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.

The authors are extremely grateful for the assistance and contributions made by Andrew Pepper and Samantha Godfrey.

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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

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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

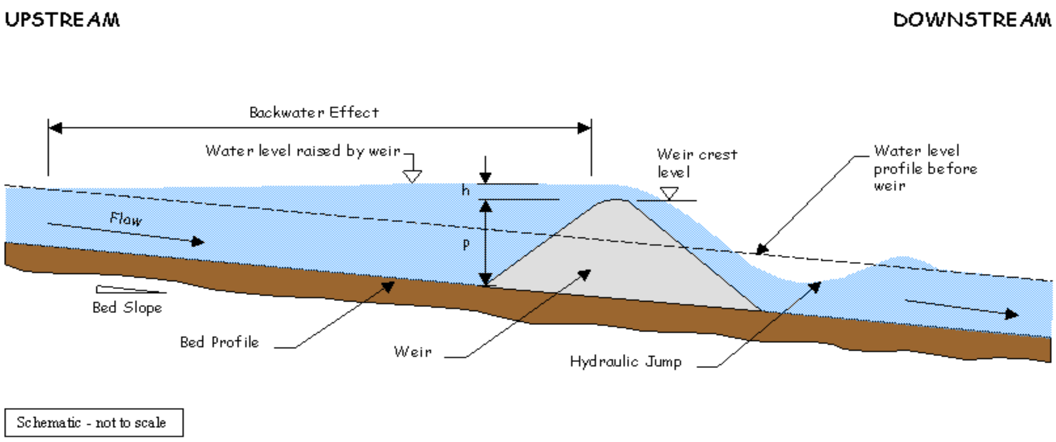


Table 1.1 Positive and negative secondary impacts of weirs

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.

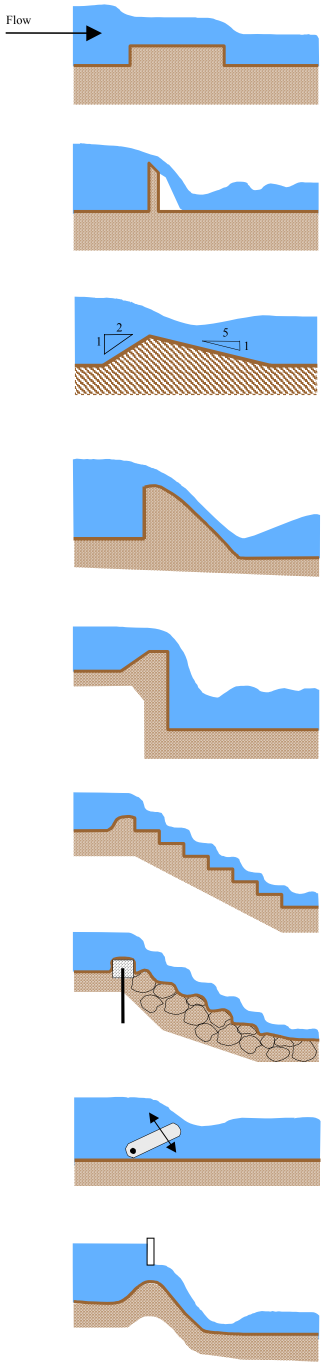
The impacts outlined in Table 1.1 only consider the impact of an established weir and do not address the impact of its construction, refurbishment or de-commissioning, the processes associated with which may have both short and long-term impacts. Prior to any works being implemented, an appropriate level 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.

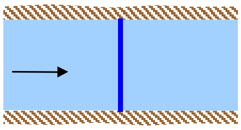
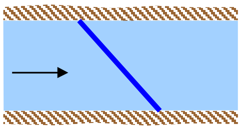
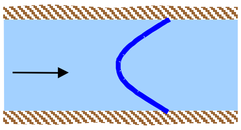
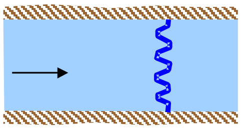
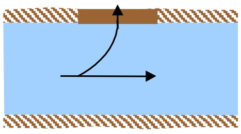
Figure 1.7a Weir types – cross sections



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

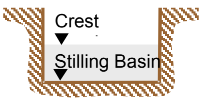
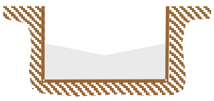
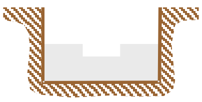
	Orthogonal	Weir spans channel at right angles to flow
	Diagonal[1]	Weir spans channel at an angle - gives increased length of crest
	Curved[2]	Length of weir crest increased. Visually attractive (see core photograph). Also referred to as a Duckbill Weir.
	Labyrinth [2]	Length of weir crest increased. 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.