such as a bridge upstream). In extreme cases, the river may attempt to meander, with the risk of damage to adjacent infrastructure. Furthermore, any material eroded from the bed and banks upstream is likely to be deposited in slower-flowing water downstream, with potential negative impacts on ecology and amenity. It can therefore be seen that the broader impacts of removing a weir can be severe, and it would normally be appropriate to employ the services of a fluvial geomorphologist to help develop mitigating measures.

(iii) Business impacts

It must not be forgotten that many old weirs still do have a continuing function (or a potential function) in respect of, for example, water abstraction, recreational use of the river, water transfer, and energy generation. Where such functions exist, they will be of fundamental importance to the decision-making process examining the future of a particular weir.

This is perhaps particularly important in the context of weirs associated with navigable waterways. In the second half of the last century, many canals were "lost" in the race to develop more modern infrastructure. This is making the current revival of canals a much more expensive exercise than it need have been. In looking at the demolition of weirs in the future, it will be appropriate to take a more far-sighted view.

1.4.4 Summary

When planning the construction (or rehabilitation or decommissioning) of any engineering structure, the more information that is available in the early stages, the more likely it will be that the works will be appropriate and cost-effective. This is particularly true of hydraulic structures, which are not only exposed to demanding hydraulic loading conditions, but also are likely to have wide-ranging impacts. It is therefore vital to undertake extensive consultation with all the stakeholders, and it may be necessary to invest substantial time and money in data collection, including topographic survey and ground investigation.

It will be appreciated from the number of separate sub-sections in this guide that there are many issues to be considered when planning works on weirs. Furthermore, it is virtually impossible to design works on weirs that will fully satisfy the aspirations of all parties who have an interest in the weir or the reach of river in which it is located. Inevitably there will be instances where there are conflicts of interest. For example, a weir that is ideal for discharge measurement may not be ideal for fish migration (ongoing research is addressing this issue); or a weir that is ideal for fish migration may prove less acceptable to canoeists. It is important to realise that, in recognising the constraints, it should be possible to identify opportunities when looking at the options available. For example, it is possible to design a weir that has both adequate provision for fish migration and safe passage for canoeists (see Figure 2.30).

What is important, therefore, is that those responsible for planning and implementing works on weirs are aware of all the issues and the potential conflicts (the purpose of this guide), and that they consult fully with interested parties in order to seek the best solution. The reader is therefore urged to make full use of the whole of this guide. Accepting that many readers will not have time to read the guide from cover to cover, we have included a checklist of considerations in Appendix B. This should not be considered as a substitute for full use of the guide, but should point the reader in the right direction.

Finally, it should always be appreciated that rivers have tremendous recreational and amenity potential. Often such potential is unavailable to disabled persons, but this could be rectified at little extra cost if considered in the early stages of planning works at weirs.

Figure 1.9a   Labyrinth weir

The labyrinth weir has a long crest length in a relatively short overall width. It is therefore good for reducing upstream water level variation in low to moderate flows. In flood flow conditions, the labyrinth effect is diminished, and the weir will tend to perform as a broad-crested weir with a crest length equal to the width of the channel.

Figure 1.9b   The same weir with weed growth

Don't forget that all structures have maintenance requirements.

River Weirs – Good Practice Guide

Guide - Section B1

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R&D Publication W5B-023/HQP

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2. SECTION B – DETAILED GUIDANCE

2.1 Safety

2.1.1 Introduction

In the UK, 438 people lost their lives through drowning in the year 2000. Of these, 199 were in rivers and streams, and 44 in canals. Indeed, in June 2002, whilst this guide was being drafted, the weir featured on the front cover (Pulteney Weir in Bath) was implicated in the death of a 37-year old man who fell into the river. According to the local press this was "just the latest incident in which people have been killed or injured after jumping into the river around the weir".

Figure 2.1 Headline from the Bath Chronicle, June 2002

BODY RECOVERED: river level dropped to help search

Missing man found in weir

By Simon Davies

THE body of a man who disappeared after falling into the river in Bath was finally recovered from Pulteney Weir yesterday.

The body, found by police divers, has been confirmed as that of 37-year-old Welshman Gary Aston, who vanished early on Sunday morning.

The Avon and Somerset Police underwater search unit had spent three days diving around Pulteney Weir in the latest attempt to find him after his fall into the River Avon.

Mr Aston, of Penygraig, Rhondda, had visited Bath Races with friends on Saturday before enjoying a night out in the city when tragedy struck.

Police said Mr Aston had been "larking about" with a friend at the back of the Waitrose store in The Podium when they were seen by security guards.

The pair ran off and jumped over a chain fence leading to the riverbank.

Mr Aston fell in the water and the other hid in bushes for a while, unaware of the tragedy.

DANGER SPOT: Pulteney Weir with the water level lowered in the hunt for the missing man

Work and leisure activities in or adjacent to water inevitably carry the risk of drowning. In this guide we have attempted to raise awareness of the risks in relation to weirs.

As a result of the death of a teenager at a sluice in Somerset, the South West region of the Environment Agency set up OPUS – Operation Public Safety. This is now a national initiative aimed at reducing the risks to members of the public.

2.1.2 The Construction (Design and Management) Regulations 1994 (CDM)

In response to the poor health and safety record in construction the CDM Regulations were introduced in 1994 to ensure that safety is considered at all stages of the design and construction process. These regulations apply to works on weirs as they do to all other forms of construction.

The CDM Regulations place duties on clients, planning supervisors, designers and contractors to plan, co-ordinate and manage health and safety throughout all stages of a project. It should be emphasised that these regulations do not simply refer to the actual process of building the works, nor just to the construction personnel working on the site – they apply to the whole process from early planning, through design, construction, and onto subsequent operation and maintenance.

Construction works that will be completed in less than 30 days, or that will take less than 500 man-days to construct, are excluded from the Regulations unless there will be five or more people on site at any time. **However, CDM applies to all design work no matter how long the work lasts or how many workers are involved. Furthermore, CDM applies to all demolition work, regardless of the length of time or the number of workers.**

The following section provides guidance on safety issues under a number of relevant headings. In order to emphasise the importance of **considering how the weir will be used** once constructed, the guidance starts with recreation, amenity and navigation issues, then moves on to operation and maintenance, and only then addresses construction.

An important part of the planning of any weir scheme will be the establishment of a Risk Register. In this all potential risks are identified, with the aim of eliminating, mitigating or reducing them as the development of the project continues. Any residual risks will remain on the register, which will from part of the Health and Safety file for the project.

2.1.3 Recreation, amenity and navigation

(i) General

Rivers offer a wide range of leisure and recreational activities, from walking along the riverbank to angling, canoeing and boating. Weirs provide a focal point for such activities, attracting people and thereby exposing them to risks, including:

- Canoeists and other water users getting trapped in a reverse roller downstream of the weir
- Risk of injury to canoeists or swimmers from submerged sharp objects (rocks, corroding sheet piles, damaged gabion cages, etc)
- Swimmers not appreciating the depth and relatively low temperature of the water
- Walkers attempting to use the weir crest as a crossing point and falling into the river
- Exposure to contaminated water

It should be noted that owners or operators of river structures have a duty of care to anyone using the river, whether such use is authorised or encouraged or not. It is therefore necessary to consider all possible uses of the river when planning and designing weirs and related structures.

Appropriate design of the weir and associated works can ensure that the risks associated with recreational and leisure activities are minimised. In particular, users of the river need to be warned about the presence of the weir and the risks that it may pose. The installation of warning signs and protective booms may be appropriate for all rivers used for recreational navigation, to minimise the risk of boats being trapped on the weir crest, or carried over it.

Protective booms have proven to be very successful in reducing the risk of boating accidents at weirs. However, there is at least one case of a protective boom being implicated in an accident when it was struck by at boat at night. The boat capsized and lives were lost. Nevertheless, the risks posed by a boom are likely to be significantly less than the risks associated with navigators being unaware of the presence of a weir. Clearly, detailed design of safety systems at weirs needs to be founded on a full understanding of the risks, and must be carried out in full consultation with the navigation authority. This will include consideration of the types of activity on the river and, for example, the ability of craft to be manoeuvred into safety when the risk becomes apparent to a boater (for example, narrow boats with small engines cannot be steered out of danger quickly).

Figure 2.2 Safety boom upstream of a weir

The boom is designed to prevent accidental navigation over the weir. Note that the boom also acts to trap debris, which is difficult to clear.

Warning signs provide an inexpensive means of risk reduction. They should be located both upstream and downstream of weirs, so that navigators approaching from either direction have advance warning of the risks. High visibility is the most important requirement, with a simple message “DANGER – WEIR”. The provision of a visual image depicting the risk should also be considered to convey the warning to non-English speakers. In situations where there is a chance that a warning may be missed, such as when the approach to the weir is on a bend, more than one sign should be provided.

Figure 2.3 Warning sign

Warning signs need to be highly visible and secure against vandalism (NB And life jackets need to be fastened if they are to be effective!). In some circumstances it will be important to provide lighting at a structure, particularly if it is likely to be used (for example by canoeists) in conditions of poor natural light.

Side weirs for flood control can pose a particular risk to the public. Often these weirs are formed from lowered sections of flood embankments, which double as footpaths or even vehicular tracks (the spill weir at Willen Lake, Anglian region, is a cycle track). Whilst safe in normal flow conditions, these weirs can be extremely dangerous in floods. Carefully worded warning signs will be required to alert people of the risks of trying to traverse the weir when it is spilling. Guidance on signage on navigable rivers can be obtained from the Association of Inland Navigation Authorities (AINA); a code of practice is currently (November 2002) being prepared.

Perhaps one of the most difficult decisions with regard to public safety is whether to provide fencing or hand railing to restrict or discourage access to potentially dangerous areas. This decision should be made after a thorough assessment of the risks, which should then be weighed against the benefits of not fencing.

Figure 2.4 Security fencing

In situations where it is essential to discourage access or minimise vandalism, fencing like this may be necessary. Fortunately, most weirs do not require such a level of protection.

(ii) Safe access

In implementing works in rivers, those responsible should consider the provision of safe access for members of the public. In particular, where appropriate, access should be considered for walkers, ramblers, canoeists, anglers, swimmers, families with young children, and disabled persons.

In particular, at weir structures used by canoeists, provision should be made for safe and easy egress from the river both upstream and downstream of the weir. Shallow sloping banks (instead of vertical walls) are one of the simplest ways of achieving this.

Consideration of access for the disabled is perhaps most relevant when a new weir or a refurbished weir creates a public crossing point over the river. Early consultation with local interest groups will identify whether it is appropriate to make special provision for disabled persons. Clearly, where there is an identified need (or a justifiable desire) to provide access for the disabled, every effort should be made to incorporate such provision into the design (comprehensive guidance in this respect can be found in the Countryside Agency's "Increasing access to the wider countryside for disabled people"). Such provision may include car parks close to an amenity.

With respect to the specific requirements of established footpaths, guidance may be obtained from the County Council Rights of Way Officer.

Figure 2.5 Stepping stones

This imaginative way of providing access at a weir via stepping-stones needs careful consideration. Its simplicity and attractive appearance must be weighed against the risks of pedestrians slipping or falling into deep water.

2.1.4 Risks in operation and maintenance

In general weirs require limited attention for their operation and maintenance. They are normally robust structures and can be expected to last for years without much intervention. Maintenance activities include clearing debris from the crest, removing silt from upstream of the weir, providing safety booms, and carrying out repairs to the structure. Movable or gated weirs require routine maintenance to mechanical and electrical plant. The most fundamental consideration with respect to all such activities is the provision of safe access. Pedestrian access to the weir crest itself should not be encouraged, for obvious reasons (slippery surface, flowing water, risk of fall into deep/turbulent water). A footbridge is likely to provide the safest means of access, but this is not always possible. An alternative for maintenance personnel is the provision of eyebolts in the abutments, to which a safety harness can be attached.

The removal of large floating debris from the weir (for example, tree trunks) can be a difficult operation. Where it is not practicable to make specific provision in the design to make this activity less hazardous, consideration should be given to how operatives can adopt safe working practices. For example, the option of providing space at the weir abutments for lifting equipment may be appropriate for larger weirs, and is unlikely to add significantly to the cost.

Future maintenance of the river reaches upstream and downstream of the weir should also be considered in the planning and design stages. Activities such as clearing vegetation, cutting back overhanging trees, removal of silt and repairs to erosion protection may form part of the channel maintenance regime in the vicinity of the weir. These activities may be carried out from the adjacent land, or from the river itself, using floating plant and equipment. In both cases it is necessary to consider how the operations can be carried out safely.

British Waterways staff are frequently faced with maintenance problems that require access to the crest of the weir. A case in point is the need to replace lost or damaged dam boards (these are commonly provided on the crest of a weir, spanning between vertical steel H-columns, to allow seasonal adjustments to canal water levels). BW have found that, if the weir upstream face is vertical, they can manoeuvre a maintenance vessel right up alongside the crest in low flow conditions, moor it in place, and thereby gain safe access to replace a missing dam board.

Weirs that incorporate a fish pass, regulating gates, and/or flow/level monitoring equipment are likely to require more maintenance than a simple weir structure. The specific requirements of any particular installation must be considered in the design process, and the design tailored to facilitate safe maintenance activities.

For any activities that require operatives to venture in or near the water, it is important that the all those concerned are aware of the risks and take suitable precautions. Reference should be made to relevant Health & Safety guidance before venturing on site.

In terms of planning the construction of a new weir, it should be noted that this might have implications for channel maintenance if this activity has previously been carried out by floating plant, because the weir will form a barrier to such plant.

Another factor to consider in the design of new or rehabilitation works, is the incorporation of the means of isolating parts of the structure, and/or temporarily lowering water levels, to facilitate inspection and maintenance. The provision of a penstock in or adjacent to a weir could, for example, allow the water level to be lowered in times of low flow, to allow inspection and maintenance of the weir crest, glacis and stilling basin. Similarly, provision for stoplogs on a fish pass or sluice could allow dewatering for inspection and maintenance activities (see Case Study N).

2.1.5 Risks in construction and rehabilitation

This guide is not the appropriate place for a treatise on construction risks. Excellent guidance can be found in "Construction risk in river and estuary engineering" (Morris and Simm, 2000). Specific risks relating to the construction and rehabilitation of weirs include:

- Rapidly increasing flow in the river
- Slippery and uneven surfaces
- Pockets of deep water where the river bed has been scoured out
- Dangerous hydraulic conditions immediately downstream of the weir
- Exposure to water-borne diseases.

2.1.6 Risk reduction measures

In the design of new or rehabilitated structures, consideration should be given to:

- Avoiding dangerous hydraulic conditions downstream of the weir
- Providing life belts and/or throwing lines on both banks (NB these tend to be a focus for vandalism, and should not be relied upon as a sole solution to a risk of drowning)
- Providing a boom across the channel upstream of the weir to warn boaters and help prevent accidental navigation over the weir
- Providing warning signs in prominent positions, both upstream and downstream
- Providing hand-railing along weir abutments (although that it should be noted that hand-railing can also restrict access for operations and maintenance staff)
- Avoiding vertical wing-walls and abutments where possible, to make it easier for people to get out of the water if they find themselves in difficulty (or to make their rescue easier)
- Avoiding leaving submerged hazards in the river that will pose a risk to swimmers or canoeists. This is often a problem when an old weir is rehabilitated, especially if the new works are constructed upstream, leaving corroding steel piles or frayed gabion baskets in the bed of the river at the old weir.

It is important to note that provision alone of the safety features listed above is not in itself sufficient to guarantee a high degree of safety. It is essential that a documented inspection regime, with appropriate inspection intervals, is established to ensure that the measures remain effective.

In the particular case of booms, these are largely intended to prevent leisure boats in inexperienced hands from being navigated over the weir. For canoeists who wish to shoot the weir, the boom may itself create a hazard, since negotiating it can require release of the paddle. For weirs used by canoeists, the boom should therefore be located well upstream of the weir if possible. Similarly, where booms are provided downstream of a weir, to prevent boaters from approaching the turbulent waters, they should be located some distance downstream, to avoid risk to canoeists for whom they can present a serious hazard.

Figure 2.6 Dangerous side weir?

This side weir regulates the water level in the navigation waterway. There are clearly risks associated with people gaining access to the structure, with a steep drop on one side and deep water on the other. Basic risk reduction measures have been provided in the form of fencing and safety equipment, but more could be done. However, it will never be possible to restrict all access or provide comprehensive safety equipment – it is a question of balance.

2.2 Legal and planning issues

This document is not the appropriate place to go into detail on the legal and planning issues that are of relevance to works on weirs. Early consultation with the planning authority and statutory consultees will ensure that such issues are raised and taken into account. However, it is worth noting the following:

The Land Drainage Act 1991 requires that the consent of the drainage authority is sought before the construction of, or alteration to, any mill dam, weir or similar obstruction on a watercourse. In the case of an ordinary watercourse, the drainage authority is likely to be the local council, but may be an internal drainage board. In the case of a main river, the consent of the Environment Agency is required for any works on the bed and banks of the river.

An ***impoundment licence*** may be required for the construction or modification of any weir. If the purpose of a weir is to allow removal of water from the stream, an ***abstraction licence*** will be required. It follows that, if an existing weir has been constructed for the purpose of water abstraction, then consultation with all parties concerned will be required before the weir is removed or altered in any way that would affect the abstraction of water. If abstracted water is returned to the river after use (including passing through a lake) ***discharge consent*** may be required**.** ***Navigation consent*** will be required for any works in a navigable river.

The Wildlife and Countryside Act (1981, as amended by the CROW Act, 2000), which is reviewed every five years, provides protection to certain listed species. It should be noted that it is an offence to take, damage or destroy the nest of any wild bird whilst that nest is in use or being built. The Act affords protection to flora and fauna under specific schedules. Schedule 1 of the Act lists protected bird species, of which there are about 85.

The Salmon and Fresh Water Fisheries Act (SAFFA) provides power for the Environment Agency to require fish passes for migratory salmonids and, as a result of the Environment Act, such fish passes must be approved in form and dimension by the Agency. Other Acts permit the Agency to require fish passes for other species, including coarse fish, eels and elvers. This is an area of technical specialism that requires consultation with experts.

The European Directive on the Conservation of Natural Habitats and of Wild Fauna and Flora (92/43/EEC) emphasises actions to conserve habitats and to restore populations of plants and animals to a favourable conservation status. As well as requiring the establishment of Special Areas of Conservation, the Directive requires wider countryside conservation measures. Annex I of the Directive provides details of specific types of protected habitats that may be relevant to weirs and Annex II lists protected species. The environmental assessment should aim to establish the presence or absence of any of these habitats and species.

Riparian owners (i.e. the proprietors of land adjacent to a river or stream) have certain rights and also certain duties. It therefore is essential that ownership of a weir, and the adjacent land, is investigated from the outset, and the consent of any riparian owner is sought before any proposals are finalised. A specific case of this is the question of mill rights, which needs to be fully explored before works are undertaken at mills. It is also important to appreciate that works on a weir may have impacts well beyond the immediate environment, and landowners both upstream and downstream could be affected (see Case Study E).

Other legislation that will be of general relevance includes:

- The Construction (Design and Management) Regulations (1994) – see Section 2.1.2 herein
- The Environment Act (1995)
- The Water Act
- The Land Drainage Act
- The Wildlife and Countryside Act (as amended by the CROW Act, 2000)
- The European Habitats Directive
- In the particular case of access to weir structures, it may be appropriate to consult the Disability Discrimination Act (1996).

River Weirs – Good Practice Guide

Guide - Section B2

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2.3 Engineering

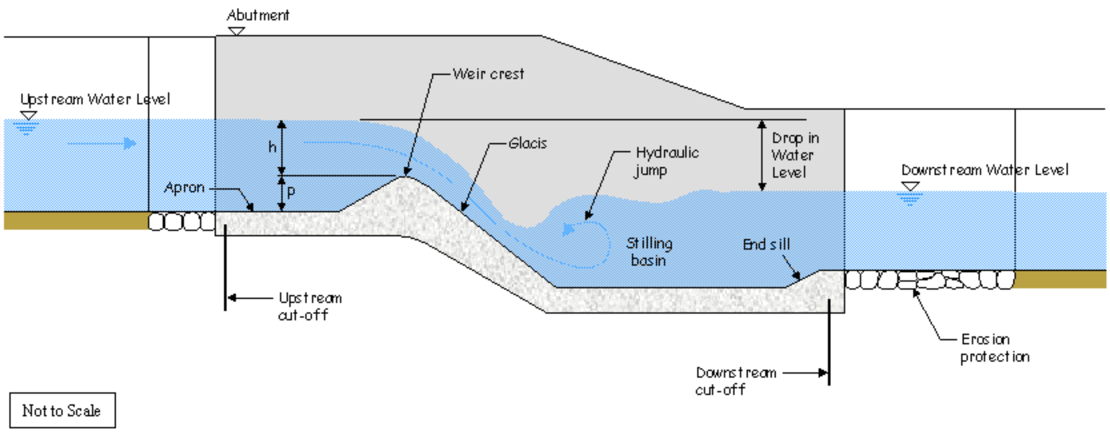
2.3.1 Introduction

Weirs are a bit like icebergs – most of the structure remains unseen throughout their life. Furthermore, the unseen portion is largely inaccessible and therefore must be engineered to remain durable with little maintenance. Weirs constructed to low design standards or skimped on safety factors, run the risk of premature damage or collapse, and may end up costing more in the long run. Weirs formed from dumped rock are often seen as an inexpensive answer. It is true that such weirs can offer a rapid, cheap and attractive structure in small rivers, but unless properly engineered, they can be demolished in the first significant flood (see Case Study E). This guidance is not intended to dissuade designers from using dumped rock, but to warn of the potential risks of not undertaking a robust engineering design whatever the materials.
The four cornerstones of good engineering for weirs are therefore:

1. Hydraulics
2. Foundations (including river channel stability upstream and downstream)
3. Materials
4. Construction (method/approach)

Figure 2.7 illustrates the main components of a weir, and the technical terms used to describe them.

Figure 2.7 The basic components of a weir structure



2.3.2 Hydraulic Design

(i) Fundamentals

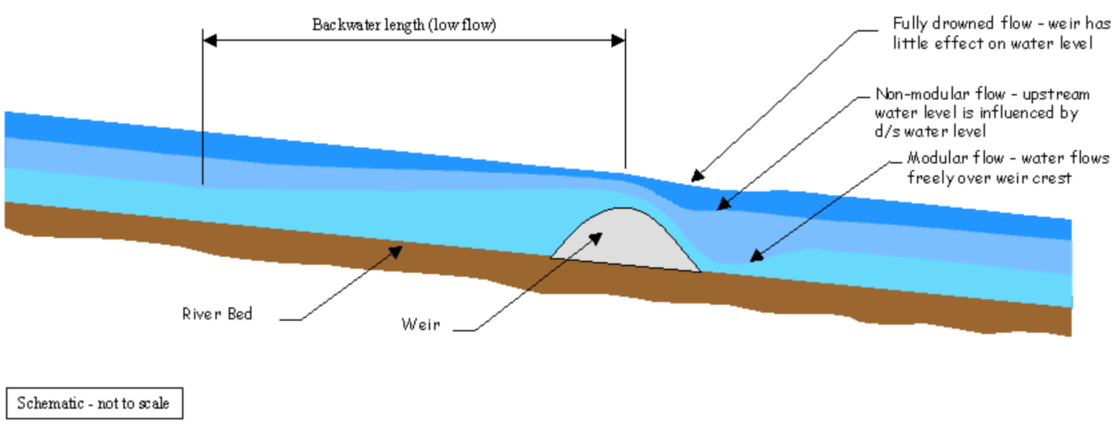
Weirs are often provided for purposes other than simply raising water levels; whether this is for navigation, flood defence or habitat improvement. One of the primary reasons that weirs have been installed over the past 50 years is for the purpose of gauging flow (discharge) in rivers, and in the UK there are about 750 gauging stations on the river network. Fewer flow-gauging weirs have been installed in recent years, in part because of the impact they have on land drainage, navigation, fisheries and recreation. In addition, the development of new gauging methods including ultrasonic and electromagnetic systems, allows flows to be measured without the need for a weir, although these alternative approaches are not without their problems.

In simple terms, the hydraulic impact of a weir is to increase the upstream water level. The water level upstream of the weir is dictated by the head (dimension "h" in Figure 2.7) required to drive the flow (Q) over the weir. Of course, the impact of the weir on upstream water level is not confined to the immediate vicinity of the weir. There is a "backwater effect" (see Figure 1.6), which extends some way upstream of the weir.

The increase in water level will, for the same flow rate, reduce the average velocity in the upstream reach, which may in turn have an impact on the sediment transporting capacity of the channel. The slower velocities will have knock-on effects in terms of water quality and habitat type. There are downstream issues as well, namely that there is likely to be a localised increase in turbulence and flow velocity immediately downstream of the weir. This has the potential to cause erosion of the river bed and banks, and may result in the creation of a deep pool downstream of the weir, and deposition in the form of a shoal further downstream (see Case Study C).

As the flow over the weir changes, the head (depth of water) over the crest will also change. This results in there being a link between the discharge over the weir and the upstream head above the weir crest; shown mathematically this is $Q = f(h)$. It is this principle that allows weirs to be used for discharge measurement. This mathematical link between upstream head and flow remains valid whilst the downstream water level is low enough to have no impact on upstream water level, i.e. whilst the flow remains 'modular' or free flowing. As flow increases in the river, the downstream water level will naturally increase since the river is being asked to carry additional water. Eventually the water level will increase to a point where water no longer freely discharges over the weir crest, and a situation occurs where a change in downstream water level will indeed have an impact on upstream level. When this occurs the weir is described as being 'drowned', 'submerged' or operating under 'non-modular' conditions (see Figure 2.8). Instead of flow being a function of upstream head only, it is now dependent upon both upstream and downstream levels, i.e.. $Q = f(h_{up}, h_{down})$.

Figure 2.8 Modular and drowned flow conditions

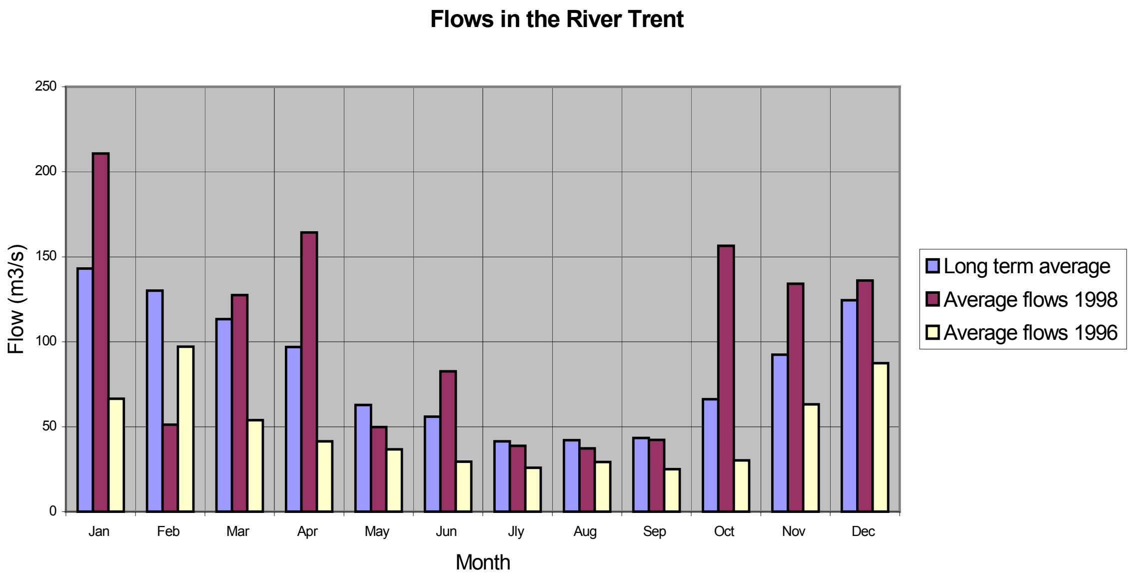


Once a flow gauging weir becomes 'drowned' it is unable to provide accurate flow measurement, unless specific arrangements have been made. As downstream water levels continue to increase still further, above the minimum levels that caused drowning, then the impact that the weir has on upstream water levels becomes less significant, see Figure 2.8. In other words, under high discharge situations where a weir becomes drowned, its impact on upstream water levels is not significant (NB This may not apply for weirs with a large head drop across them).

(ii) Flow range

Rivers in England and Wales generally exhibit significant seasonal variation in flow, but this may not be pronounced. Figure 2.9 gives an indication of the flow range in the River Trent at Stoke Bardolph weir.

Figure 2.9 Flows in the River Trent



The figure is based on data for the period 1970 to 2001 (32 years of record). It can be seen that the long-term average monthly flow shows a distinct seasonal pattern, with the highest flows generally occurring in January, and the lowest in July/August. However, examination of actual monthly average flows for the years 1996 (a generally dry year) and 1998 (a rather wet year) shows that the average flow rates hide a wide range of variation. So, for example, the long term average flow for the month of October is about 65 m^3/s, but it 1998 the monthly average was more than twice this at 155 m^3/s, and in 1996 less than half at 30 m^3/s. It is important to acknowledge this natural variation, not only in terms of the design of a weir, but also in terms of planning construction activities in the river.

Furthermore, even this does not tell the whole story, as the peak flow experienced in 1998 exceeded 400 m^3/s on at least one day in each of four months of January, March, April and October, with a recorded maximum of 484 m^3/s. The highest recorded peak occurred in November 2000 when the discharge reached 1019 m^3/s.

At the other end of the scale, typical low flows in the summer months are about 40 m^3/s, but fell to around 25 m^3/s for the summer months of 1996. In 1976, the UK's famous drought year, the flow in August fell to an all-time low of 15 m^3/s.

Such variations in flow are typical of UK rivers, although clearly the range of flows likely to be experienced at any weir site will vary with the size of the river and the size and nature of the catchment area upstream.

A weir must be designed to operate satisfactorily in all flow conditions. It is therefore important that all available flow data for a river are obtained when planning the construction, rehabilitation or demolition of a weir.

Although rare flood conditions are likely to impose the most demanding loads on the structure, the structure must withstand the relentless everyday wear imposed by flowing water. However, it is also important to examine the performance of a weir in all flow conditions for reasons other than durability:

- What will the visual appearance of the flow be in low flow periods? (For example, it may be preferable to have the low flow concentrated in one part of the weir rather than spread thinly across the full crest length – this can easily be achieved by incorporating a low-flow notch in the weir crest (see Figure 2.11).
- Will some flow conditions restrict the passage of migrating fish?
- At what flows might dangerous hydraulic conditions occur?
- Will the weir form a tempting crossing point at low flow conditions, and will this be safe?

Note – There is no specified or standard requirement to design a weir for a particular flood flow, but it is advisable to design for at least the 1% annual food (100-year return period), and it would be wise to check performance for more extreme floods (up to, say, the 1000-year flood for a major weir).

(iii) Drop in water level

A weir, by definition, raises the upstream water level in a river for most, if not all flow conditions. In doing so it creates a sudden drop in the water level in the river, the nature of which changes with changing flow conditions.

Figure 2.8 illustrates the impact of a weir on water levels for different flow conditions. It can be seen that the influence of the weir is greatest in low flows. In high flows, weirs are often drowned, such that it is not apparent to the casual observer that there is a weir there at all. The bigger the drop in water level across the weir, the less likely it will drown in high flows.

(iv) Flood flow conditions

It is important to pay particular attention to the performance of a weir in flood conditions, when water is likely to flow on the adjacent flood plain. In such conditions there is a risk of the weir being by-passed, and this could have serious implications if it has not been allowed for in the design. In particular, the by-passing flow could undermine the weir wingwalls or abutments, ultimately leading to the formation of a new channel leaving the weir stranded. This problem is much less likely if the weir has only a modest impact on the water level in the channel in flood conditions.

In cases where the weir is likely to be by-passed, it may be appropriate to design for this. A channel can be formed around the weir, at a safe distance from it, to direct flood flows around the structure. The bed and banks of this channel are likely to require protection against erosion to ensure that it remains stable and effective in operation.

There is no absolute guidance on the size of flood to be accommodated by a weir, but it is recommended that the performance and safety of a weir is assessed for at least the 1% annual probable flood (100-year return period).

Figure 2.10 Weir on the River Exe flood bypass channel

The first photo shows the weir when the bypass is not operating, the second when the river is in flood.

(v) Flow gauging weirs

One of the most common reasons for constructing a weir in the last fifty years or so was for the purposes of monitoring flow in rivers. Many of these weirs were constructed with the aim of monitoring low flows, amidst rising concern about the reliability of water supplies for domestic and industrial uses. Because of this focus on low flows, many such weirs were by-passed in flood conditions and gave unreliable data on high flows.

More recently the construction of flow gauging stations has focussed on recording flood flows, spurred on by the recent spate of floods in the UK, which exposed some significant gaps in our knowledge of flood flows and levels in many rivers. Even though many of the new stations use ultrasonic or electromagnetic flow measuring techniques, weirs are still being constructed for flow gauging purposes.

Figure 2.11 A flow gauging weir with a central low-flow section

Flow gauging weirs are often required to measure both high and low flows accurately. One way to achieve this is to have a low flow section in the weir. The flat-vee weir (see Figure 2.12) is another alternative.

For modular flow conditions, the flow rate over the weir can be determined with good accuracy from the measurement of upstream water level alone. In high flow conditions such weirs tend to drown, and it is necessary to measure water level downstream as well, and for even greater accuracy, at the weir crest (see Crump weir below).

The ideal flow-gauging weir is capable of recording both high and low flows. Traditionally such structures had a central low-flow section, but more recently we have seen an increase in the use of flat-vee weirs. The flat-vee weir is less likely to trap silt upstream, and has better accuracy over a wide flow range. However, in attempting to measure both high and low flows, there is potential for making conditions for fish passage worse. The flat-vee weir presents particular problems for fish (see Section 2.3.10).

The most common cross section adopted for a flow-gauging weir is the Crump profile, named after E S Crump who developed it in the 1940s with the aim of accurately measuring low flows as well as high flows. This weir is normally constructed in concrete with an upstream face sloping at 1:2 (vertical : horizontal), and a downstream face at 1:5. The weir needs to have a sharply defined crest for accuracy of flow measurement, so this is normally formed by a steel insert in the concrete. To allow accurate flow monitoring throughout the flow range, tapping points are provided in the crest leading to a stilling well for accurate measurement of water level (from which the flow at the time can be calculated). Crump weirs have the potential to provide passage for fish – reference to the latest guidance is recommended (see Section 2.3.10).

Flow gauging weirs should be constructed in straight reaches of river or stream where the flow is not turbulent, such that the approach flow conditions are uniform, otherwise the measuring accuracy of the weir will be reduced. All flow gauging weirs require a crest constructed to close tolerances to ensure that the flow measurement is as accurate as possible. Requirements for flow measuring weirs are set out in BS 3680, Measurement of liquid flow in open channels.

Figure 2.12 Construction of crest for a flow gauging weir

For accurate flow measurement, this flat-vee weir has a steel crest insert that is precisely positioned prior to casting in concrete.

(vi) Aeration of the nappe

The nature of water flow over a weir depends on many factors. Contrast the natural cascading flow illustrated in Figure 2.29 with the clean "nappe" of the flow over a tilting gate weir (Figure 2.13 below). In certain situations it is important to achieve a smooth undisturbed flow of water over a weir. This may be for visual appearance, or to reduce the risk of vibration in an adjustable steel weir. In the latter case, the nappe (or jet of water over the weir) is not in contact with the weir glacis once it has spilled over the crest. The gap between the weir and the nappe can exhibit pressure fluctuations if not properly aerated.

Figure 2.13 Aerated nappe

In this structure aeration of the nappe is ensured by providing a gap between the walls of the structure and the edge of the tilting gate. An alternative way to achieve this is to provide a flow splitting device in the centre of the weir crest. This divides the jet leaving the weir and allows air free access to the underside of the nappe. In both cases the aim is to reduce the risk of vibration of the weir gate.

(vii) Model studies

Hydraulic structures have to perform satisfactorily across the full range of flow conditions that will be experienced during their lives. For simple geometric structures that follow standard designs (for example, a Crump weir), the hydraulic performance is sufficiently defined by theory to allow the design to be prepared following available guidance. For more complex structures, particularly where the designer is looking to achieve different characteristics for differing flow conditions, it is recommended that model studies are undertaken. This is most likely to require a *physical* model (i.e. a scale model constructed in a hydraulics laboratory).

Indicators of the need for a physical model include:

- A weir geometry that is complex (i.e. the weir cannot readily be represented by a single cross section)
- A weir shape/form that varies from standard structures
- Where specific hydraulic features are required (or need to be avoided) in certain flow conditions (such as might be required for the safety of canoeists)
- Where an existing structure is being significantly modified to achieve specific hydraulic performance (see Case Study B).

The big advantage that a model study offers is the ability to test a range of solutions over a wide range of flow conditions (see Figure 2.21).

2.3.3 Foundations

(i) Introduction

Apart from destruction by hydraulic forces, the most common cause of weir failure is loss of foundation support. This can be caused by construction on weak foundations (for example a peat layer) but is more often the result of loss of foundation material through seepage (see (ii) below), or undermining of the apron due to erosion downstream.

In approaching the design of a weir, or the rehabilitation of an existing structure, it is therefore important to have information on the nature of the foundation. This is most often obtained through drilling boreholes or digging trial pits, and the most important parameters are nature of the material (e.g. peat, clay, sand, gravel, mudstone), the depths of the various horizons, permeability, and bearing strength.

In the particular case of existing structures, especially if there is doubt about the integrity of the structure, it may be appropriate to make use of non-invasive investigation techniques, such as ground-probing radar. Such techniques can, if properly applied, give information about voids in or under the structure, or the thickness of the various construction materials. Specialist advice should be sought about appropriate techniques, and evidence of successful use in similar circumstances should be requested before embarking on expensive experimental methods.

(ii) Seepage

Seepage under or round a weir can destabilise the structure by removing finer soil particles and eventually creating voids. In extreme cases, seepage flow returning to the river downstream of the weir can cause a piping failure, in which the riverbed loses all strength. This can undermine the weir apron and lead to complete collapse. This problem is generally avoided by providing cut-offs (see Figure 2.7) in the riverbed at the upstream and downstream ends, most commonly in the form of sheet piling (steel, concrete, timber). The cut-offs extend the seepage path and reduce the hydraulic gradient that causes piping. It should be remembered that this is a three-dimensional problem and that the cut-offs should extend into the banks of the river under the wingwalls to increase the length of the seepage path round the sides of the structure.

Seepage through the weir structure is common in many old masonry weirs and, in many instances, this is of no great consequence and can be ignored. Over a long period of time, this type of seepage can become problematic, with risk of structural failure (e.g. risk of un-bonded masonry blocks being washed away in a flood). In this case, it will probably be necessary to repair the structure by grouting (risk of pollution) or by dismantling and reassembling the structure.

Weirs constructed from gabions require particular attention with regard to seepage. Gabions are permeable and unless the boxes are sealed in some way, low flows in the river will tend to pass through the weir rather than over it. As well as running the risk of erosion of the foundations of the weir, flow through the weir will create unfavourable conditions for fish. Gabions can be sealed by a concrete facing or by use of an impermeable membrane, which must be tied into the bed and banks of the river to avoid being undermined or by-passed.

Figure 2.14 Repairs to mortar joints in a masonry weir

Repair of mortar joints in a masonry weir using a proprietary product to resist erosion damage (photograph courtesy of Easipoint, Chorley, Lancs).

(iii) Uplift

Hydrostatic pressure under the weir structure will lead to uplift forces that can cause failure of the weir if not adequately resisted by the weight and strength of the structure. In general, the provision of an upstream cut-off wall will decrease uplift, whereas a downstream cut-off will increase uplift. The bigger the difference in water level across the weir, the more serious the uplift problem is likely to be.

Uplift forces can be resisted by increasing the weight of the structure (by increasing the thickness of the concrete floor, for example), or they can be reduced by the provision of suitable drainage (for example, pressure relief valves in the weir apron).

The worst case for uplift is likely to be in low flow conditions when the water level difference between upstream and downstream is highest, and there is little weight of water on the downstream apron. The use of stop logs or sandbags to maintain the upstream water level and allow dewatering of the weir apron for inspection can compound this problem. In extreme cases, the uplift force on the apron could cause it to lift and crack, requiring expensive repairs.

Uplift can also be problematic in high flow conditions if the energy of flow over the weir is sufficient to push the hydraulic jump off the downstream apron. This results in conditions where there is little weight of water on the apron, yet uplift forces are high due to high upstream and downstream water levels.

(iv) Stability

In general, weir structures impose a relatively low pressure on their foundations, and therefore differential settlement leading to deformation and cracking is unlikely to be a problem. If there are weak layers in the foundation (e.g. peat), it may be necessary to removed them or, in extreme circumstances, to support the weir on piles. In the early days of weir construction, when construction methods were limited by available technology, the use of timber piles to support weirs on weak alluvial soils was quite common. This may be a key factor in the design of major remedial works to an old weir, as the timber piles can present formidable obstacles to the driving of steel sheet piles.

Figure 2.15 Northenden Weir, River Mersey

The presence of old timber piles can complicate remedial works to weirs, especially if it is necessary to drive steel sheet piles through the old timber piles.

Excavations in river beds are inherently unstable due to the nature of the bed material and the presence of water. Major works in rivers will therefore almost certainly require the construction of a cofferdam (using steel sheet piles or earth fill). This will need to be dewatered to allow construction of the foundations, requiring substantial pumping capacity.

The overall stability of the river channel will, in theory, be enhanced by the construction of a weir, but local changes in flow direction and velocity will increase the risk of erosion of the bed and banks. There is therefore often a need to protect these with some form of revetment to ensure long-term stability of the channel. Conversely, the removal of a weir from a river could destabilise the channel over some considerable distance upstream and downstream, leading to environmental as well as structural damage.

(v) Archaeology

Rehabilitation works to existing weirs and, indeed any excavations in rivers in urban areas, may expose archaeological remains of considerable significance. In the case of the flood alleviation scheme for the town of Kilkenny in Ireland, extensive archaeological investigations were carried out prior to the construction works. (See also Section 2.4.6).

(vi) Fluvial geomorphology

The construction of a new weir, or the removal of an old one, will have an inevitable impact on the sediment regime of the river, with both positive and negative results. Sedimentation and erosion patterns will change, affecting the performance of the structure and the environment in which it is located. To a large extent these changes can be predicted, but assessing the degree of change, and the associated impacts, requires the input from a specialist in the field – a fluvial geomorphologist.

For all substantial structures, and particularly in rivers where sediment movement is significant, it is recommended that a fluvial geomorphologist is engaged to advise on the likely impacts and the available mitigating measures. Issues will include:

- The impact of sedimentation and erosion on aquatic flora and fauna in both the short and long term
- Design features that can reduce the impacts
- The stability and long-term sustainability of any environmental features introduced into the river (e.g. gravel shoals)
- The need for and type of erosion protection of the bed and banks.

2.3.4 Materials

There is no doubt that good quality concrete is one of the most durable materials available for the construction of weirs. However, there is a wide range of materials to choose from, and the choice should be made on environmental and economic grounds as well as engineering need. In addition to materials having to be robust enough to withstand the hydraulic loading, consideration should be given to the aesthetic impact of materials on landscape and ecology. This applies equally to the materials to be used in the weir itself; and to the materials that should be utilised in associated mitigation measures. Whereas a sound and smooth concrete surface may be excellent for hydraulic performance and durability, a more heterogeneous/rougher surface will be beneficial for small fish and eels/elvers. As ever, arriving at the right solution will be a question of striking the right balance between potentially conflicting requirements.

Locally sourced materials are often used for small weirs, whilst reinforced concrete is normally the material of choice for larger projects. The visual impact of concrete and steel may be softened through the use of coping stone more appropriate to the surrounding setting (see Case Study N). For instance block-stones may be keyed in to hide underlying concrete or gabion baskets. In an urban environment it may be appropriate to use vernacular bricks or local stone to disguise an underlying structure of concrete or steel sheet piling. Care should be taken not to over-mitigate, nor to cause partial loss of the function of the weir through the use of inappropriate materials.

Figure 2.16 Concrete weir

This weir may be hydraulically efficient, but the stark concrete finish makes the structure unattractive (and the lack of hand railing raises questions of safety).

The following points should be considered in respect of the materials to be used on a weir:

- Where possible materials requiring bulk transportation should be obtained from local sources and from accredited suppliers

- Where hardwoods are to be used, they should come from Forest Stewardship Council approved sources
- Brick and stonework should complement any existing structure
- Material from decommissioned weirs should be re-used, recycled or disposed of appropriately. Contaminated soil, including river bank material that contains invasive species (Japanese knotweed, Himalayan balsam, hogweed) should be treated and disposed of as contaminated waste
- "Soft" or "Green"- engineering techniques, e.g. bank stabilisation using faggots (Hemphill and Bramley, 1989), should be used where appropriate. Materials should be obtained locally where possible, and care should be taken that there is no transmission of tree diseases (Alder fungus).
- In areas prone to vandalism, care should be taken to select materials that are less easily damaged or defaced (in this respect, concrete is preferable to gabions, for example)
- The devil is often in the detail. For example, steel open tread flooring may be ideal for access platforms for maintenance personnel, but may be inappropriate for public access (it is not an attractive construction material, and dog claws can get caught in it). Timber decking can look very attractive, but may become very slippery in wet conditions, particularly in shaded areas.

Table 2.1 lists the main options for basic construction materials, with some guidance on their attributes and limitations. It should be remembered that much of a weir's structure remains hidden from view (below ground or below water), so the use of more attractive/environmentally appropriate materials above water level may not add greatly to the cost.

Table 2.1 - Materials for the construction of weirs

Material	Uses	Limitations
Brick	Small structures in an urban setting. The right choice of brick can create an attractive weir. Engineering bricks should be selected where durability and frost resistance is required.	Long-term durability, including loss of mortar and frost damage. Avoid brick on the weir crest and glacis as it can become very slippery with time
Concrete	A good engineering material, durable and suited to many applications. Frequently used for discharge measuring structures.	Can be unattractive. Exposed areas can be improved by the addition of a brick or masonry facing, exposed aggregate finish, or patterned formwork to create micro-habitats.
Masonry	Commonly used in the early days of weir construction. Can be very attractive. Can be used to disguise a concrete structure.	Old weirs may exhibit loss of mortar leading to seepage through the structure.
Steel sheet piling	Often a component of modern weirs because of ease of construction, use as a cut-off, and use in temporary works	Unattractive if not faced in masonry or brickwork. Corrosion may be a long-term problem. Less hydraulically efficient than a more even surface such as concrete or brick.
Rock	Ideal for forming a "natural" structure	Must be properly engineered to ensure

	with least impact on the environment. The size of the stones is important. Too small and they may be washed away; too large and the water will flow round rather than over them (see Case Study N).	that it does not get washed away in the first flood (see Case Study E). Good quality durable stone is required to ensure long-term integrity. For a significant drop in water level, a sheet pile cut-off may be required. Flow can "disappear" into the rock in low flow conditions. .
Gabions (wire baskets filled with stone)	Can be a cheaper alternative to concrete or masonry, with a more natural appearance when colonised by vegetation. Inherent permeability can aid drainage through retaining walls. Can be used in mattress form for erosion protection, or box form for retaining walls. However, not universally liked – see limitations opposite.	Need to be properly constructed with due attention paid to filling the gabions, limiting or preventing seepage, and durability of the wires. Corrosion rates can be unacceptably high in acidic waters - the use of plastic coated wires will reduce corrosion. Can be hazardous to swimmers, canoeists, and other river users if wires deteriorate with time. Can be prone to vandalism – avoid in places where the level of access by children is likely to be high.
Timber	Ideal for small temporary structures.	Durability and stability.
Fibre-glass	Has been used for the crests of weirs used for electronic fish counters	Durability in high flows – vulnerable to vibration damage and impact from floating debris.
Earth	Earth weirs are commonly used as side weirs to evacuate flood flows from the river. Often these are un-reinforced earth structures, with a grassed surface.	Un-reinforced earth can be used for low intensity flow. For high intensity flow the surface of the earth weir will need to be reinforced with geotextile, concrete revetment or gabion mattress.

As far as cost is concerned, this is a function of the material cost as well as the associated construction cost. Costs of haulage of materials may be significant if the source is some distance away. For example, if the locally available stone is too small to use as dumped rock, it may be cheaper to use a gabion mattress (which can be filled with the available small stones) rather than import suitable sized rock from 100 km away to form a dumped stone weir.

2.3.5 Construction

(i) Risks

Construction in the unpredictable environment of a river is risky, both in terms of health and safety, but also in terms of financial risk. Risks can be reduced by:

- Selecting the right contractor for the job (experience of similar works) and ensuring good site supervision when the works are in progress
- Carrying out a thorough site investigation prior to commencing the works. The extent of the investigation will depend on the scale of the works. For major works, a comprehensive geotechnical investigation will be required
- Making available to the contractor as much information as possible about the site and the hydrology/hydraulics of the river, particularly in relation to the frequency and duration of flood flows, (so that he can properly assess the risks in planning

his approach to the works)
- Being aware of the activities and needs of all potential river users
- Being aware of the impacts of construction activities on the river environment, and taking steps to mitigate these
- Taking account of any environmental restrictions that will affect the timing of works (e.g. migratory fish runs, bird nesting season).
- For a comprehensive treatise on risk, refer to "Construction risk in river and estuary engineering" (Morris and Simm, 2000).

A risk register should be set up in the early stages of any project, no matter how small. This should identify all the risks that might impact on the delivery of the project (in terms of quality, cost and programme, as well as ability to meet the project objectives). The risk register should be a living document that is developed as the project proceeds, with the intention of identifying all potential risks and taking steps to eliminate, reduce or mitigate them. For example, in the early stages of development of a weir refurbishment project, risks might range from cost escalation due to lack of knowledge of the weir structure, to pollution due to the exposure of contaminated sediments. The risk of both of these can be reduced by carrying out a thorough survey/site investigation, the extent of which will depend on the size of the project and the perception of the level of risk.

(ii) Access

All construction works require access to the site to allow the movement of plant, labour and materials, and to facilitate the removal of any waste from the site. In the context of river works, sites are often difficult to access and may incur negative environmental impacts. Access requirements should therefore be investigated early in the planning process so that:

- The design can be adapted if necessary to suit any restrictions on access (physical or environmental)
- Negotiations with affected landowners and other interested parties can be started in good time (see Case Study M)
- Enabling works, such as tree pruning or footpath closure can be organised in advance of the works starting on site. Such works may be season-dependent – this should be considered early on in the planning process.

(iii) Temporary works

Temporary works are those required as an essential part of the construction works (or demolition works), but which will generally be removed as the construction progresses. Some temporary works may be left in place to form part of the permanent works – for example, steel sheet piling used for a cofferdam can be partly left in to form upstream and downstream cut-offs (see Case Studies K, L and M).

In the context of work on a weir temporary works might include:

- Temporary diversion of the river to allow construction of the weir in dry conditions (see Figure 2.17)
- Cofferdams in the river to allow work to progress on the weir in stages (see Case Study K)

- Access road across a field that will be removed on completion of the work
- Contractor's site accommodation and security fencing
- Temporary bridge or ford across the stream to facilitate access to both banks
- Temporary fish passage.

These works can have significant environmental impacts and therefore should be considered in the development of the design to ensure that adverse impacts are minimised, and that environmental opportunities are recognised and taken up.

It must also be remembered that temporary works in the river will have to function in varying flow conditions, and may be exposed to large floods. Information on the flow conditions in the river should therefore be made available to those responsible for designing and constructing the weir (see Section 2.3.2 (ii))

Figure 2.17 Temporary diversion of a stream

The stream in this photograph has been diverted through a temporary fabric culvert, keeping land acquisition and environmental impact to a minimum.

(iv) Environmental Impact of construction activities

The consideration of environmental impact when planning the implementation of construction works applies whatever the nature of the project. In the context of work in rivers, and in particular on weirs, specific attention should be paid to:

- Increased flood risk (obstruction to the river by temporary works)
- Pollution (sediment, waste material, fuel, hydraulic oils, etc, getting into the watercourse)
- The need to provide for fish (temporary fish passage may be required, or a fish rescue operation from, for example, a cofferdam)
- The need to avoid spreading any invasive or alien plant species
- The need to avoid any adverse impacts on protected species that inhabit river corridors and associated areas.

More details are provided in Section 2.4

(v) Public safety during construction works

All construction sites have to be made safe for members of the public. In general this means excluding the public from the site by the use of suitable fencing. Works on weirs are no different, but have the added safety issue of risk of drowning. It is important therefore to ensure that a construction site is adequately fenced, with clear warning signs and, if necessary, security patrols in areas where children are likely to attempt to gain access to the site.

(vi) Sequence and timing

Unfortunately the best time for carrying out engineering works in a river is normally in the summer (i.e. when flows are at their lowest), but this is often the time when adverse environmental impact is likely to be greatest, and recreational use at its highest. For minimum impact on fish, construction in the autumn and winter is probably the best option. A compromise is often therefore required. With proper planning and consultation it is possible to minimise the impacts without unduly compromising the engineering operation (or greatly increasing the cost). Particular seasonal activities to avoid include:

- Angling, especially organised events and competitions
- Navigation and boating (from Easter to Autumn)
- Bird and mammal breeding
- Fish migration, spawning and ova development

2.3.6 Weir rehabilitation

(i) Introduction

Weirs are rehabilitated for a number of reasons, including:

- Repair of structural damage
- Installation of erosion protection measures
- Overcoming seepage problems
- Installing a fish pass
- Change in use/function

Such works often require a sensitive approach to construction to ensure that the heritage value of the structure is preserved and that environmental impacts are minimised (see Case Study L).

A particular problem associated with old masonry weirs is the loss of mortar joints and subsequent dislodging of masonry blocks on the glacis. Although not initially serious, once several blocks have been dislodged in one area, the loss of fill material in the heart of the weir can lead to major structural damage costing much more to repair.

Before embarking on a major weir rehabilitation project, it is important to gain as much information about the weir as possible. Detailed and reliable drawings are often not available for old structures, in any case they will not tell you the current condition of the weir. It is therefore important to carry out a thorough survey of the existing survey, if necessary using divers to examine the underwater parts (see Case Study L).

(ii) Site investigation

A thorough site investigation is just as important for the rehabilitation of an existing weir as it is for the construction of a new one. However, it is often difficult to get accurate information (on, for example, the weir foundations) without very intrusive techniques. Some success has been recorded with non-destructive investigation techniques but often the results are of limited practical use. This may mean that the rehabilitation works have to begin with only limited information on the weir sub-structure. In such cases, the contract for the works must be set up in such a way as to allow the design of the remedial works to be refined as the construction progresses.

Rotary-cored holes drilled into the crest or glacis of a concrete weir will reveal the nature and quality of the basic structure. Such methods in masonry weirs will reveal the thickness of the masonry facing, but core recovery in the underlying fill is likely to be poor. For masonry structures, there is no substitute for isolating parts of the structure and digging trial pits.

Site investigations at weirs being considered for rehabilitation should also consider the possibility of encountering contaminated sediments upstream (particularly in the case of weirs with an industrial heritage – see Case Study F). There is also the possibility of exposing significant archaeological finds during the course of the works.

In order to carry out a thorough investigation of an existing weir to determine the extent of rehabilitation required, it will often be necessary to de-water the structure (see section (iii) below). This is best done in the summer months when there is a better chance of low flow conditions. Parts of the weir can be isolated for de-watering in turn, so as to limit the impact on the flow conditions.

If dewatering is not practical, a team of specialist divers can be employed to carry out an underwater survey. At least one diver on the team should be a qualified engineer, capable of interpreting what he observes – often this involves "feel" as much as observation, as visibility under water can be poor.

(iii) De-watering

Most repair works require de-watering to expose the structure and give reasonably dry conditions. In its simplest form, this might involve sandbagging off part of the weir crest to do a patch repair. For more extensive repairs, the construction of an earth or sheet pile cofferdam to isolate part of the structure is required (see Case Study L). Water is then pumped from the enclosed space (continuous pumping may be necessary to combat seepage inflow) to allow the repair works to proceed. There are also proprietary portable dam systems formed from structural frames and an impermeable membrane that can be use to effect a temporary closure of a stream to allow remedial works to go ahead. For major works, the temporary diversion of the river or stream may be considered, allowing unrestricted access to the weir. However, such a diversion would itself require a temporary weir structure as well as a channel diversion, to ensure that the diversion was stable for the duration of the works.

In all cases, the temporary works must be designed to cope with a range of flow conditions, with due regard to both environmental and hydraulic factors (for example fish pass provisions, and the need to ensure safety in flood conditions). Dewatering may also require provision for fish rescue.

2.3.7 Weirs on navigable waterways

(i) River weirs

Weirs on rivers designed to maintain water levels so as to permit navigation are often very substantial structures. Many of these structures are owned and maintained by navigation authorities, in particular British Waterways. Many rivers would not be navigable for much of the year without the increased depth of water provided by weirs. Water levels can be raised by up to 3m on the upstream side and the structure may be up to 100m long and incorporate fish passes, movable gates and flow control devices. Many of these weirs were built either in the heyday of canal construction. Typically they are constructed from a mixture of masonry and timber with recent refurbishment being undertaken with concrete and steel sheet piles. Remedial works to these weirs tends to be restricted to summer periods when river flows are low, although emergency works may have to be carried out in more challenging flow conditions.

Figure 2.18 A weir on the River Thames

The weirs on major navigable rivers like the Thames are often gated and generally complex structures.

(ii) Side Weirs

Navigation canals consist of level reaches of water (pounds) between lock structures. Any excess water draining into a pound (say, from local high ground, or perhaps from an adjacent motorway) has to be discharged out of the canal to avoid unacceptable variation in the water level. This is generally achieved by the use of side weirs.

A side weir, as its name suggests, is located in the side of the waterway, and has its weir crest set slightly above the normal water level in the canal. Thus, when excess water drains into the canal, and the water level rises in response, the side weir starts to operate. Flow over the side weir is discharged into a local stream or drainage channel.

In most respects side weirs are similar to conventional weirs. Their hydraulic performance is, however, more difficult to analyse (May, Rickard et al, 2002). Key performance issues for side weirs include:

- Provision of safe access over the weir for pedestrians using the tow path
- A design that reduces the risk of debris accumulating on the weir
- Often a requirement for seasonal changes in the crest level (through the use of stop logs) to cater for different canal water level regimes.

Figure 2.19 Side weir

This side weir has provision for adjustment of the crest level using stop-boards. Note the hand railing to improve safety.

(iii) Typical weir problems

The following typical problems have been identified by British Waterways:

- Damaged and irregular crests
- Upstream and downstream scour
- Scour behind wingwalls
- Downstream apron maintenance and repair.

In the particular case of side weirs, which are designed to evacuate excess flow from a waterway without necessitating a large rise in water level:

- Incompatible combinations of weir length and downstream culvert capacity (i.e. the weir can pass more flow than the culvert downstream can accept)
- Access restricted, particularly when installed on towpath.

(iv) Typical remedial works

The following are typical of the remedial works that are carried out by British Waterways in the maintenance and improvement of the many weirs that form part of the navigable waterways that they are responsible for:

- Crest repairs and cleaning
- Extension of crest length of side weirs to increase discharge capacity, plus the provision of new outfall culverts with equivalent capacity
- Provision of labyrinth weirs, and/or the incorporation of sluices to reduce water level variation at locks
- Addition or refurbishment of sluices to allow water level to be lowered so that the weir crest can be inspected in dry conditions
- Steel sheet piling to stabilise erosion damage
- Stone revetment and grout-filled mattresses to protect the bed and banks downstream of weirs

- Underpinning walls and foundations that have been undermined by erosion

2.3.8 Weir demolition

No weir should be demolished without full consideration of all the likely impacts. Key factors to be considered are described below.

(i) Impacts – Immediate

Water level in the river upstream of the weir will be lowered throughout the flow range and the velocity of flow will increase. This will expose parts of the river that have not been seen for some time and will change the aquatic regime and its associated flora and fauna. There are likely to be environmental concerns and these will have to be discussed with the Environment Agency and other interested parties (e.g. local angling clubs).

Local groundwater levels in the surrounding land may fall in response to the lower water level in the river. This may have an adverse impact on the local ecology in the short and long term.

The potential loss of amenity value through the demolition of any weir should not be overlooked, even if there is no apparent local interest in the structure. For the removal of any significant structure, particularly one that has been there for many years, it will be necessary to get the support of the local planning authority.

In any demolition activity there is a risk of releasing pollutants into the environment. In this case of a weir, this could result in contamination of the river or stream during the demolition process. Demolition works are likely to mobilise sediment that could have an adverse impact on fisheries downstream.

Many weirs were constructed in an era when our rivers were heavily polluted by industrial waste. As a result, the accumulated sediments that are found upstream of old weirs can be heavily contaminated. These contaminants are relatively safe when left in place, but could be released into the river system with disastrous consequences if the weir is demolished. It is therefore essential that, when considering the removal of an old weir, the possibility of encountering contaminated sediments is investigated, and plans to deal with the problem are prepared (see Case Study F).

Perhaps the safest way to deal with such a problem is to isolate the affected area by creating a diversion of the river and then removing the sediment in relatively dry conditions disconnected from the river. This option may not be practical, in which case every attempt must be made to create a barrier around the area being excavated to ensure that the contaminated sediment cannot be carried away in the river flow as work proceeds, or after the work has been completed.

(ii) Impacts – Longer Term

In the longer term, retrogression (i.e. erosion) of the river bed upstream may continue. The rate of retrogression will depend on river slope, bed material and flow regime (most bed movement will tend to take place in flood flows). The greatest impact is likely to occur in cases where a very old weir is removed, because the channel regime upstream will have adapted to the flatter water surface slope, and the bed level will have built up due to siltation over the years. With the steepening of the water surface slope due to removal of the weir, this accumulated bed material will tend to be eroded and deposited somewhere downstream.

Any structures in the zone of influence upstream, and immediately downstream, could suffer from foundation damage. This would affect, for example, the foundations of a bridge upstream or the footings of riverside walls. This could prove problematic because often the depths and details of foundations are unknown. It might be necessary to monitor bed level after the weir has been removed.

Land drainage in the reach upstream will be enhanced. This may be beneficial or detrimental depending on the local environment.

(iii) The demolition process

It goes without saying that demolition is most easily done in low flow conditions, but to minimise impacts to the whole aquatic community, all environmental constraints should first be checked to determine the best time for the works.

Whatever the time of year, floods could occur and contingency procedures should be included in the demolition process (in terms of emergency action, safety, avoiding damage to plant, etc). Use should be made of any flood warning facilities – this can be achieved by registering the site with the local Environment Agency Flood Warning team.

The geometry of the river may dictate the sequence of demolition. In general, starting the demolition in the middle of the weir, or on the inside of the bend (if the weir is not in a straight reach) will help to avoid adverse impact. Provided that the work is carried out in low flows, it should not be necessary to take the weir crest off in stages across a river's full width. Instead, the contractor should create a hole (say 5m wide in the case of a large weir) to the full depth, and then work progressively away from it. However, this will inevitably concentrate the flow with increased risk of erosion, especially if a flood occurs during the work.

It will be important to consider access to ensure that material can be removed from the river and transported away without undue difficulty. However, the foundation of the weir should generally be left in place to provide armouring for the bed so as to prevent further erosion, but avoid leaving anything that could be hazardous to swimmers or canoeists.

Wherever possible, the products of demolition should be recycled. For example, masonry from the weir could perhaps be used to protect the bed and banks of the river. This could help to reduce costs of disposal of waste, and reinforce areas vulnerable to erosion.

(iv) Geomorphology

For any significant weir demolition work, it would be useful to employ the services of a fluvial geomorphologist to confirm local impacts and devise remedial works. Contact with the River Restoration Centre (www.theRRC.ac.uk) may yield further helpful guidance.

2.3.9 Weirs suitable for canoeists

(i) General

In the context of this guide, a canoeist is taken to mean a person in a kayak that is designed for use in white water. It is, of course, recognised that canoes take many forms, and it is necessary to consider the safety of any and all river users. Indeed, it is often the casual users (for example, young children in dad's old lath and canvas double canoe) who are most at risk.

To many canoeists, there is very little challenge in the placid waters of a canalised river. However, the weirs that often form part of the engineered infrastructure of canalised rivers, can offer the sort of water conditions that canoeist seek. These challenging conditions inevitably involve some risk, but properly engineered, the risks can be reduced without losing the excitement. This section presents preliminary guidance on the design of weirs suitable for canoeists. More detailed guidance can be obtained from the British Canoe Union (www.bcu.org.uk).

Many existing weirs do not provide safe or suitable conditions for canoeists. When modifications are carried out to such weirs, or when new weirs are constructed, it is essential that the potential interest of canoeists is considered in the planning and design process (see Case Study H). It will not always be appropriate to make weirs suitable for canoeists, but ignoring the safety of river users in the design of such works will render those responsible liable to prosecution in the event of an accident, especially if the river is known to be used for canoeing.

(ii) The hydraulic jump

A hydraulic jump is a mass of turbulent water that occurs when very fast flowing water meets much slower and deeper water (see Case Study H). Hydraulic jumps are therefore frequently a feature immediately downstream of weirs. Canoeists refer to them as *standing waves* (which describes their appearance) or *stoppers* (which describes the impact that they can have on a canoe!). A fundamental feature of the hydraulic jump is the rotating flow pattern, illustrated in Figure 2.7, which can prevent anything caught in the jump from escaping. It is this feature that poses the greatest risk to a canoeist (and to anyone finding themselves in the turbulent conditions downstream of a weir). The return current brings the canoe or swimmer back to the base of the weir, trapping them in turbulent water with the inevitable risk of drowning.

The form of a hydraulic jump varies greatly with a number of factors, including:

- The rate of flow at the time
- The drop in water level at the weir
- The depth of water downstream
- The geometry and shape of the weir (in plan as well as section), including the presence or absence of a stilling basin.

The following sections describe the features to avoid in a weir design to reduce the risk of dangerous or damaging conditions for canoeists. In the case of the design of a significant weir structure, especially if the shape is unconventional, it is recommended that physical model studies are undertaken to allow a safe design to be developed.

It is recommended that advice is sought from the British Canoe Union (BCU) for any weir project (new of rehabilitation) where there is any chance of a canoeing interest.

Figure 2.20 Canoe weir

This weir at the Nene White Water Centre near Northampton is adjustable to create different conditions for canoeists (photograph courtesy of the Nene White Water Centre website).

(iii) Design features that are unsuitable for canoeists

The following are features to avoid if at all possible:

- Vertical drop weirs, where the flow plunges vertically after passing over the crest
- Weirs where the hydraulic jump forms a stopper across the full width of the weir (often a feature of symmetrical weirs with a horizontal crest) – providing a low point to the crest can create an open-ended stopper, allowing a canoeist to escape at the sides
- Uniform shallow flow over the weir crest – can cause damage to the canoe if depth of flow is less than about 10 cm. The provision of a low section in the crest will concentrate the flow, allowing the canoeist to shoot the weir (such a feature may also improve conditions for fish passage, but note that flat-vee weirs are not favoured by fisheries officers)
- Vertical walls – these obstruct the canoeists paddle, reflect waves causing surges in the weir pool, and can close the end of a stopper preventing escape. They also make egress from the water much more difficult than a sloping bank
- Stepped weirs
- Obstructions – any submerged obstruction on the weir spillway or in the stilling basin can damage a canoe or cause injury. The risk is particularly high in the case of sharp or pointed obstructions, such as torn gabion wires, projecting steel reinforcement, or the tops of unprotected steel sheet piles. The indiscriminate dumping of materials generated by the renovation of a weir should also be avoided, as this too can create obstructions in the river
- Raised sills – often constructed at the end of a stilling basin to reduce the risk of bed scour, these can create intense underwater currents that can trap a swimmer or canoeist
- Horseshoe weirs – can lead to condition that trap swimmers in the middle of the river, making rescue difficult (the Pulteney weir featured on the front cover has claimed several lives, including an 18-year old canoeist)

It must be remembered that rivers that are attractive to canoeists also support a thriving fish population, and any works at weirs must take into account the needs of both (see Figures 2.21 and 2.30, and Case Study J). Some fish passes may present a hazard to canoeists. Guidance should be sought from the BCU and fisheries officers.

The problems that can result from lack of consultation are illustrated by the case history of Dolwen weir, which was constructed in the late 1990s. There was no right of navigation on the reach of river in question (downstream of Llanidloes) but small numbers of canoeists regularly used the river. This fact was apparently overlooked, and there was little consultation with the canoeists. After the weir was constructed, a canoeist became trapped in the hydraulic jump (stopper) downstream of the weir. Fortunately fellow canoeists rescued him, although not without some difficulty. Following consultation with the Environment Agency's Safety Officer and the BCU, the following remedial works have been incorporated into the weir:

- A large "Danger – Weir" sign 100 m upstream of the weir
- A ledge upstream of the weir to facilitate egress from the river
- Chains on the abutment walls of the weir to assist egress

It is clear that early consultation could have avoided this problem, and the safety features could have been incorporated into the design at lower cost. Some guidance on canoe access and egress points can be found in the Environment Agency's Recreation Facilities Design Manual.

(iv) Suitable features

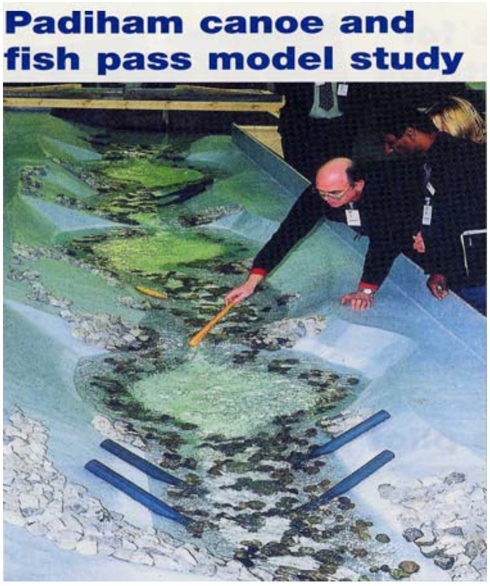
The ideal weir for a canoeist would have the following features:

- A lowered portion of the crest to concentrate the flow and allow the weir to be shot even in low flows
- Open-ended hydraulic jumps to allow the canoeist to escape from the ends
- A well-defined "tongue" or jet of water downstream of the weir, allowing the canoeist to break out and move into the safer eddies at the sides
- Sloping banks (rather than vertical walls) to allow waves to break on them thereby dissipating the energy
- Adequate and safe access and egress points both upstream and downstream of the weir

One of the most promising types of weir for canoeists is the flat-vee or shallow-vee weir, commonly used for flow gauging. The River Witham at Grantham flows over modified flat-vee weirs constructed specifically to provide conditions suitable for canoeists. However, it should be noted that the flat-vee weir is not good for fish passage.

In situations where hazardous features already exist, or cannot be designed out, it is strongly recommended that warning signs are provided some distance both upstream and downstream of the weir, and that egress and access points are constructed above and below the weir.

Figure 2.21 Physical model of the proposed fish and white water canoe pass at Padiham (Photograph courtesy of BHR Group)



This photograph illustrates the value of a physical model tests for complex structures with multiple functions. The Padiham weir project (see Case Study J) aims to improve condition for fish and canoeists, without increasing flood levels. The model allowed a number of configurations to be tested up to the 100-year flood, and the designs were modified to achieve optimum performance.

2.3.10 Weirs suitable for fish

Many of the weirs constructed in our rivers delay or totally prevent the migration of fish. The ability of fish to jump or swim upstream over a weir varies greatly with the species and sizes of fish (see Case Study G). Although it is generally accepted that a drop in water level of 0.30 m is acceptable for fish migration, even this small differential may defeat many fish (0.15 m is enough to discourage small fish such as bullheads or fry)

Since fish are an important element of the biodiversity of our rivers, and migration is a part of their natural lifecycle, it is important to consider carefully the requirements for fish in the construction or rehabilitation of any weir. The list below will act as a guide to the factors to be considered, but is no substitute for expert guidance, which can be obtained from fisheries officers. It should be noted that the Salmon and Freshwater Fisheries Act requires that approval from the Environment Agency is obtained for the design of any fish pass (see Section 2.2).

New structure – the need for a new weir should be questioned. Is there an alternative? If not, then include facilities for fish passage.

Existing structure – reinstatement/replacement/repairs must take account of fish pass issues, and not make conditions worse for fish. Often rehabilitation offers the opportunity to right the wrongs of the past and improve conditions for fish (see Case Studies A, C and D). Opportunities for the removal of existing structures that obstruct fish passage should be explored wherever possible. If not, perhaps the upstream retention level can be lowered to reduce the drop in water level across the weir

- Head difference (drop in water level) – should be kept to the minimum required, with due regard to limitations of different means of providing fish passage. Weirs should, wherever possible, be passable by all fish species that inhabit the river reach (which will vary depending on the time of year)

- Depth of water downstream – shallow water downstream will not allow salmonids to build up speed to jump the weir
- Configuration – all the features that go to make up a weir (with or without gates) can be engineered in such a way as to improve conditions for fish. Expert guidance should be sought by the designers
- Location – in respect to other associated structures, and indeed to different elements of the weir in question, can have a bearing on conditions for migrating fish
- Fish passage – the need is for migration both upstream and downstream
- Construction materials – the avoidance of smooth homogeneous surfaces can help to provide conditions more favourable for fish. Materials that have uneven surface conditions and are porous are preferred. Permeable construction materials (such as gabions) must be sealed to avoid flow passing through.
- Approach conditions – fish swimming upstream should not be faced with challenging flow conditions as they approach the weir. Ideally swimming in this region should require little effort – such conditions are most likely to be achieved if there is a deep pool downstream of the weir.
- It is important to note that the provision of good conditions for fish does not have to compromise other weir functions such as discharge monitoring or providing facilities for canoeists. In France there has been considerable research into the design of facilities to allow safe navigation of weirs by canoeists. Such facilities exist side-by-side with similar provisions for fish (see Figure 2.30).

2.3.11 Hydropower and weirs

The presence of a weir and consequently the existence of a differential head (drop in water level) between the upstream and downstream faces of the structure, offers a useful opportunity to harness the potential energy for the purpose of power generation. Over recent years a number of low head hydropower systems have been developed with the intention that a small-scale alternative energy source can be utilised. It is clearly encouraging that these sustainable technologies can be used for beneficial purposes.

A recent study carried out for Anglian Region of the Environment Agency (Paish and Howarth, 1999) concluded that the installation of hydropower would be economic at several sites in the region with a relatively small change in the electricity tariff rates. This is very promising, especially bearing in mind that the Anglian region is predominantly flat and not well endowed with weirs with a large head difference.

However, not all weirs are suitable. There is a fundamental requirement for a high enough water level to ensure that water is always above the top of the intake pipe. The ponded water allows some of the sediment in the stream to settle out before entering intake, and provides water storage to compensate for short periods of water shortage. There also needs to be sufficient head above the intake to prevent air entering the pipe and consequently the turbine. For low head applications such as would be encountered on a river in England and Wales it is typical to find cross-flow, axial-flow or propeller turbines being used.

Where fish (migratory and residential) inhabit the watercourse, the presence of a turbine intake presents a potential hazard, most notably to those fish moving from upstream to downstream that could be sucked into the turbine (see below). Early planning should include the consideration of strategies for protection of migratory and resident fish species and should focus around the three principles of fish protection: ecological, behavioural and physical.

Problems can also occur in low flow conditions when turbines are activated. If the turbines take a significant proportion of the flow, the water level upstream of the weir may be drawn down quite quickly, leading to problems for boats and ecology (e.g. Beeston weir, River Trent – here the problem was solved by raising the weir crest). The installation of a hydropower plant may also have impacts on the local river ecology, through the change in flow patterns downstream). It should be noted that the operation of a hydropower installation will require an abstraction licence from the Environment Agency.

Consideration should therefore be given to the following in the planning and development of low head hydropower installations:

- River corridor survey
- Fish survey
- Provision of suitable alternative fish routes
  - Fish passes (but note that careful design is required because when the turbine is operating, fish attempting to migrate upstream may tend to congregate in the fast flowing water downstream of the turbines, rather than downstream of the fish pass)
  - Diversion channels
  - Fish lift
- Provision of screens or other devices to prevent or discourage fish entry into the turbines and to direct fish to a safe downstream passage
  - Mechanical screens to prevent access to the turbines with a physical barrier of a mesh size sufficiently small to block most fish getting through. The main disadvantage of this technique is that the screens often get blocked and require regular maintenance.
  - Electrical screens, which usually consist of live electrodes suspended vertically along a ground conductor. The electrodes generate electrical pulses across the flow and present an invisible barrier to stop fish progressing further or diverting them into a safer route to allow for onward migration.
  - Behavioural devices (louvres, bubble, acoustic, and combined acoustic/bubble)
- A trash rack to prevent floating debris from entering the pipe but bearing in mind that trash racks must be cleaned regularly. Stop-logs or a valve should be provided to shut off the flow from the intake during maintenance or repair. An air vent should be placed just downstream of the valve to prevent the pipeline collapsing when it is emptied with the valve closed.
- Investigation of the environmental, ecological, geomorphological and amenity impacts of the construction of a hydropower installation.

Footnote: At the time of writing this, an interesting article appeared in the Proceedings of the Institution of Civil Engineers (Civil Engineering, November 2002, Volume 150, Issue 4). This article promotes the use of old water mills for the generation of power. This would be achieved by rehabilitating the structure with a new water wheel designed to generated electric power rather than grind corn!

2.3.12 Gated weirs

Gated weirs are a common occurrence on rivers throughout the UK. They provide a useful function in terms of coarse and fine control of water levels for flood defence purposes as well as navigation. Gated weirs quite often have a fixed weir alongside, such that it is not necessary to adjust the gates on a day-to-day basis. Although much of the guidance in this document is applicable to gated weirs as well as fixed weirs, there are some particular issues that should be considered on gated weirs. The main reason for having a gated weir is for water level control. The allowable tolerance on water level variation will have a significant effect on the design of the structure.

Figure 2.22 A large gated weir on the River Thames

Access for operators, recreational users and the public should be considered at an early stage in the design of new structures and for the refurbishment of existing structures. In particular it is important to focus on the safety of access to all those walking alongside or over a structure as well as those floating underneath it or operating it. It should be noted that in general gated structures tend to span large rivers and often offer a convenient crossing point for pedestrians. Equally, consideration should be given to the management of gate operation in terms of public safety, particularly in flood conditions. The enclosing of rotating or moving machinery will reduce the risks to members of the public, but also the degree of protection afforded the operators during maintenance must also be considered in the design process. Questions of operability of the structure during periods of planned maintenance or during unplanned failure of the gates need to be accounted for, and a risk assessment and emergency action plan prepared. For example, it will be wise to have a supply of replacement components, and to adopt some degree of standardisation between components on different gated structures.

Debris impact on the structure both from a structural stability perspective but also in terms of restricting or preventing operation of the gates needs to be considered. Booms or barriers can collect or deflect debris. Placing a boom at an angle to the flow can encourage debris to move to one side of the river and may facilitate clearing of debris. Consideration of the methods of removal of trash and debris (barge, hand raking etc), and the storage of the material removed, are more important for gated weirs than for free-flow structures.

Gated weirs can provide excellent facilities for canoeists (see Case Study H). However, it is not normally safe for canoeists to pass through or over such structures. Signs or booms should be installed to discourage such passage, and provision made for canoeists to exit safely from the river and carry their canoes round the weir.

Gated weirs can also incorporate suitable conditions for fish passage, but care is needed to avoid creating conditions that would attract fish to a point where they cannot progress further (e.g. to the turbulent and fast flowing water downstream of a partially open sluice gate). The location of any fish pass needs to be considered carefully in this context.

Many gated structures are associated with former and now defunct water mills, but the structures themselves often still have a role in regulating river levels, and hence have an impact on flood risk. Rehabilitation of such structures (see Figure 1.2 for an example), which are often in private ownership, offers the opportunity to resolve operational responsibilities, with the Environment Agency taking on this role where there are flood defence implications.

River Weirs – Good Practice Guide

Guide - Section B3

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R&D Publication W5B-023/HQP

Research Contractor:
Mott MacDonald Ltd and University of Hertfordshire

2.4 Environment

2.4.1 Introduction

(i) General

Weirs have formed one of the fundamental means of controlling rivers for centuries. They have been constructed for diverting flows to provide power to water-mills; creating a deliberate obstruction to allow fish to be caught; as a means of channelling water for its use in potable water supplies and electricity generation; or simply as a means to create increased depth to allow navigation. When weirs have occasionally been introduced solely for conservation purposes, it has generally been in the upper river valley to vary habitat by creating longer glides and pools, or on lowland rivers to reduce the impact of low flows and to retain wetland. With the advent of alternative modes of transportation as well as a reduced reliance on water as a source of power, the need to control rivers with weirs diminished and with it the commitment to maintain many of Britain's weirs. The exception is perhaps the large number of weirs that form an integral part of Britain's waterways. The continued maintenance and ultimate replacement of these weirs is fundamental to the operation of the canal and navigable river system, which is going through a phase of renewed interest and investment.

Figure 2.23 A mill weir

Outside the waterways system, the declining requirement for weirs raises the commonest single environmental problem associated with weirs (see Case Study E). Over time they may have become valued for themselves as historic features, or as the means whereby water has been impounded and now supports adjacent wetlands. They are often more of a liability than a benefit in terms of flood control but for environmental reasons their preservation and frequent repair become desirable. River managers are therefore frequently faced with the decision as to whether to undertake expensive repairs to crumbling weirs or knock them down. Except for weirs associated with flow gauging stations, the construction of a new weir is a relatively rare event. However entire replacement of an existing weir on a closely adjacent site is not uncommon. All these options will have both positive and negative environmental impacts and a strategy for action needs to be established on the merits of each individual case.

The requirements set out in both national and international environmental legislation to conserve the environment are steadily increasing, but should not be considered especially onerous in relation to weirs. However, there is a clear requirement to carry out an Environmental Impact Assessment (EIA) for any scheme to construct, rehabilitate or demolish a weir. Very few individual weirs are listed but they may be protected as part of a listed historic landscape, such as an eighteenth century landscaped park, or else require protection as an integral part of a wetland SSSI. With careful planning and the inclusion of environmental assessment at an early stage, the long-term viability of a preferred engineering option (construct from new, refurbish or remove) should be enhanced.

To focus the reader's attention, Section 2.4.2 first introduces the positive and negative impacts of weirs. Then specific environmental issues are discussed in relation to landscape, fisheries, heritage, water quality, recreation, and nature conservation.

(ii) Sustainability

There are lots of different interpretations of the concept of sustainability. The basic definition of “providing for today’s needs without compromising the ability of future generations to meet theirs” can be applied in many ways, and is far too esoteric for a practical guidance note on weirs.

In the context of weirs, sustainability is more likely to be achieved if all the stakeholders have been consulted, and their views taken account of in the development of the project.

Specific sustainability issues relating to weirs might include:

- Avoiding creating a structure that has a high maintenance requirement
- Making provision for fish and other wildlife
- Making the best use of recreational opportunities provided by the weir (a facility that is valued and well-used is much more likely to be sustainable than one that is regarded as a constraint on recreational activities)
- Ensuring that the structure does not pose a safety risk to users of the river and its environs
- Ensuring that the works add to the environment rather than detract from it.
- Paying due attention to materials and construction methods
- Taking account of future development proposals that could be affected by the weir, or that could have an impact on the weir.

Figure 2.24 Low weir for environmental improvement

This low weir was constructed for environmental enhancement. It has a modest drop so as not to obstruct fish movement, an uneven crest to create interest, and dumped rock on the banks downstream to resist erosion. However, the designer has neglected to confine the river upstream, and there is a risk of the weir being by-passed on the far bank. Construction of a low stone wall would easily solve this problem.

2.4.2 The direct impacts of existing weirs

Table 2.2 below presents the principal physical and environmental effects associated with the operation of weirs (i.e. once they have been constructed).

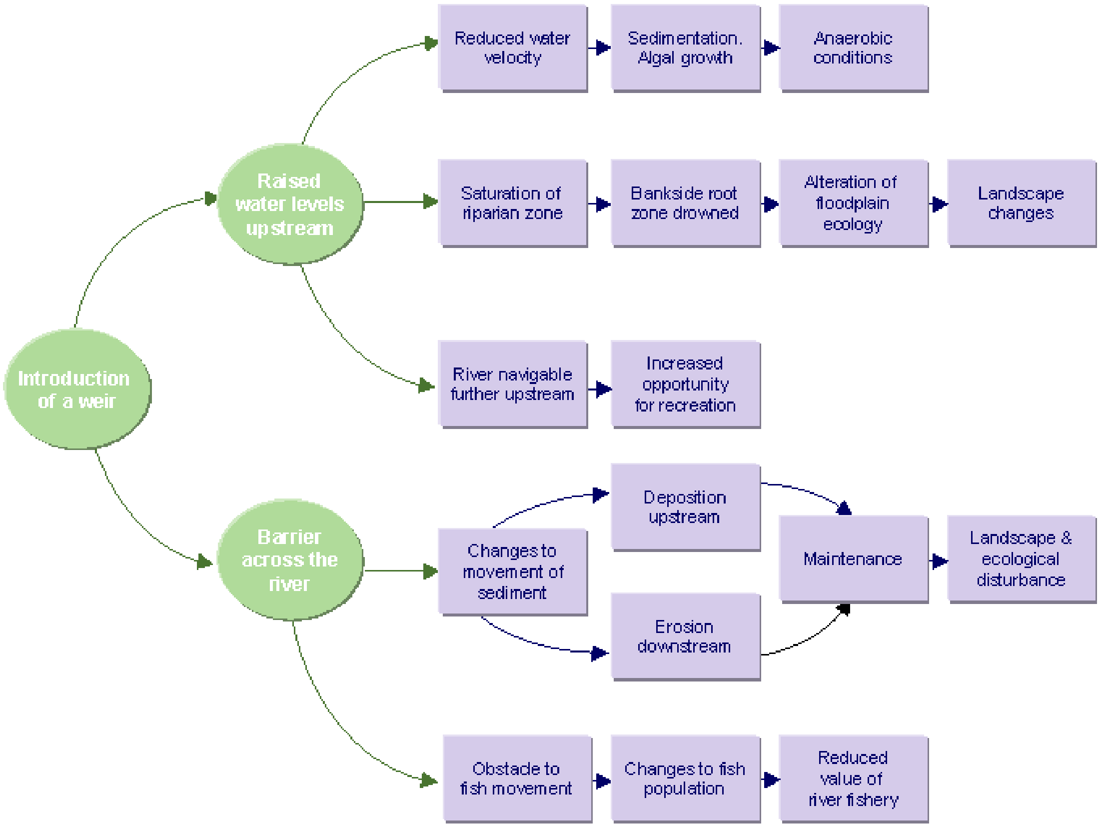
Table 2.2 Principal physical and environmental effects associated with weirs

Parameter	Upstream of the Weir	At Weir	Downstream of the Weir
Velocity of flow	Slower and more uniform	Rapid	Turbulent and varied
Depth	Deeper with little variation	Shallow	Variable
Wetted area	Consistent area, even at low-flow	Uniform or varied according to design; notches and fish passes reduce area at low-flow	Varies in response to changes in flow
Water levels	Variation tends to be relatively small over a wider range of flows, especially for gated weirs	Fall in water level at weir is highest at low flows, and tends to reduce with increasing flow	Water level in the channel downstream varies in response to the flow
Effect on flora and fauna	Maintained high water table for floodplain wetlands. Animals and plants favoured by ponded conditions and fine sediment predominate – e.g. water lily, swan mussels. However, the overall impact may be lower diversity of habitat for flora and fauna, and water quality may suffer in low flow conditions.	A weir may present an obstruction to the movement of fish and other species. Increased depth of water upstream may drown fish spawning areas. However, exposed surfaces can provide habitat for algal and moss growth. Where slopes are not steep and fissures are present, rooted crowfoot can take hold. Walls are favoured sites for dipper nests	Gravel river beds and tugging currents create habitat for milfoil and invertebrates such as blackfly and stoneflies. Sedimentation frequently creates spawning areas, particularly for salmonids and rheophilic species.

Further guidance on the environmental impact of river works can be found in the Environment Agency publication Scoping the Environmental Impact of River Channel Works and Bank Protection (2001).

The primary effect of a weir, to increase the depth of water upstream, can cause a significant change to the character of a river. Figure 2.25 below illustrates some of the impacts on a river resulting from the operation of a weir (as opposed to the construction process).

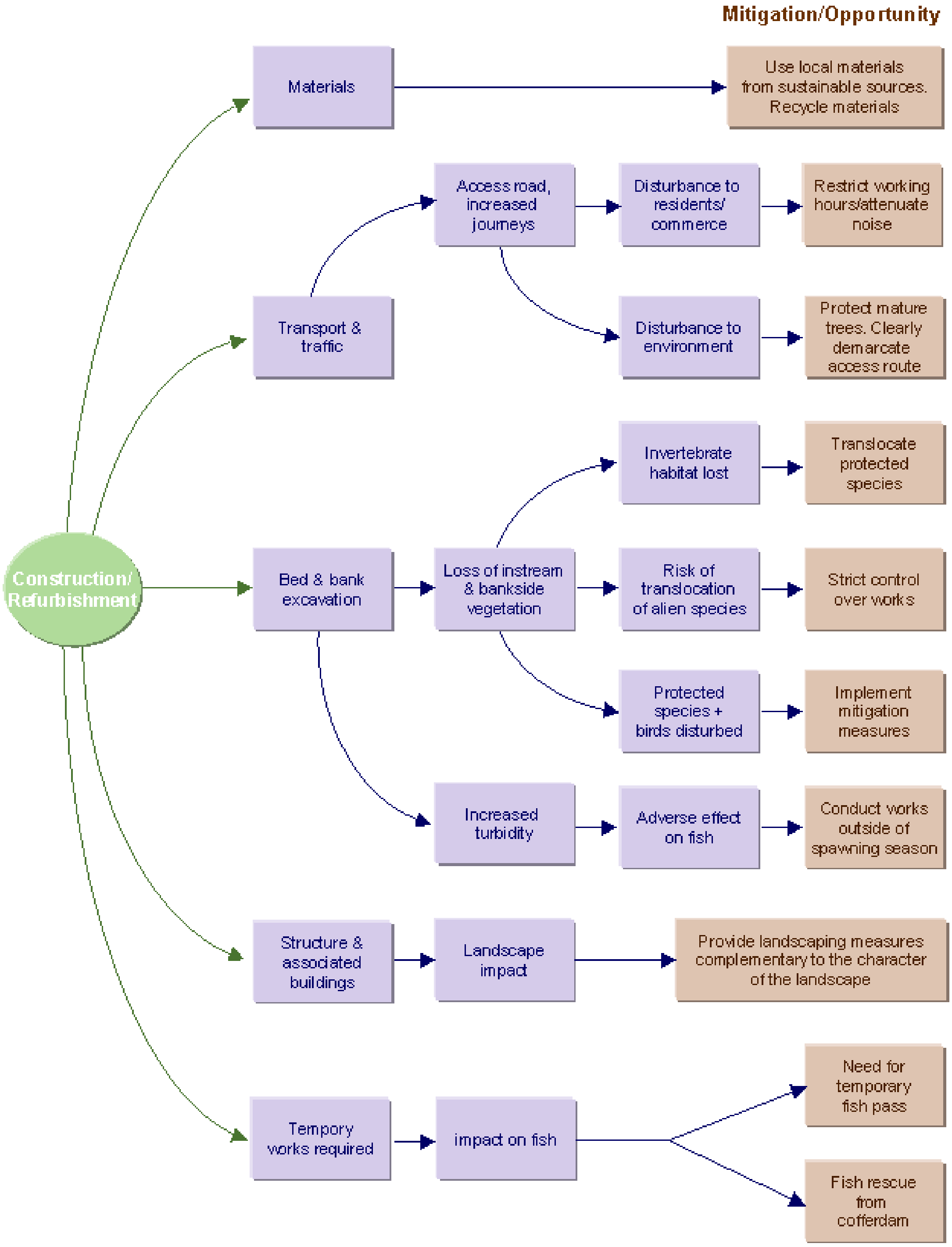
Figure 2.25 Examples of environmental impacts resulting from the introduction of a weir



Slowing and deepening a river in the upper reaches of the river valley may give it characteristics similar to those experienced in the middle reaches. Weirs create a more uniform environment in the river upstream, with consequential more uniform ecology and biodiversity. Areas that typically exhibit distinguishable characteristics lie immediately downstream of a weir where there is fast, broken water synonymous with the upper river valley. Hence weir pools often hold fish species more commonly found further upstream, including trout and barbel. Coarse sediment deposited downstream of the weir pool may be similar to that found in the upper river course, allowing fish that would not normally spawn so far downstream to deposit ova. In such an instance the weir has firstly created an upstream habitat (a primary impact) and subsequently allowed an upper river valley species to extend its territory thereby creating competition between species (a secondary impact).

Table 1.1 in the introductory section presents positive and negative potential impacts resulting from the existence of a weir. The impacts presented do not include those that may occur during the construction, refurbishment or de-commissioning of a weir. These are processes that may have short and long-term impacts, and which should be identified through an appropriate level of environmental assessment. Figure 2.26 presents some of the impacts commonly associated with construction process and introduces the concept of including 'opportunities' for mitigating an impact.

Figure 2.26 Examples of impacts resulting from the construction of a weir



The majority of impacts that result from construction works can generally be mitigated. Mitigation measures are addressed in outline in Section 1.4. The secret of success rests with identifying the potential impacts in the early stages of planning, and developing appropriate mitigating measures in full consultation with stakeholders. A maintenance programme similar to an environmental management plan may be developed as part of a duty of care, to ensure that the mitigation measures are permanent. When a weir is removed to return a river reach to its original form, mitigation measures, other than those required to ensure channel stability, may not be necessary.

2.4.3 Environmental issues

The main scenarios of repair, new construction or demolition were introduced in Section 1.4. They are discussed in more detail below, with an emphasis on the environmental issues to be addressed.

(i) Repairing/maintaining weirs

This is the commonest situation involving weirs. Detailed considerations will include:

- Initial survey and consultation. This is the most important first step and should involve discussion of whether to repair as well as how to do it, or indeed, whether to do nothing apart from maintain the structure in a safe condition. Ecological and archaeological features of the weir, which give it value, need to be well understood in order to protect and enhance them. These might include, for example, nesting grey wagtails or historic features such as fish traps or mill sluices. Engineers should not proceed with repair without consulting the relevant environmental bodies, including fisheries officers to establish the need for fish passes. A structured approach to environmental screening should be adopted, which may lead to the need for an EIA.
- Use of materials and design sympathetic to the existing weir. Thus crude patching with concrete may be inappropriate though concrete may be used if carefully designed and/or disguised, for example, by masonry facing (see Case Study M). Introduction of steel sheet piling to a weir where none is already present will similarly need careful design. At the repair stage, opportunities may arise to enhance an existing weir, by for example cladding an ugly concrete structure in timber.
- Careful consideration of associated features. Many historic mill weirs are connected with a complex of mill-races and subsidiary weirs and pools, which are of ecological and historic importance. These should not be swept away as part of the restoration process. Similarly repair of bridges and lock structures, and the construction of associated new headwalls and fencing, need to be carried out sympathetically. “Scaffold-tube” fencing should be avoided whenever possible (see Figure 2.27 and contrast this with Figure 1.3).

Maximum opportunity should be taken for enhancements as part of restoration (see Case Study M). Most commonly this may involve creation of fish passes and establishment of nest sites and roosting ledges. However it may also involve maintenance to mill ponds or associated tree planting.

If a weir already exists there may be opportunities for local small-scale energy generation. Such an opportunity for sustainable power generation may tip the balance in favour of rehabilitation as compared with demolition (see Section 2.3.11).

Figure 2.27 Unattractive fencing

There may be sound safety reasons for the proliferation of fencing at this side weir, but the end result is very unattractive, with the fencing dominating the scene. Wherever possible use should be made of more natural materials such as timber, or a more attractive design of fence (see Figure 1.3).

(ii) Constructing new weirs

The most common reason for the construction of a new weir is for flow gauging (discharge metering) stations, although low weirs are also sometimes built to improve habitat diversity and in association with current deflectors to reduce erosion. In addition replacement of existing weirs can involve starting entirely afresh on an adjacent site. In the latter situation there is a need for a sympathetic understanding of and reference to the structure that is being replaced.

The first decision will be whether to construct a weir at all and this should be taken with the help of the relevant environmental bodies. If sensitive habitats or other features are likely to be affected by the higher water level immediately upstream of the weir, then careful consideration will be needed before deciding to go ahead. However in environmental terms impounding upstream areas is often a wetland enhancement opportunity. New weirs should be located in a way that their construction does not involve the felling of mature trees or removal of other valuable features.

Any new weir will create a new obstruction and so it is important that appropriate provisions are made for the passage of fish and boats. The layout of the different elements of the weir should be considered carefully, for example in the context of providing conditions suitable for fish and canoeists. Otter passes may sometimes be necessary so that otters are not forced to cross adjacent roads at periods of high flow. (see Figure 2.31)

As with repair of weirs, the associated infrastructure is often visually and sometimes ecologically more problematic than the weir itself. New head walls and wing walls should be set within the line of a bank and be married into the surroundings. River banks downstream of a weir are often subject to erosion. Heavily engineered solutions to this problem should be avoided, so solutions such the use of willow and reed may be preferable to concrete or very crude stoning. Fencing and signage should be visually consistent. Footbridges require consistent and sympathetic design for handrails, kick-boards, ramps and steps.

Materials should be carefully selected. In many areas, stone, brick and timber are generally most appropriate to the river landscape although these may be needed in association with concrete in order to provide a sufficiently robust and durable structure.

The walls beside a weir are often very steep and visually raw for some time after construction especially if capped by crude steel railings. In these circumstances planting climbers to hang over the edge is desirable and relatively cheap. Native plants might include wild clematis, ivy or honeysuckle although in an urban situation, vigorous plants such as *Rosa mulliganii* or even Russian vine may have a place. Appearance can also be improved by adopting a less uniform finish to concrete surfaces, such as exposed aggregate. Whatever the final form of the works, it is important to make sure that the scale is appropriate to the setting, and that any maintenance requirements are fully appreciated from the outset.

Weirs are especially valuable for birds such as dipper and grey wagtail, and plants such as mosses and liverworts if there are chinks, holes and uneven surfaces. Clearly too many holes imperil the structure but it should still be possible to design in pipes, bars and ledges for nesting birds and not automatically create smooth surfaces everywhere.

Weirs by their very nature will be silt traps and this may lead to the need for regular maintenance, which is both expensive and creates regular disturbance to habitat. Keeping a watercourse as natural as possible may ultimately be more sustainable

(iii) Removing weirs

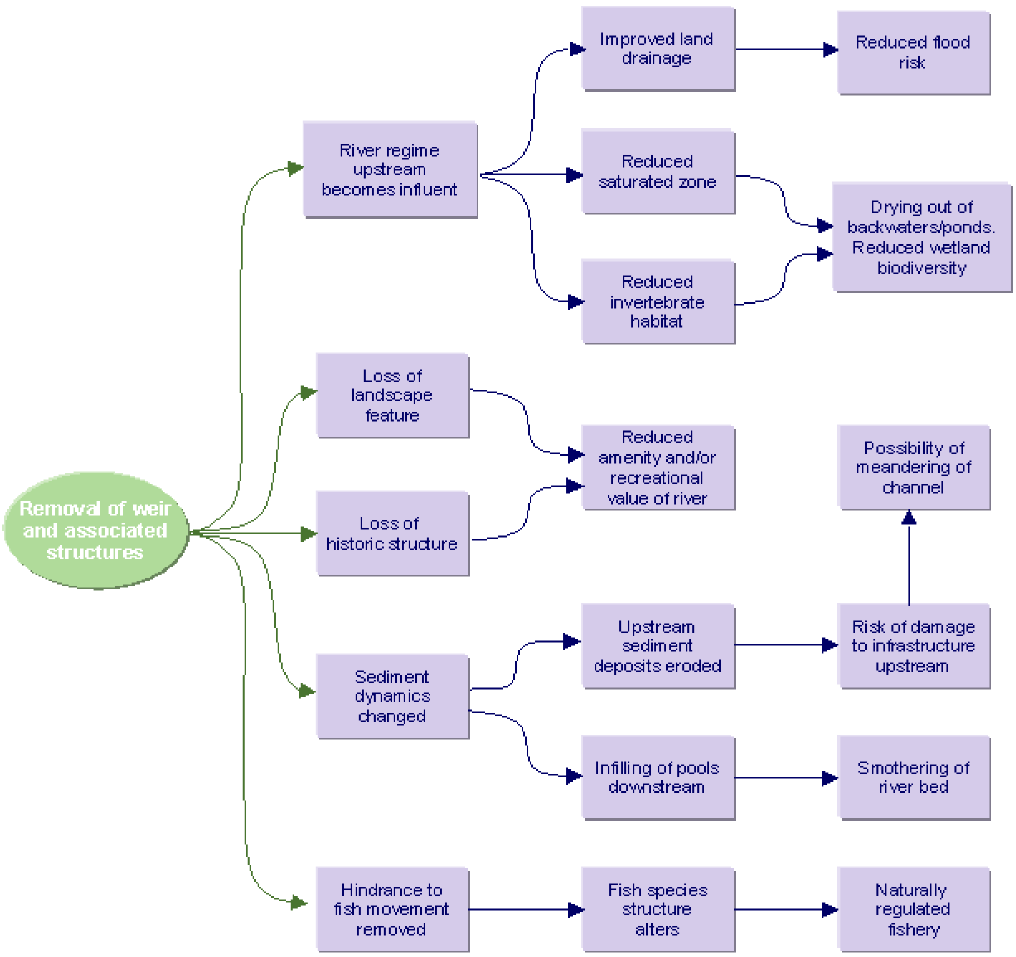
The circumstances for removing a weir are generally associated with a reasonable desire to return a river to its natural form. In Europe and America there is increasing support for the idea that an unmodified river is more dynamic and therefore likely to support a wider range of habitats and biodiversity. However, to return a river to its natural form would require more than simply removing a few obstacles. For instance to return the River Thames to its natural, braided form in the lower valley would require the removal of structures introduced by the Romans two millennia ago, which channelled as well as deepened flow. Nonetheless there are many circumstances, notably upland chalk streams, where weir removal is a benefit. It is important to make decisions based on a fundamental understanding of the geomorphology of a channel.

River managers who consider removing a weir may find themselves facing a conflict of values. While returning the river to a more natural state might have an overall benefit for habitat and landscape, the weir may have intrinsic historic or landscape interest. It may also support navigation or adjacent wetland as well as providing ecological niches for certain specialists such as grey wagtails nesting in the walls or water voles dependent on impounded water immediately upstream. There is also a debate among fishermen between those who favour a wilder river with smaller fish and those who prefer a more artificial system impounded by weirs in which fish are stocked and where there may be fewer of them but larger specimens. Occasionally, the removal of a weir may allow the migration of coarse fish species into a trout fishery, which would clearly be an unwelcome consequence. In all such circumstances there will need to be proper consultation and discussion between environmental specialists and stakeholders before the decision is taken to remove any weir, and removal will tend to be easier to achieve on smaller more upstream reaches of watercourses and in rural areas where river movement may be less of an issue. Where they exist, Water Level Management Plans will also be an important tool in decision taking.

When taking a decision to retain or remove a weir, the first question to ask is 'Why is it there?' If it is not needed for flood defence or to prevent erosion upstream, and the original reason for its existence is unknown or now invalidated, then the logical next step may be to remove it. That is, provided that it is of no intrinsic heritage interest and does not impound water to create important wetlands. The second stage is then to carry out a survey of the river in order to establish whether the removal of the weir would imperil the foundations of buildings or risk the survival of dependent wetland habitat. Sometimes it is just as easy to reduce the height of the weir crest, which is cheaper and also leaves some archaeological interest in the river-bed. If there is a risk that the removal of the weir would lead to a chasm-like watercourse, then berms which grade into the channel may mitigate this.

Figure 2.28 presents some positive and negative environmental impacts that may result from the removal of a weir. It should be appreciated that certain positive aspects on one river may be negative on another.

Figure 2.28 Examples of impacts that may result from the removal of a weir



2.4.4 Landscape and visual issues

Perhaps the most visually important structures on rivers are bridges, many of which have long been listed and protected. Weirs however may often come a close second in importance on the river scene. Many of them are equally historic and some, such as the spectacular medieval mill weir below Warwick Castle, form an integral part of important listed landscapes. The drama of falling water has been exploited by landscape designers from earliest times from the makers of Moghul gardens to the English eighteenth century landscape school. Very occasionally there have been inspiring modern weirs, one of the best in Britain being the weir below Pulteney Bridge in Bath designed by Sir Hugh Casson (see cover photograph). Yet weirs are seldom valued on a par with bridges. When building a new weir, the opportunity to make something really spectacular is seldom seized or budgeted for. When repairing an historic structure, it is often crudely patched in concrete or steel. Landscape architects or architects should be involved in design or repair of all weirs of reasonable size.

Section 16 of the Water Resources Act 1991 imposes a duty of care on the Environment Agency to protect sites of nature conservation interest and to take account of any proposals that may impact upon their amenity. Furthermore, there is a requirement to promote conservation to enhance the quality of the aquatic and related environment for the benefit of wildlife and people. A respect for the visual quality of a weir and its river setting is embraced by this duty of care. The following specific issues should be considered:

Scale. The structure should fit comfortably into the river setting. It can be dramatic but over-dominant structures such as bridges and gantries should be minimised.

Plan. A weir does not always have to take a right angle route from bank to bank. A diagonal or curved weir is often attractive - Casson's famous weir at Bath curves across the river at a deliberately oblique angle from the bank (see also Case Study K).

Materials. In terms of cost and construction, concrete and steel may often be necessary, but especially when repairing old weirs built of other materials, brick facing or stone copings to concrete walls should be considered. Timber can also be used to mask the cruder features of some modern weirs. When concrete is adopted it should be used imaginatively. In comparison to the world of architecture and structural engineering, there is often a lack of basic knowledge of the different concrete finishes that are available to engineers responsible for weirs. The need for consultation with specialist companies and also training is evident in this area (see Case Study M).

Clutter. Associated fencing, signs, operational buildings, lighting, bank protection, certain kinds of fish pass and access roads all need to be considered in relation to the overall design.

2.4.5 Fisheries

(i) General

Many weirs are constructed low down in a river's course where stream velocities and surrounding landuse practices differ significantly from those in the headwaters. By altering the regime of a river, weirs may interfere with its natural ecological progression. The rivers of England and Wales are often described by a fish zone classification system that reflects the type of water synonymous with, rather than the actual species present. Upland headwaters are referred to as the "trout zone," downstream of which is the "grayling zone," below which is the "barbel zone," and finally the "bream zone" in the lower river course above the tidal zone. The construction of weirs may extend one zone at the expense of shortening another.

In England and Wales river fisheries are mainly of interest to anglers. The 'coarse' fish species, that include pike, carp, chub, roach, dace, bream, barbel, perch and gudgeon are no longer captured for consumption. They once were, and were the reason for many weirs being constructed to allow the installation of fish traps. Due to the diminishing returns of eels and elvers to Britain's rivers, traditional eel fisheries are no longer an integral part or reason for the function of a weir.

The migrational habits of salmon and sea trout are vital to their continued existence and are well understood. However, it is increasingly evident that all fish species have a need to migrate, although the distances involved are generally not so great. Fish migrate for a variety of reasons, including spawning, colonisation, feeding and shelter. Where obstacles limit the movement of certain coarse fish species the ability to form large spawning shoals is reduced and lower stock recruitment, population depletion and isolation may follow. This can be exacerbated during flood events when fish swim down weirs to take refuge in the main channel. If there is no fish pass in the weir, these fish may not be able to return upstream.

The ability of fish to swim upstream over a weir is dependent on the type of fish, its size and physical condition, the drop in water level, the velocity of flow of the water, and even the temperature of the water. Case Study G gives some guidance on this subject.

(ii) Angling

Angling is one of Britain's most popular pastimes, and it goes without saying that the interest of anglers should be considered when any works on weirs are being planned. Indeed, anglers are likely to be attracted to weirs because fish tend to congregate in the water downstream of the weir. However, it should be appreciated that the interests of anglers and those of fisheries officers do not always coincide. Early consultation with both groups offers the best way to avoid problems when weir works are undertaken, particularly in the case of rehabilitation or demolition of an existing weir that is known to be used by anglers.

2.4.6 Heritage and Archaeology

The Romans introduced water mills to England and the 'Domesday Book' records almost one million water mills. The vast majority of these mill sites can still be accounted for. A classic group of historic weirs, mill races and sluices, which has been respected by the modern water industry, can be seen on the Great Ouse at Godmanchester.

From the seventeenth century, weirs were constructed on many of our major rivers to allow sufficient draft for boats. On the Thames there were flash locks made of vertical timbers called rymers against which rested wooden paddles with long handles. When a boat was to pass, the paddles were pulled up and the rymers removed. The water which previously been dammed behind the weir poured through in a torrent or ‘flash’, the boats shooting the rapid like a canoe. Amazingly there are an estimated 11 surviving paddle and rymer weirs on the Thames. The conservation of these is undoubtedly important.

In the Industrial Revolution many weirs were adapted or built for textile and paper mills and these in turn have begun to be valued as part of our industrial heritage. At the same time weirs were built to impound lakes in parks and gardens. At Ashburnham in 1762, Capability Brown adapted the old mill weirs for a series of cascades. Many of these weirs are now in a poor state of repair. At Honington Hall in Warwickshire in 1987, the then Water Authority rescued from imminent collapse an eighteenth century weir adorned with sculptures of water gods.

Many weirs contain the foundations of earlier weirs buried within them well preserved in the permanent damp conditions. Repairs carried out in 2001 to the weir at Greenham Mill on the River Kennet revealed Elizabethan timbers at the base of the structure. Having been de-watered it was too late to save them but they were accurately surveyed in association with English Heritage and dated by dendro-chronology. Weirs sometimes impound adjacent areas and so preserve related structures that remain buried in the saturated ground. These include fish traps that formed an integral part of some weirs, designed to catch the loosely named “coarse” fish as well as elvers (migrating upstream), and silver eels (on their way down), lampreys, salmon and trout. Weirs are often part of a larger historic river landscape including bridges and sluice gates. They are often an important part of the amenity of a valuable mill house, which is also someone’s home.

When considering repairing or removing a weir, the first stage in heritage terms is to do a search of the Sites and Monuments Record (SMR) and consult the County Archaeologist. The latter will be found within the County Archaeological Services in England and Welsh Archaeological Trusts in Wales. If the weir turns out to be part of a Scheduled Ancient Monument or listed historic landscape, then English Heritage may need to be involved. However it is a remarkable fact that very few weirs, except those that form part of larger important historic landscapes, are listed in any form and very often little is known about them. An archaeologist with good local knowledge can generally do a valuable map regression and there are sometimes good papers on the water mills of a particular river in the County archives. There is a pressing need to set up an asset register survey of these sites. Such a project is being commenced in the Thames Region. The best national audit of weirs is arguably that which is held by British Waterways but it is of course restricted to their navigable waterways.

Following a desk-top search it is desirable that an archaeologist maintains a watching brief and if divers go down to check foundations for structural problems, they should ideally be trained to look out for signs of archaeological interest such as old timbers. Any finds should subsequently be recorded and as much as possible left in-situ.

With the exception of Treasure Trove, ownership of artefacts lies with the riparian owner who should be informed of discoveries and advised of their rights of ownership.

Case Study M, in Appendix C, presents an excellent example of restoration of a mill weir.

2.4.7 Water Quality

It is often said that a weir will improve water quality through aeration of the flow as it cascades over the structure. It is undoubtedly true that water is aerated as it passes over a weir, especially if the flow is turbulent (Figure 2.29), and that this aeration is beneficial to water quality. However, the construction of a weir in a river or stream flattens the gradient, and reduces the opportunity for natural aeration by creating deeper more placid conditions upstream. Many rivers support an effective pool and riffle system, and the riffles are quite effective in aerating the water. In situations where the quality of the water in a river is poor, it is unlikely that the construction of a weir will have a significant impact on the water quality. Indeed, it may create secondary problems such as foaming, which until recently was a common feature downstream of weirs on many of our rivers that pass through industrial areas.

Figure 2.29 Virginia Water

Opportunities to construct weirs like this are very rare. The aeration effect of most weirs is modest, and is certainly not a primary benefit.

Where weir works are being considered in rivers that still exhibit poor water quality, the design should attempt to mitigate the problem. For example, provision should be incorporated for removing the debris that floats down our urban streams and tends to accumulate at weirs. Leptosporosis, or Weil’s disease is one of the main areas of concern with regard to the risk posed to people who come into contact with polluted water. Weil’s disease is caused by a bacterium that is transmitted through rats’ urine. Humans may become infected when open cuts or mucus membranes come in contact with urine contaminated water. The favoured environment for its survival and transmission is warm water such as is found in sewers, but may also occur in the summer in water impounded by weirs. If there is any reason to suspect that the water at a weir is likely to harbour the bacterium, members of the public should be warned by appropriate means to avoid contact with the water.

2.4.8 Recreation, amenity and navigation

(i) Recreation and amenity

Recreational activities on rivers in the 21st century probably do not differ enormously to those enjoyed by the characters as depicted in 1908 by Kenneth Graham in "The Wind in the Willows," but with the decline of commercial river traffic on Britain's waterways, a river's uses today are dominated by leisure activities. The main limitations to recreation in the proximity of weirs are associated with safety and water quality. Substantial weirs with powerful flows of water may be prone to having undertows; and water quality is compromised through the extensive use of rivers for regulated disposal of treated wastewater and other effluents including road run-off and industrial discharges.

As well as the visual amenity created by water cascading over a weir, weirs are often important recreational resources for canoeists and anglers. During the environmental assessment consultation should be conducted with national bodies and local interest groups, including local canoe clubs and angling clubs, to determine the importance of a weir and river reach as a recreational resource. There are health and safety issues associated with recreational activities conducted at or in close proximity to weirs (see Sections 2.1 and 2.3.9). Where a canoe club relies on a weir for its activities it may be more beneficial if the weir is refurbished or reconstructed to be safer rather than demolished so as to remove the risk and liability to the owner of the structure.

Figure 2.30 Weir with a canoe pass on the River Medway

This gated weir not only has a fish pass (far left) but also incorporates a canoe slide

(ii) Navigation

Weirs are key to the continued flow of water where navigation locks create impoundments on either the main channel or an associated cut permitting traffic to pass up and downstream. So long as the locks are operated efficiently the weir should ensure that a minimum depth is maintained upstream to permit the navigation of vessels.

In the same way that road traffic surveys are conducted prior to works being carried out on Britain's roads, consideration should be given to timing works on weirs for periods in the year when navigation is at its lowest. The preferable period for works is during the summer months whilst flows are at their lowest and daylight working hours longest. However, this tends to be the time of the year when navigable rivers are at their busiest, predominantly with leisure craft.

On some rivers, for example the Thames, there is a statutory right of navigation, and restrictions on the works that can be carried out on weirs and other river structures. Clearly in such cases it is essential that the navigation authority is consulted when any works to weirs are planned, whatever the scale or ultimate purpose of the works.

2.4.9 Integrating Nature Conservation with Weir Design and Construction

The integration of environmental improvement into schemes serves two purposes:

1. Off-setting construction impacts
2. Off-setting operational impacts

It is relatively simple to identify construction impacts, and many of these can be mitigated through the application of standard best practice methods for the construction industry. However, careful thought is often required to provide appropriate operational impact mitigation measures. For instance, how should the permanent loss of a sand martin colony be mitigated when engineering design requires the crumbling river-cliff to which they return annually to be protected against erosion? How can water quality be guaranteed upstream of a weir during periods of summer low flow? How can fish passage be preserved during differing flow and water level conditions?

The design of mitigation measures to improve wildlife habitat should be conducted in conjunction with English Nature (CCW in Wales), the Environment Agency and the local branch of the Wildlife Trust. The involvement of English Nature is obviously of paramount importance should the work being conducted be within a statutory designated area, but under other circumstances English Nature may rely on the local Wildlife Trust to help them reach a decision.

Where mitigation measures include the planting of vegetation to screen a weir and its associated structures, it may be necessary to obtain approval from the Countryside Agency. Again, this is of particular relevance should the works area and mitigation measure be situated within an Area of Outstanding Natural Beauty or other statutory designated landscape.

Figure 2.31 Otter ramps

Otter ramps have been retro-fitted to this gauging weir. This particular design is rather flimsy and could collapse under the weight of a child (or several fat otters?). Had the ramps been considered from the outset, they could have been engineered much more effectively.

As with the construction of many structures to the side of a river or stream, there are often opportunities to improve habitats (see Case Study B). These may include:

- Sand martin burrows in the wingwalls upstream and downstream of the weir;
- Nesting ledges for dippers to the side of the weir;
- Overhangs beneath which swallows, swifts and martins can construct their nests;
- Damp conditions to either side of the channel for the proliferation of bryophytes and lichens;
- Overhangs immediately above the water to provide refuge to fish from predators;
- Low in-stream obstructions set into the bed of the river such as heavy boulders, downstream of which deeper areas and slack water should form (but note that such features may present risks to human water users, including canoeists and swimmers).

Opportunities for habitat creation as a mitigation measure specifically related to the design of the weir are not always available. Under such circumstances alternative mitigation measures should be considered that indirectly benefit the flora and fauna of the river and riparian zone.

A simple mitigation includes the use of neighbouring structures, such as a bridge or a building, for providing nesting boxes for dippers, flycatchers and wagtails. Often a lost habitat may be impossible to replace, in which case biodiversity should be increased in other ways. Backwaters may be created in which fish can shelter during floods, or improved bankside planting to benefit invertebrates as well as to stabilise banks. Roosting sites for bats can perhaps be created in old buildings. Where there has been considerable loss of habitat through weir construction and associated bank protection there may even be an opportunity for the creation of a pond to the side of the stream and an associated marshland (See Case Study B).

Figure 2.32 Weir on the Jubilee River

The Jubilee River is a man-made flood diversion channel for the River Thames. It has a modest perennial flow to improve its environmental value. The weir in the photograph has been provided to maintain a high water level so that ground water levels in the surrounding area are not drawn down.

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River Weirs – Good Practice Guide

Appendix B

Charles Rickard, Rodney Day, Jeremy Purseglove

R&D Publication W5B-023/HQP

Research Contractor:
Mott MacDonald Ltd and University of Hertfordshire

APPENDIX B - PLANNING AND DESIGN CHECKLIST

eneral Considerations

New weir

- Is the weir really necessary?
- Have alternatives to a weir been considered?

Refurbishment of weir

- Is there an opportunity to improve the weir for fish, canoeists, amenity, and/or environment?

Removal of a weir

- Have all of the potential impacts been assessed?

Consultation

- Identify all stakeholders and interested parties

Fundamentals

- Ensure that the objectives of the project are clear

Design Issues

Hydraulic design

- Flow range in river. Design maximum flow
- Impact on water levels throughout flow range
- Impact on flood risk
- Check that hydraulic jump is always in stilling basin

Safety issues

- Public safety
- Safety of boaters and canoeists
- CDM Regulations
- Operation and maintenance activities
- Need for warning signs, fencing, life-saving equipment
- Safety during construction

Structure

- Need for cut-offs to reduce underseepage
- Design to prevent bypassing in floods

Environmental Issues

Potential impacts

- Disruption/loss of fish migration and spawning
- Damage to local landscape
- Affect on local groundwater regime
- Loss of historic/heritage value
- Local wildlife (otters, birds, invertebrates)
- Loss of amenity and recreation value
- Local residents (noise, view, access rights, etc)
- Land acquisition issues

Environmental design

- Landscape design
- Appropriate materials/finish/colour
- Potential to improve habitat variety
- Current/future water quality constraints
- Appearance in low flows

Operational issues

- Safety of O&M personnel
- Need for lighting at the weir site
- Assessment of likely trash/debris load
- Facilities for debris removal/storage
- Safe access to all parts of the structure
- Site security, fencing, walkways
- Need for periodic removal of sediment
- Operating plan when weir or equipment fails
- Provision for dewatering (e.g. stoplog grooves)
- Maintenance plan and schedule
- Maintenance equipment needs

Decommissioning

Surveys and investigations

- Gather all available data on flows and levels
- Topographic survey of the site and environs
- River corridor survey
- Consultation with fisheries officer
- Establish land ownership
- Recreational use of river (canoeing, angling, etc)
- Historic / archaeological survey
- Investigate access routes for construction

Legal and planning

- Navigation rights on river
- Are any rights of way affected
- Land drainage consent
- SSSI, SAC, AONB
- Is planning permission needed?

- Check sub-structure for uplift
- Need for erosion protection on bed and banks
- Stability and durability in flood flows

Hydrometric (flow monitoring) weirs

- Suitable approach flow conditions
- Sufficient head across weir in all flow conditions
- Choice of appropriate weir type
- Sediment/weed growth problems

Opportunities

- Improvements to local habitat
- Remove barriers to fish migration
- Improved conditions for wildlife
- Improved conditions for canoeists
- Opportunities for hydropower generation
- Opportunities for recreation and amenity

Geomorphological issues

- Sedimentation (new weir)
- Scour of upstream sediment (demolition/lowering)
- Scour downstream of a new weir
- Erosion in response to removal of a weir
- Mitigating measures

Construction issues

- Pollution control during construction
- Timing to minimise impact (fish, birds, river users)
- Temporary diversion of footpaths
- Need for fish rescue
- General disturbance to established habitats
- Noise during construction
- Access for construction
- Risk of damage/disruption in flood flows
- Temporary works (e.g. flow diversion)
- Public safety/information (fencing, signboards, etc)

- Has ownership of the weir been confirmed?
- Is refurbishment an option?
- Check full range of impacts first
- Release of contaminated sediments
- Impact on water levels and groundwater
- Exposure of archaeological finds
- Historic / heritage loss if removed
- Impact on navigation and amenity use
- Impact of river ecology
- Impact on river geomorphology
- Impact on upstream infrastructure

River Weirs – Good Practice Guide

Appendix C - Case Studies A-D

Charles Rickard, Rodney Day, Jeremy Purseglove

R&D Publication W5B-023/HQP

Research Contractor:
Mott MacDonald Ltd and University of Hertfordshire

The case studies in this Appendix are intended to illustrate a range of weir projects that bring out many of the lessons incorporated into this guide.

A Alrewes Weir – improvements to a large weir on the Trent
B Crimpsall Sluice – demolition of a sluice and construction of a rock weir
C Hoo Mill – construction of a rock chute
D Nethertown Weir – addition of a fish pass

Case Study A - Alrewas Weir

Alrewas weir was originally constructed to provide water supply to the Trent and Mersey Canal. Improvements in water quality over the past 25 years led to increased fish populations in the Trent, but the weir presented a barrier to fish migration upstream. In 1996 the Environment Agency decided to install a fish pass at the weir to further improve the fisheries status.

Figure A1 - Alrewas Weir, River Trent

Land adjacent to the weir was recognised as a historic heritage site, containing the site of a medieval village. A multi-disciplinary team was established, comprising the Environment Agency (fisheries, engineering, conservation and environmental impact assessment staff), British Waterways (owner of the canal and embankments), English Heritage, the county archaeologist and the two local landowners. The option of installing a fish pass in the weir structure itself was quickly ruled out, with the preferred option being a small bypass channel with a fish pass. This would involve making use of a small triangle of land bounded by the River Trent and the Burton stretch of the canal, see Figure A2. This land was not actively used by the landowners and had little environmental value. A route for the bypass channel was identified using the natural lie of the land, which included several pools, Figure A3. It was agreed that the Agency would purchase the triangle of land for a small fee. Additional benefits incorporated into the scheme included provision of an otter holt (there was evidence of otters in the area), and a planting regime both on the triangle and along the banks of the River Trent.

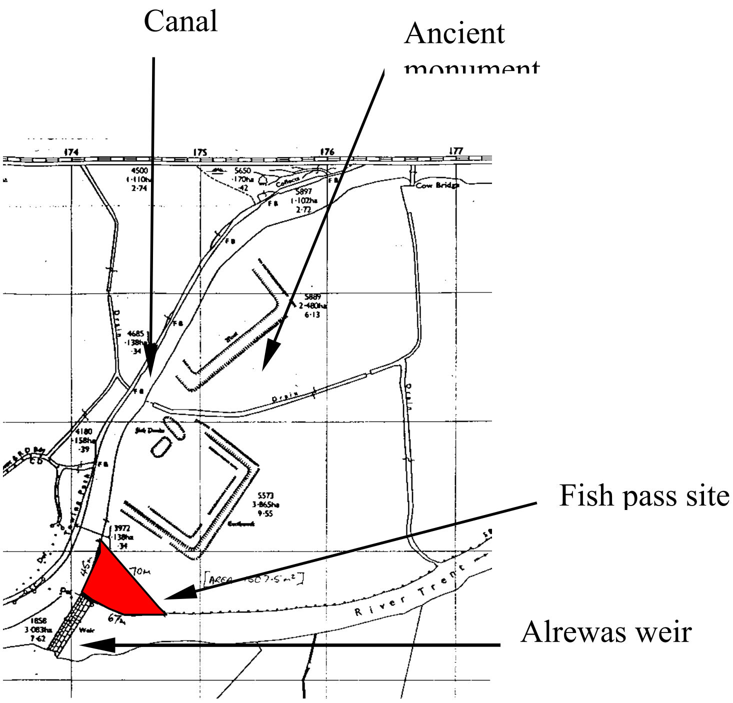


Figure A2 – Site Plan

Figure A3 - Undulating land viewed from the river towards canal, prior to construction

The fish pass installed was a Larinier pass with superactive bottom baffles, which discharged into a series of channels and pools before flowing into the River Trent. The channel and pools were lined with sandstone on the bed and banks. The otter holt was established adjacent to the bypass channel and extensive vegetation planting was carried out. Concrete wingwalls were provided on the fish pass structure in the canal embankment to prevent bypassing of the structure. A small footbridge was installed to improve access, and recesses were installed at the inlet to facilitate dewatering and maintenance. Figures A4 and A5 show the site during and after construction respectively.

Before construction commenced agreement was reached with English Heritage as to the techniques to be used and the route that vehicles would take to get to the site to avoid the medieval village. As part of this process an additional fee was paid to a local landowner for access rights, and improvements to a bridge were undertaken. In total the cost of the job was approximately £20,000 (1996 prices), including land purchase, otter holt, and planting. Early on in the construction phase the archaeologist identified some ancient fish weirs. After inspection and following the taking of samples, permission was given for these to be demolished. In total the construction took about four weeks.

Figure A4 – Three photographs of the construction of the bypass channel and pools

Figure A5 - Aerial photograph of finished channel

Some five years after completion the whole area has recovered, with vegetation gaining hold across the entire site, including the stone facing on the bypass channel. Fish such as chub, dace, barbel and possibly pike are using the pass. Figures A6 and A7 show the current state of the site.

Figure A6 - The fish pass looking upstream towards the canal

Figure A7 - The site five years after completion showing established vegetation

Lessons learned

- Multi-disciplinary teams enabled a balanced and inclusive scheme to be designed, built and monitored
- Additional environmental gains can be achieved at relatively small cost if carried out at the time of the main capital works
- Fish passes do not necessarily have to be placed within the weir structure

Case Study B - Crimpsall Sluice Replacement Scheme

Crimpsall Sluice on the River Don was built during the 1950s to serve both as a flood defence structure and for water level regulation in the Sheffield and South Yorkshire Canal. By the late 1990s it was deemed to be unserviceable. Several options were considered, including full refurbishment and replacement with a fixed weir. Replacement with a new weir was the preferred option. There was some concern about carrying out works in the existing channel so an alternative approach making use of the former course of the River Don was investigated (Figure B1). The benefit of this approach was that the new weir could be constructed in relatively dry conditions and without the need for extensive cofferdams. It also presented an opportunity to obtain an environmental gain through the use of a rock weir. For many years the water quality in the River Don had been improving but fish had difficulty in passing beyond Crimpsall Sluice due to the water level difference across the structure. Based on experience in the USA, Canada, Denmark and Australia, it was established that a rock weir sloping at about 1 in 25 would allow fish to migrate upstream.

Figure B1 - Aerial view of site

After extensive model testing, to examine crest alignment options, stone sizing and bank protection requirements, a final design for the rock weir was decided upon. A rock chute sloping at approximately 1 in 30, with a drop of 2.8m, was installed into the former river channel over a total length of about 100m. Figure B2 shows a view looking upstream from the toe of the weir once operational. It can be seen that flow is relatively evenly distributed, with a number of pools and protruding rocks. In addition extensive bank stabilisation has taken place, with rock riprap along both banks. The crest at the head of the rock chute is vee-shaped on plan (Figures B3 and B6) to maximise the flow over the weir. The rock used was a magnesian limestone from local quarries, with a nominal rock size of 600mm. The rock was placed to a thickness of 1200mm on a 150mm granular underlayer on a geotextlie (NB – appropriate design of a rock hydraulic structure is important – compare with Case Study E). Figure B3 also illustrates one of the disadvantage of such structures, in that they have a tendency to collect debris which is difficult to clear safely. In fact on this weir debris is naturally removed when high flows pass over the weir.

Figure B2 - New rock weir in October 2002

Figure B3 - Debris trapped on weir crest

Although only completed in October 2000, considerable improvements in biodiversity of the surrounding area and the river have been achieved already at the time of the writing of this manual. The grass mound, see Figure B4, which was previously accessible is now part of an island which can only be reached by boat. As part of the scheme design, a sheltered backwater area was formed, Figure B4, which provides a fish refuge during high floods, preventing them from being swept downstream. This also acts as a sheltered breeding site for a number of fish species. Since completion salmon and eels have been recorded upstream of the weir for the first time since the Industrial Revolution, and the reach immediately above the rock chute has significant numbers of coarse fish including barbel, chub and dace. This is seen as an indication that the barrier to fish migration has been removed, and a recent study on the downstream slope of the weir has indicated that fish are also resident in certain areas of the weir structure itself.

As part of the mitigation measures undertaken during the construction of the new weir, a number of water voles were removed from the oxbow channel, temporarily moved to Blackpool Zoo, before being reintroduced to a specially adapted wetland area adjacent to the newly opened old channel. The wetland area was formed with minimal excavation, and establishment of vegetation was by transplantation from the oxbow channel and from the grass mound, which ensured local species were used and kept costs to a minimum.

Figure B4 -View of the inaccessible island and refuge for fish

The final stage of the £1.1 million project was to decommission the existing sluice, with the removal of the gates and overhead machinery and gantry, and the installation of a mass concrete weir between the existing abutments. The new weir crest was constructed 100mm above that of the rock weir crest to encourage water to pass through the old River Don channel. A notch in the weir in the sluice ensures that some water always passes through it to provide a freshening flow. The finished scheme shown in Figure B5.

Figure B5 - View of the finished works

The Environment Agency worked together with English Nature, Doncaster Metropolitan Borough Council, and the Doncaster Naturalists' Society, to create a new rock weir that is proving a considerable success both in terms of its environmental benefits, as well as a functioning flood defence structure. Soon after completion, the floods of 2001 tested the new weir towards the upper end of its design discharge, with no adverse effects of rock movement. The pond in the cut off length of the river is now a site of scientific interest and has dragonflies, newts, water voles and other wildlife resident. A further benefit of the project has been to recreational users of this part of the River Don. The area is popular for fishing, especially now that there are plenty of fish present, and is also visited extensively by walkers, ramblers and local residents.

Lessons learned

- Lateral thinking can result in a scheme with the desired functionality but with additional environmental and recreational benefits
- Dumped rock can provide a sound hydraulic structure, but it is important that it is properly engineered, with appropriately sized rock placed to sufficient depth (NB in most situations, a dumped rock weir will require a concrete crest to ensure even flow distribution)
- Model tests can help to refine a design to ensure that the prototype performs as desired. Such tests are particularly important for unconventional structures.

Case Study C - Hoo Mill

Hoo Mill is an old mill building now converted into a small residential house located alongside the River Trent. Immediately outside the house is an access road crossing the river and which some time ago was strengthened through the installation of a reinforced concrete box section. However in doing so the invert of the box section was set above the downstream river bed. This led to rapid and significant erosion downstream leaving a scour hole several metres deep and caused the invert of the bridge to act as a weir. This presented an obstacle to fish.

Figure C1 - The invert of the box culvert acting as a weir

To overcome the problem, the Environment Agency has created a rock chute, sloping at an angle of 1:20, for a length of some 30 m downstream of the bridge. Some 700 tonnes of 0.5m-sized local limestone rock was used to fill the scour hole and create the chute, Figure C2. A trench was excavated across the river at the downstream end of the cute and subsequently filled with rock to provide protection against further erosion. Some easement fees, totalling £1,400, were payable to local landowners for access, and improvements to the boundary of one landowner's property was carried out where scouring had caused the collapse of the river bank.

Figure C2 – The completed rock weir in operation

The total project cost was approximately £15,000. Such was the success of the scheme that construction workers observed fish swimming past their feet up the chute as they were placing the final few stones. Figure C3 shows the scheme immediately after completion whilst Figure C4 shows the scheme several years later. Although some movement of stone has taken place the chute is still fully operational.

Figure C3 - Completed rock chute with rebuilt bank protection

Figure C4 - View of the site in October 2002 with bed remaining stable

Lessons learned

- It is important to avoid setting culvert invert levels too high
- A relatively cheap scheme using a rock chute overcame the scour problem and avoided the need for a specially designed fish pass
- Monitoring of rock structures is recommended as it has been noticed that some movement of rock has taken place over several years

- It is interesting to note that, in this instance, local road hauliers were reluctant to transport stones larger than about 0.5m as they considered that these would damage their lorries!

Case Study D - Nethertown Weir

South Staffordshire Water (SSW) is licensed to abstract water from two locations on the River Blithe. Water is drawn from Blithfield Reservoir and is also pumped from the lower Blithe at Nethertown, some 500m upstream of its confluence with the River Trent. The existing licence sets a minimum compensation release of 23 ML/d from the reservoir upstream and a minimum residual flow from the Nethertown intake to the Trent confluence of 9ML/d. SSW wished to increase abstraction rates.

The abstraction point at Nethertown was monitored using a notch located in the centre of the weir to allow 9 ML/d to pass down to the Trent. The weir presented a barrier to the migration of fish from the River Trent because the flow velocity through the notch was usually high and there was a significant drop in water level. The river length below the weir was silting up due to low flows and was not good fish habitat.

After discussions with SSW, the Environment Agency indicated that they would grant permission for the additional abstraction on the condition that the water company installed a fish pass. This was accepted and the monitoring weir now has a Larinier fish pass located in the centre of the structure where the notch had originally been located. The pass is 0.6m wide with 100mm high baffles and a 15% slope which gives 104 l/sec (9 ML/d) at a depth of 0.18m

To ensure the lower Blithe does not run dry and to provide a scouring flow during maximum abstraction, SSW have constructed a pipeline to re-circulate 15 ML/d from the River Trent immediately upstream of the Blithe confluence into the Blithe immediately below the weir and back to the Trent. This recirculation only occurs very rarely and the fish pass is in operation for most of the year.

Figure D1 – The original weir with its new fish pass

Lessons learned

- Negotiation can lead to a win-win situation for all parties.

River Weirs – Good Practice Guide

Appendix C - Case Studies E - J

Charles Rickard, Rodney Day, Jeremy Purseglove

R&D Publication W5B-023/HQP

Research Contractor:
Mott MacDonald Ltd and University of Hertfordshire

The case studies in this Appendix are intended to illustrate a range of weir projects that bring out many of the lessons incorporated into this guide.

E Former Mill Weir – collapse of a weir, repair, another collapse, repair again
F Rother Weir – remedial works to improve a dilapidated weir
G Logie Weir – a fish counting weir
H Hambledon Weir – improved conditions for canoeists
J Padiham Weir – proposed improvements to provide white water facility

Case Study E – Former Mill Weir
Background

A weir on a river in the north of England impounded water for the purpose of milling when it was originally installed over 100 years ago. The weir, which was constructed of masonry and concrete, spanned the full width of the river with a crest length of approximately 15m, causing water levels upstream to be some 2.5m higher than they would have been naturally. The weir allowed water stored upstream to be abstracted through an inlet structure to an adjacent millpond separated from the river by an earthen embankment constructed on the river bank. The embankment is approximately 4m high from river bed to crest level. The millpond contained a supply pipe to the adjacent works, and an overflow arrangement allowing excess inflow to discharge back to the river downstream of the weir. There was also a sluice structure midway along the length of the river embankment. The millpond has a capacity of about 11,000m^3 of water (which is less than the capacity that would bring it within the auspices of the Reservoirs Act 1975 - 25,000m^3 is the lower limit). It was thought that the millpond had been polluted with a number of chemicals from the foundry processes carried out at the adjacent works. At some time in the past 30 years the local sewerage undertaking installed a 375mm diameter foul sewer within the bed of the river upstream and downstream of the weir. The sewer was constructed through the upper part of the weir structure, possibly weakening it, and then, immediately downstream of the weir, continued beneath the riverbed. In late January/early February 2001 a flood caused a breach of the weir resulting in approximately two thirds of the crest length being washed away.

Figure E1 - Weir breach viewed from downstream.

The remaining third of the masonry weir can be seen on right hand side.

It can be seen that the effect of the collapse of the weir was to cause a significant reduction in the effective crest level on the right side (looking downstream) of the river where only the concrete core of the weir was left in place. The remainder of the weir containing the sewer pipework was undermined over part of its length. Figure E2 shows the effect upstream, where water levels decreased by up to 2m causing severe erosion of the riverbed and banks, and exposing the sewer which had previously been covered by the bed material. The sewer did not have a concrete surround.

In addition to erosion of the river bed there was erosion along a 30m length of the toe of the earth embankment to the millpond extending from immediately upstream of the weir, as well as signs of erosion at the base of a 5m high masonry retaining wall on the left bank. There had also been considerable erosion immediately downstream of the weir creating a sizeable scour hole. Since flows were concentrated on the right hand side of the river following the breach, there was continuous erosion of the right bank. Ownership of the weir was not clear and it was necessary for the owners of the millpond to engage their solicitors to establish ownership, which after several weeks of searching turned out to be a third party who no longer owned land or property in the area. The weir owner was an elderly person who, inexplicably had been left in ownership following land transfers and property disposals many years ago. He played no part in the work carried out subsequent to its collapse. The weir did not serve a flood defence function, nor was there any navigation or specific amenity value to that stretch of the river.

Figure E2 - View from upstream of weir, after breach.

Note the erosion that exposed the foul sewer and the damage to the earth embankment on the right hand side. This caused the collapse of a sluice gate and surrounding brickwork structure connecting to the millpond.

Remedial Action Taken

Immediately following the breach event, due to concerns about the millpond embankment, the owner engaged a Panel Engineer under the Reservoirs Act to inspect the embankment and provide advice on the measures necessary to maintain its stability. The outcome of this was a recommendation for the embankment to be stabilised by placing heavy stone riprap along the length of the embankment toe, as well as the provision of gabion baskets in the immediate vicinity of the weir. It was also recommended that rip rap be placed against the toe of the masonry retaining wall on the left bank of the river. Coincident testing of the pond water indicated that the water was not contaminated, but that there were deposits on the bed of the pond containing chemicals related to the industrial processes carried out historically at the adjacent works. The risk of pollution of the river from these deposits was considered to be low. The millpond owners contacted the Environment Agency at an early stage, and also the local water company who were the owners of the foul sewer as there was considerable concern about pollution should it collapse. To protect the integrity of the sewer, the water company decided that the breached portion of the weir should be repaired. Following consultations between the water company's contractor and the Environment Agency, a stone weir was constructed. Figure E3 shows the plan view of the repair. The arrangement was intended to provide acceptable conditions for the migratory fish in the river based upon Environment Agency guidance.

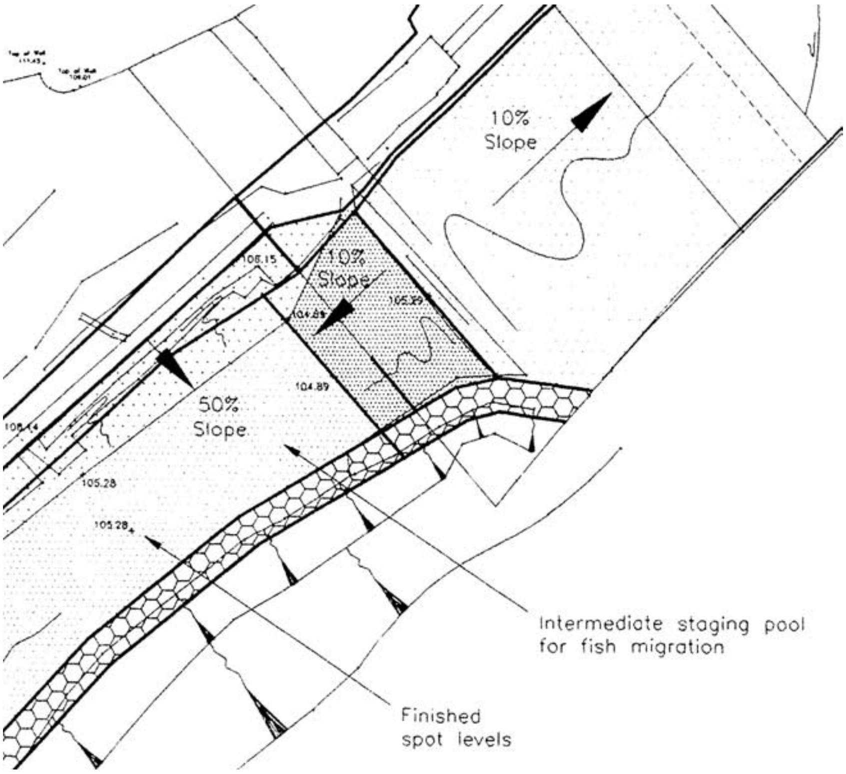


Figure E3 – Plan view of the weir repair

The repaired stone weir was completed at the end of August 2001. Figures E4a and E4b show upstream and downstream views of the weir just before its completion, to a level that was approximately 0.5m below the previous crest level. In Figure E4b some of the gabion baskets used to stabilise the toe of the embankment are visible and improvements to the original weir structure have been undertaken where the sewer pipe passes through the weir. At the same time, the sewer pipe was protected by the laying of concrete filled bags where it was undermined and exposed.

Figure E4a

Figure E4b

By November 2001, parts of the repaired section of the weir crest began to move until, during flood events in January 2002, the repaired section was completely washed away. The resulting collapse is shown in Figures E5a and E5b. It can be seen that a number of the large boulders placed to form the weir have washed into the downstream pool and undermining of the remaining weir structure has taken place. It should be noted that the gabions installed to protect the embankment and the riprap on the opposite bank provided sufficient protection to avoid any further erosion. However, Figure E6, taken in April 2002, shows that the sewer pipe is once again above bed level, albeit supported with bag-work.

Figure E5a

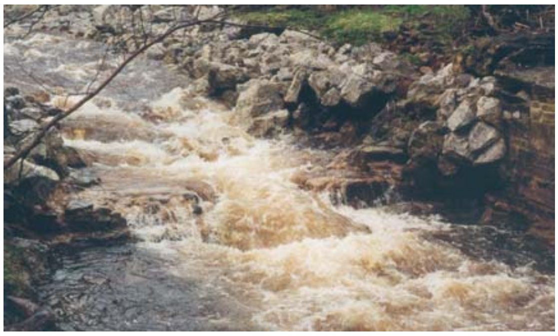


Figure E5b

Figure E6 - State of weir, April 2002

A re-evaluation by various agencies was subsequently undertaken and a decision was made to once again replace the weir. This was completed during September 2002. Once again a rock weir was established, this time with some much larger rocks, Figure E7. Additional measures included creating a riffle upstream of the weir, which has been used to both cover the pipeline that was previously exposed and to form a pool upstream of this, Figure E8. Downstream of the crest of the weir the drop has been spilt into a few small steps encouraging plunging flow and energy dissipation, Figure E9. In addition to this some remedial action has also been taken to place riprap along the river banks to prevent erosion. In October 2002 the weir was operating effectively with good energy dissipation downstream and no evidence of bank erosion or movement of the stone boulders on the weir.

Figure E7

Figure E8

Figure E9 – Note the attractive natural appearance on the weir

Lessons learned

- Old weirs often no longer serve the function for which they were originally constructed. As such they may be neglected and infrequently inspected (if at all).
- Such weirs may be located in places where access is difficult, and may be hidden from view by dense tree and bush growth.
- It is sometimes difficult to trace the owners of these neglected structures.
- In cases of failure, prompt action may be needed to avoid a flood or pollution incident, and to restrict the amount of damage caused to adjacent structures.
- The stability of rock weirs requires careful consideration. In particular:
- The size of the stones used
- The thickness of the rock layer
- The need or an underlayer of gravel or geotextile to prevent fine foundation material from being washed out, undermining the rock
- The need to stop flow passing through the rock structure (in low flows this would cause the weir to appear dry, in high flows it could destabilise the weir)
- In this case, it might have been more appropriate to replace the weir with a concrete structure, faced with masonry to mimic the original structure. This very much depends on the setting of the structure and its heritage value.
- Demolition of a weir that has collapsed may be the best option, but the impacts of so doing (engineering and environmental, short-term and long-term) need careful investigation before the decision is taken.

Case Study F – River Rother

Restoration of an open-cast coal mining site required a diversion of the River Rother. The reach to be diverted was regulated by a dilapidated weir (Figure F1), which was known to have significant deposits of contaminated sediment upstream. The solution was to create a new reach of river with a new weir. The most seriously contaminated material was removed from the old channel and disposed of safely. The old river reach, together with the old weir, was backfilled to close the channel and to seal in the remaining contaminated sediment.

The new weir comprises a concrete structure (Figure F2) with extensive dumped rock downstream to form a riffle (Figure F3). The slot in the concrete weir crest provides a concentration of flow in dry conditions. This, together with the low flow channel in the dumped rock downstream, helps to provide a passage for fish migrating upstream. The new river channel has been constructed to a meandering planform (Figure F4) to ensure that, in the longer term, it takes on the appearance of a natural river.

Figure F1 – View of the old weir

Figure F2 – View of recently constructed weir showing concrete structure and rock downstream

Figure F3 – View of the new weir in operation

Figure F4 – View of the recently formed river channel

Lessons learned

- Old weirs in industrial areas often have accumulations of contaminated sediment upstream. If this sediment is disturbed and thereby released into the river water downstream, it could cause extensive environmental damage.
- New weirs need to cater for **fish** as well as **flow**, and must operate satisfactorily in **low** as well as **high** flow conditions.
- Rock riffles can provide an attractive environment for fish as well as increasing the diversity of invertebrates, plants, animals and birds. The rock riffle also acts to dissipate the energy of falling water (taking the place of a conventional stilling basin). To be effective, the rocks must be large enough to resist movement in high flows. It is normal to provide a geotextile underlayer to the rock to prevent erosion of the foundation material.

Case Study G – Logie Fish Counting Weir

Many fish are capable of swimming upstream over a weir in conditions where the drop in water level is small, and/or the flow velocity on the weir glacis is not too fast. Salmonids are capable faster swimming speeds than the coarse fish species. However, for all fish, actual capabilities will depend of the **size** and **condition** of the fish, as well as the **water temperature.**

In order to check whether a weir will form a barrier to migrating fish it is possible to compare the swimming speeds of fish with the flow velocities they may encounter at the weir. The following table gives the "burst" speed of salmon of various sizes. It should be noted that the confidence limits for such speeds are very wide – for example, perhaps between 0.6 m/s and 3.5 m/s for a 400 mm fish. It should also be noted that the swimming speeds of other fish species are likely to be less.

Salmon	**Fish Length (mm)**				
	200	**400**	**600**	**800**	**1000**
Burst Speed (m/s)	1.6	2.3	2.9	3.4	3.8

For the design of weirs to facilitate fish counting, a flow velocity of 3.0 m/s over the weir has been suggested as a limiting value. This may be acceptable for salmon but would not be for almost all coarse fish species. On a river with a very large fish population or abundant habitat throughout the system, it may be acceptable to have a weir that only allows, say, 75% of the fish that want to get over the weir to actually do so. On rivers with low populations or little habitat it may be desirable to get all the fish over the weir.

A fish-counting weir on the North Esk (Figure G1) at Logie has been operational for at least 20 years successfully counting fish, and salmon have been observed ascending the weir against flow velocities of 3.5 m/s. It is therefore possible that the 3m/s rule is conservative as far as fish movement is concerned, and that salmon can cope with higher velocities than has previously been suggested. It is also possible that 3.0 m/s is only achievable by only part of the population and 3.5m/s by even fewer fish at very specific river temperatures.

It is therefore recommended that expert advice is sought before drawing any conclusions about the ability of fish to ascend a weir against a certain velocity of flow. Some references are given below.

References

1. M H Beach, (1984). *Fish counter design - criteria for the design and approval of fish counters and other structures to facilitate the passage of migratory fish in rivers.* Ministry of Agriculture Fisheries and Food. Fisheries Research. Technical Report 78.
2. Environment Agency R&D Technical Report W2-026/TR1 *Swimming Speeds in Fish: Phase 1*.

3. Environment Agency R&D Technical Report W2-026/TR2 *Literature Review - Swimming Speeds in Fish*.

Further reading

Environment Agency R&D Project Number: W6-084 (ongoing). *The investigation and specification of flow measurement structure design features that aid the migration of fish without significantly compromising flow measurement accuracy, with the potential to influence the production of suitable British Standards*. HR Wallingford (2002).

Figure G1 - The Fish-counting Weir at Logie on the North Esk

Acknowledgements

Original information and photograph courtesy of Dr Rodney White, HR Wallingford, with further information provided by Darryl Clifton-Dey, Environment Agency.

Lessons learned

- In considering the ability of fish to ascend a weir structure, it is essential to take account of all relevant data, and not depend solely on one publication. In particular, it is important to get information about the particular river or stream at the location of the weir from local fisheries officers.

Case Study H - Hambleden Weir

Hambleden Weir is a gated weir that has been used for many years as a facility for white water canoeing, with a slalom course used by many top competitors and clubs. In addition to this the weir offered a range of other amenities with many water sport clubs using the area as a base. Following a reconstruction of the weir in 1996 the flow into the downstream pool was changed significantly, to the extent that it was no longer viable as sports location. Furthermore changes to the flow also led to erosion of the river bank downstream. This was partly due to the operating regime that directed a substantial portion of the flow to pass through the part of the weir that was adjacent to one of the banks.

As a result of these events several studies were conducted to investigate ways of improving the flow through the weir. Research at the University of Nottingham identified that the addition of a series of kickers (adjustable wedge-shape blocks) on the downstream apron would shoot the flow up before it entered the pool, recreating the wave pattern that had previously been so popular with canoeists.

Figure H1 – Before addition of the of the "kicker" devices

Figure H2 – After addition of the "kicker" devices

Figure H3 - Canoeist (Photograph courtesy of Chalfont Park Canoe Club)

Lessons learned

- Full consultation with all interested parties at an early stage would have reduced the likelihood of difficulties being encountered after the weir was refurbished.
- Retro-fitting the "kickers" was considerably more expensive than would have been the case had the work been done as part of the refurbishment
- Physical model studies are useful in situations where the impacts of changes are difficult to predict, and/or where it is desirable to examine a number of options

Case Study J – Padiham Weir

Padiham Weir (Figure J1) was constructed on the River Calder in the 1950s to control the abstraction of cooling water to the adjacent, and now demolished, Padiham Power Station. Since the closure and subsequent demolition of the power station in the early 1990s, the weir has been defunct and serves no useful or operational purpose in its current state.

The former Padiham Power Station site has recently been decontaminated and brought back into economic use. A green business park – Shuttleworth Mead – has been constructed on the site and acts as a focus for stimulating economic development in the area.

Through incorporating the abandoned weir into a proposal for a canoe facility, the transformation of the site will be complete and leisure, recreation and community benefits will be brought to the area to complement the economic benefits derived from the new Business Park. The weir stands as a man-made barrier to public enjoyment of the river, as well as being a barrier to the migration of fish in the River Calder.

The Environment Agency initially considered Padiham Weir in terms of improving the movement of fish in the River Calder. A detailed assessment of the environmental context was undertaken by the Environment Agency, which culminated in a comprehensive report *Padiham Weir Project Appraisal Report* (12th April 2001, Environment Agency). The project appraisal report included an options appraisal, with one of the options being a 'fish pass and white water canoe facility'. This proposal had the full support of the BCU, particularly in view of the lack of facilities in the North West.

The Environment Agency has taken the lead role in developing the project proposal to date, and will continue to do so until construction is complete. With construction complete, the operation and maintenance of the Padiham Weir canoe centre will be the responsibility of the BCU with some on-going support from the Environment Agency. The landowner – Ribble Industrial Estates – has agreed to lease the land on the riverbank to the BCU for ninety-nine years at a nominal rent of £5 pa.

Outline of the Project

The project involves the construction of an island extending to 108 metres upstream of the existing weir, which will produce a divided channel. The southern channel will contain the main part of the river, controlled at its downstream end by the weir. The northern channel will contain the white water canoeing facility. An artist's impression of the proposed facility is shown in Figure J2.

The northern channel will have the existing weir removed at its western end and three pools will be constructed and will allow white water canoeing to take place on an east-west axis. Each of the three pools will have access and egress points for canoeists. In addition to the white water course, a canoe access agreement will be put in place along a two-kilometre stretch of the River Calder centring on Padiham Weir. A series of ingress and egress points will also be established at suitable points. In essence, this will

provide canoeists with a more varied set of conditions on which to practice their skills, receive coaching and generally develop and enjoy their sport.
Figures J1 and J2 are presented on the following page.

Lessons learned:

- Weirs present opportunities as well as constraints
- The Environment Agency can act as a focus for making best use of the opportunities created by weirs.

Figure J1

Figure J2

River Weirs – Good Practice Guide

Appendix C - Case Studies K - P

Charles Rickard, Rodney Day, Jeremy Purseglove

R&D Publication W5B-023/HQP

Research Contractor:
Mott MacDonald Ltd and University of Hertfordshire

The case studies in this Appendix are intended to illustrate a range of weir projects that bring out many of the lessons incorporated into this guide.

K Bishops Weir, Kilkenny – construction of a new weir with interesting features
L Northenden Weir – remedial works and the addition of a fish pass
M Little Bollington Weir – conversion of a mill weir to a flow gauging weir
N Staines Weir - a new weir with rock glacis, and fish and eel passes
P Stort Weir – the impact of changed conditions downstream of a weir

Case Study K – Bishops Weir, Kilkenny

A new weir is to be constructed as part of a major flood alleviation scheme in the town of Kilkenny, Ireland. The flood alleviation scheme involves dredging of the river bed and modification of existing weirs to reduce flood levels through the town. These works will also reduce water levels in the river in low flow conditions. A new weir is to be constructed on the river at the upstream end of the town, in order to maintain the low flow water levels close to existing conditions.

The new weir is to have a horseshoe shape on plan to mirror the shape of an existing weir downstream, and is to have a low flow section for visual amenity reasons. The figures below show the weir under construction. The main weir structure is of reinforced concrete, but with stone facing to give the impression of a masonry structure. A steel sheet pile cut-off has been provided to limit seepage under the weir, and this is carried through into the banks to reduce the risk of the weir being outflanked. Dumped stone is being used to form the abutments, avoiding the use of vertical walls for safety and amenity reasons.

Figure K1 – The first half of the weir under construction.

This is the left-hand half of the weir viewed from downstream. The river is flowing from right to left behind steel pile cofferdam in the background. The furthest part of the concrete is the "nose" of the weir (i.e. the most upstream part). Note:

- the recess in the concrete to take the masonry facing
- the low flow dip in the weir crest immediately behind the temporary footbridge centre-right
- the sloping abutment in the right foreground

Figure K2 – Similar to Figure K1 at a later stage of construction, with masonry facing in place

Figure K3 – The left-hand half of the weir from downstream.

Note the concrete wall on the left is a temporary structure that will allow removal of the sheet pile cofferdam when the second half of the weir is constructed. The concrete wall will be removed when the second half of the weir is complete.

Figure K4 – Flow diverted over the completed left-hand side of the weir

The concentration of flow over the low flow section can be clearly seen by the vee-shape of the white water downstream. The temporary concrete wall keeping water out of the right-hand half the weir (under construction) is just visible on the centre-left.

Lessons learned

- Consideration of the construction process during the development of the design is likely to facilitate construction and reduce costs
- Mimicking the form of existing weirs can help a new weir to blend in to the environment.
- The adoption of innovative temporary works can simplify construction, reduce risks, and limit environmental impact.

Acknowledgement

Photographs courtesy of Mott MacDonald, Dublin.

Case Study L – Northenden Weir, River Mersey

Northenden Weir was originally constructed to provide a head of water for Northenden Mill, and it is thought to date back to 1530. Although no longer needed for its original function, the weir is important in maintaining the regime of the river at this location.

The weir spans the river diagonally, with a 50 m crest that is gently curved on plan. It is located on a right-hand bend in the river, and the crest level is slightly higher on the outside of the bend. The downstream apron of the weir is gently sloping over a length of about 15 m.

The weir crest is formed from sandstone blocks, 1.2 m to 1.7 m long and 0.5 m wide. The crest blocks sit on a masonry wall, whereas the masonry apron sites on a grid of timber piles backfilled with gravel and clay (Figure L2). It was apparently designed as a "wet weir", that is somewhat permeable so that the timber piles remained moist.

The drawings produced following a survey of the weir are reproduced as Figures L5 and L6. The weir apron is made up of six bays. The two bays that are located adjacent to the right bank have recently been repaired. The repairs comprised replacement of the existing damaged sandstone blocks with a reinforced concrete apron. The concrete apron has been pigmented and finished to mimic the existing masonry (Figure L3), and it is underlain by a granular layer with outlet pipes to maintain free drainage. The joint between the new apron and existing masonry has been filled using an epoxy mortar.

A Larinier type fish pass has been added as part of the rehabilitation works.

Figure L1 – Part of the weir isolated by a cofferdam to allow remedial works to the weir and the construction of the fish pass
(NB The cofferdam has been formed form a clay core protected by rock, with sandbags providing additional height).

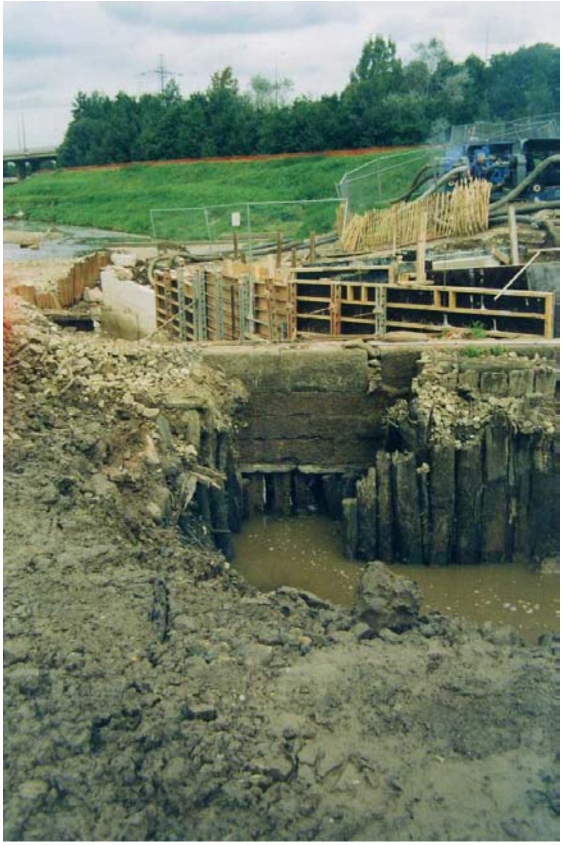


Figure L2 – Excavation reveals the timber piled sub-structure

Figure L3 – New weir taking shape adjacent to the fish pass

(Note the concrete finish on the weir glacis to imitate the original masonry).

Figure L4 –Completed weir structure with the new fish pass on the far bank

Lessons learned

- Detailed surveys of the existing structure are very helpful in determining the extent and nature of remedial works required
- Simple cofferdam arrangements (e.g. earth bunds) may be all that is needed for remedial works to existing weirs, but it is important to consider the impact of flood flows on these, both in terms of crest level and also resistance to erosion).
- Foundations of old weirs often include timber piles.
- It is important to consider under-drainage for weirs on permeable foundations.

Figure L5 - Plan of weir

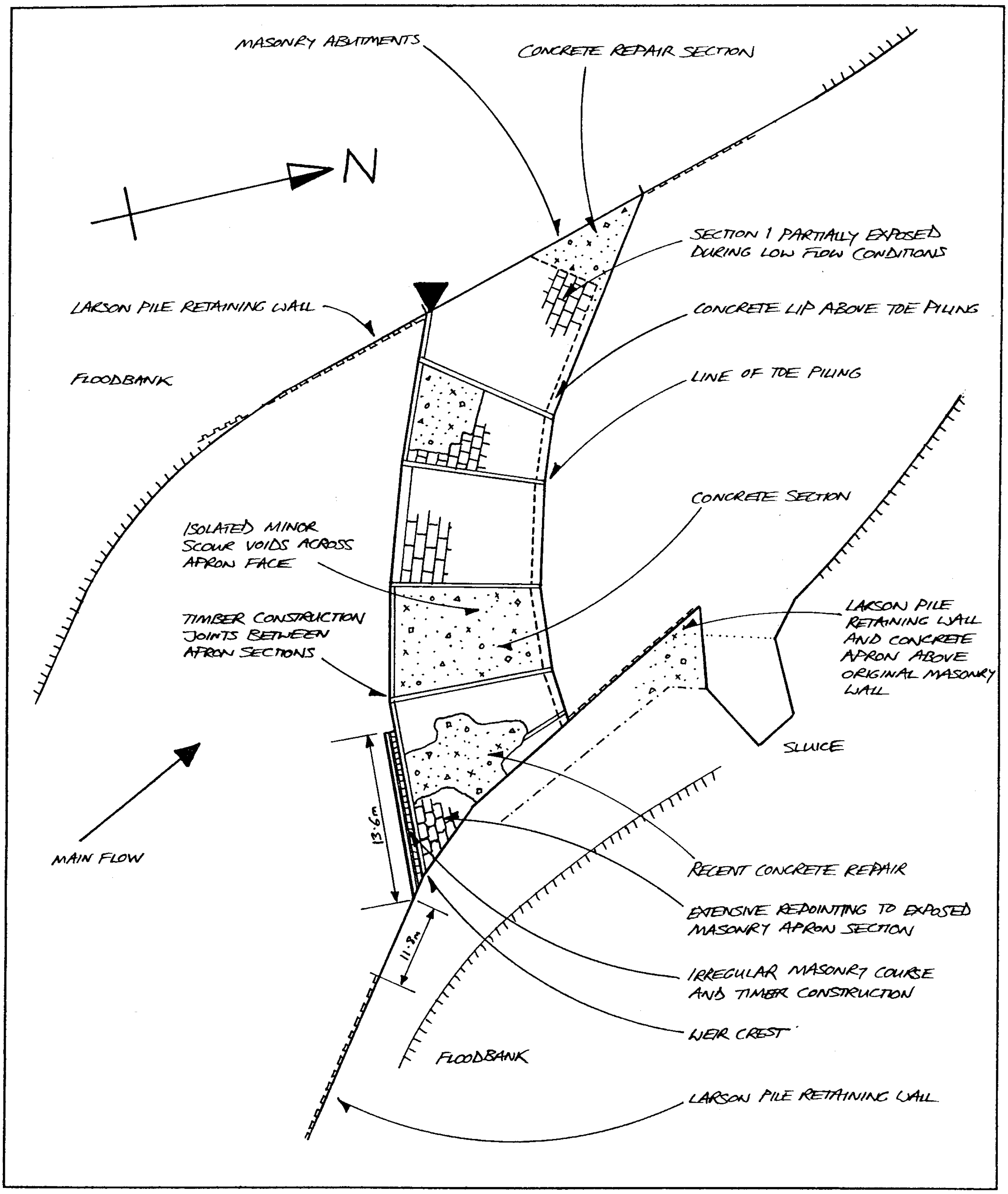
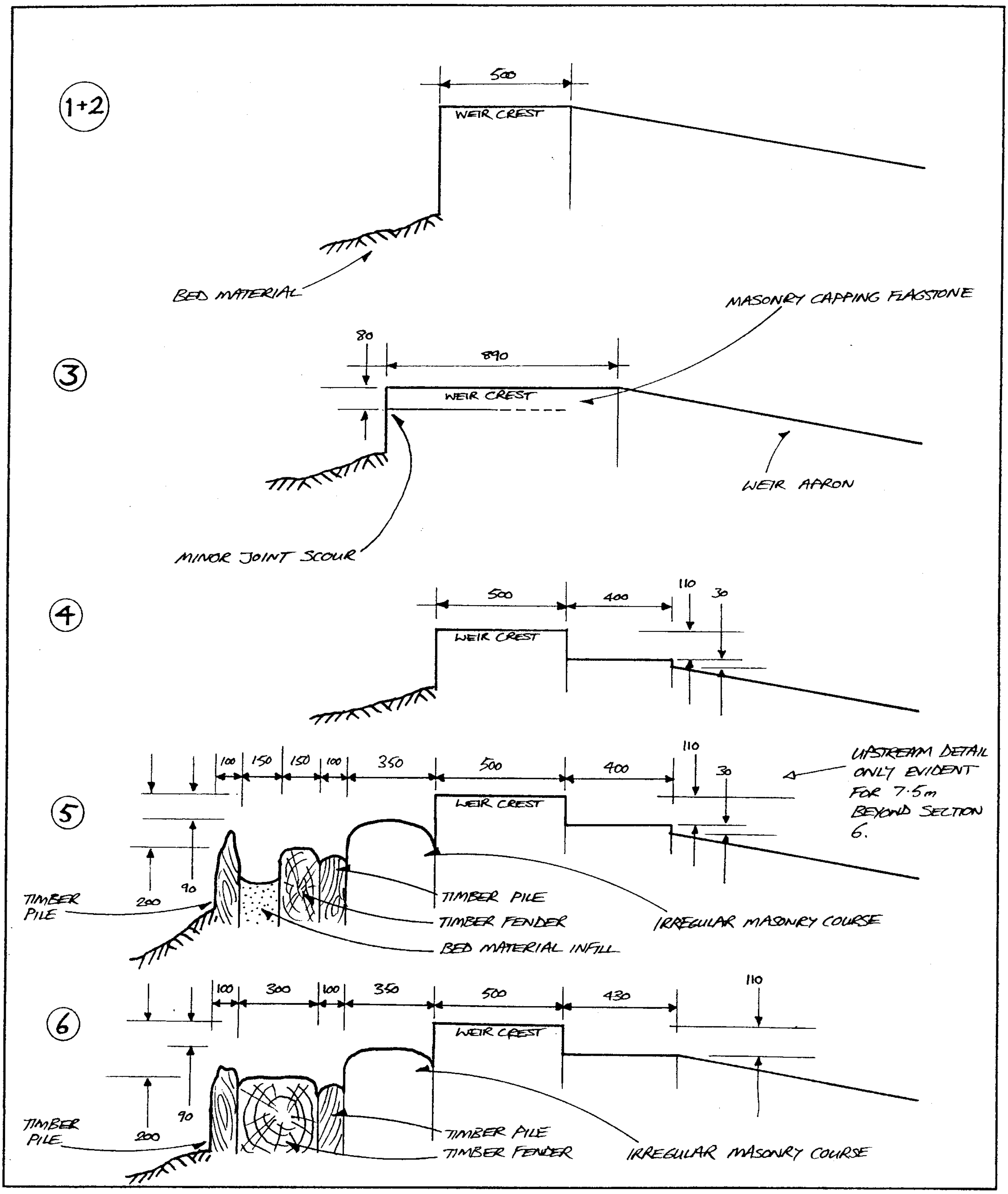


Figure L6 - Weir cross-sections



Case Study M – Little Bollington Weir

A flow measurement station was required on the River Bollin for monitoring low flows for water resources purposes. Alternative locations and solutions such as electromagnetic gauges were considered but were discounted for a number of reasons. It was eventually decided to undertake remedial works to an existing weir structure at Little Bollington. The works would provide a British Standard flat-vee weir for gauging purposes without causing significant impact on this sensitive area or altering the existing river regime.

Figure M1 – The weir before the works were carried out

The works involved removing the top section of the existing weir and reconstructing it to comply with British Standards. The new top section was founded using thirty-six 8 metre long concrete piles into the underlying mudstone. Both the wing walls and the weir structure were constructed from reinforced concrete and clad using stone sets. Significant temporary works were required to enable construction but these were designed to provide residual environmental improvements once construction was completed. The weir structure would remain under the ownership of the landowners.

(i) Temporary Works

Flows in the river range from a minimum of approximately $2m^3/s$ to an in-channel capacity of approximately $37m^3/s$. The higher flows could not be contained within a temporary flume through the work, and there was insufficient space for a bypass channel. The only option was to make use of a badly silted and debris strewn millrace running from upstream of the weir, under a residential mill complex, and discharging some 100m or so downstream of the works. The millrace and structures adjacent to the channel required considerable protection works in order to cope with the expected high flows and velocities.

Figures M2 – The millrace channel before the works, and M3 - Carrying river flow during the progress of the works

The design of the temporary works was dependant on the flow capacity of the millrace and the requirement not to increase the frequency of or raise flood water levels upstream of the works. This resulted in a restriction in the height of the sheet piled cofferdam that was designed to overtop before the millrace capacity was exceeded. The works were suspended for some months over the winter period whilst flows were prohibitively high, making activities on the weir face such as piling and laying the stone sets impractical.

Figure M4 – The new weir crest neatly joining the existing glacis

Figure M5 – Stone facing to the concrete walls

Figure M6 – Completed wall and instrumentation building

Public and Landowner Relations

Prior to the diversion of the river flows, protection works to the millrace which ran on the eastern side of the weir had to be undertaken. Access to the eastern bank was via a private road upon which were located two small bridges. Structural surveys of the bridges, one of which was a listed structure, confirmed their unsuitability to carry heavy traffic. Discussions with the landowners resulted in the leasing of adjacent fields and the construction of a bypass route including a temporary bridge.

The weir lies within the Dunham Massey Hall estate, which is owned by the National Trust and open to the public. To facilitate the works a permissive footpath was diverted. However, the working area was still very visible to the public and prompted a keen interest from visitors to the hall. Information boards were positioned at strategic locations and a briefing sheet was prepared for the Contractor to enable him to respond to casual enquiries.

Due to the proximity of residential properties, the timing of noisy construction operations, particularly the piling works, was restricted. Monitoring was undertaken to ensure compliance with the acceptable noise levels specified by the local Authority.

Adjacent to the weir is a mill building that has been converted into residential apartments. The millrace runs underneath this building where a water wheel would have been located. The residents took a keen interest from the initial proposal stage, and sought to influence the design. A number of residents meetings were held during the design and construction process at which the programme and progress were discussed. These prompted a number of debates during which the rationale behind the project was explained. Resistance to the works due principally to the disturbance involved was significantly overcome by encouraging the residents to participate in the development of the environmental improvement works (an area they were particularly interested in) particularly to the millrace.

The National Trust, as the owner of the weir, also took a keen interest in the development of the design and throughout the construction of the works. The aesthetic appearance of the completed structure was paramount in obtaining their agreement and, following lengthy negotiations, the weir and gauging hut were constructed from materials that complemented the other structures on the estate (see Figures M5 and M6).

Given the rich historical heritage of the area an archaeological watching brief was commissioned under the guidance of the Assistant County Archaeologist. A report on the archaeology was archived at the local studies library. Excellent relationships between all parties meant that there were no delays due to recording information or the archaeological investigations themselves.

Figure M7 – The completed weir

Lessons learned

- Old mill weirs can be converted into flow monitoring structures
- Works on old weirs often present opportunities for environmental enhancement

- Early consultation with all stakeholders helps to ensure a successful project. In particular, engaging members of the public and local residents in the design and construction process can considerably improve public relations.
- Temporary works are often an important consideration, especially in terms of dealing with flood flows
- Involving the county archaeologist early in the planning stage will help to avoid delay and disruption of the construction process.

Case Study N – Staines Weir

Figure N1 – Weir, as originally constructed

Figure N2 – Weir, with corrected flow

A weir in a retail park under construction with a crest formed from the capping beam of steel sheet piling. The rock fill on the glacis is intended as an aesthetic and ecological enhancement, but is perhaps laid too regularly. In the photo all flow is running through the rocks and emerging at the toe. This was corrected by shovelling pea shingle over the rocks, which lodged in the interstices of the rock, ensuring that sufficient flow ran over the glacis rather than through it.

Three years later (right), with an increased flow, the weir is a popular feature. Some rocks have moved slightly, and although occasionally some debris is caught, it is often moved on by the next flush. The weir has required no remedial works, maintenance or clearance – routine or otherwise – since its construction in mid 1997. Immediately adjacent to the weir is a Larinier fish pass, and adjacent to that, against the right bank, is an eel pass.

Note the use of block stone for the coping on the right bank downstream.

Note also the provision of stop-log grooves at the downstream end of the fish pass. Similar grooves at the upstream end allow for dewatering of the pass to allow inspection and maintenance.

Case Study P – Weir on the River Stort

Figure P1 – View from downstream

Figure P2 – Undermining at rigid revetment and lack of scour protection downstream

This low weir, believed to have been installed to retain an upstream level of water for environmental purposes, was normally largely submerged by the high water level retained by a sluice downstream. When the sluice jammed open, the tailwater level at the low weir dropped from the blue line to that shown in these photographs.

A hydraulic jump now occurs at the toe of the lowest apron, beyond which there is no formal scour protection. Previously the weir was drowned out in moderate flow conditions, and no hydraulic jump occurred. At lower flows the hydraulic jump occurred on one of the concrete steps, allowing energy to be dissipated without causing erosion.

Note the undermining of the rigid left bank revetment. Such revetments nearly always suffer from this effect, as they are incapable of adapting to even moderate erosion (contrast with the flexible-type revetment, such as rock or gabion mattress).

River Weirs – Good Practice Guide

Appendix D

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R&D Publication W5B-023/HQP

Research Contractor:
Mott MacDonald Ltd and University of Hertfordshire

APPENDIX D - FURTHER ILLUSTRATIVE PHOTOGRAPHS

The photographs in this section are intended to illustrate particular design or construction issues that have not been illustrated within the text.

Figure AD1 - Grassed side weir

Here a simple lowered reach of flood embankment acts as a side weir. Note the provision of a hard crest (in this case brick, but it could be concrete) to ensure even flow distribution thereby minimising the risk of erosion of the embankment.

Figure AD2 - Side weir with fixed debris deflector

This side weir has a debris deflector that is just immersed in the water so as not to obstruct flow but to prevent debris getting washed over the weir where it could obstruct the small outfall channel.

Figure AD3 - Side weir with narrow footbridge

Situations such as this are not uncommon, but it is appropriate to consider the risks posed by the narrowness of the bridge and the lack of handrail on both sides.

Figure AD4 - Side weir with fish pass

The effectiveness of this fish pass is questionable in view of the difficult approach conditions (shallow flow and sharp turn).

Figure AD5 - Side weir in operation

Note the hydraulic jump downstream of the weir glacis.

Figure AD6 - Weir with ford

The stilling basin for this weir also acts as a ford, providing vehicular access across the stream. Although safe in the conditions pictured, it is necessary to consider appropriate safety measures for flood flows (warning signs as a minimum).

Figure AD7 - Construction of a flat-vee weir

Note the curved concrete wingwalls providing good hydraulic conditions for accurate flow gauging. Dumped rock erosion protection has been provided on the river bed but has yet to be placed on the banks. The wingwalls could perhaps be extended further into the river banks to ensure that there is no risk of by-passing in floods.

Figure AD8 - Warning sign and fencing

The dangerous condition presented by deep water upstream of the weir, and the large drop downstream might justify more secure fencing.

Figure AD9 - Weir with low flow notch

This notch has clearly been added to allow gauging of very low flows.

Figure AD10 - Variable configuration weir at the Nene White Water Centre, Northampton

The weirs on this custom-made white water canoe course can be adjusted to give different conditions to test the canoeists' skills**.**