River Weirs – Good Practice Guide

Guide - Section B2

Charles Rickard, Rodney Day, Jeremy Purseglove

R&D Publication W5B-023/HQP

Research Contractor:
Mott MacDonald Ltd and University of Hertfordshire

2.3 Engineering

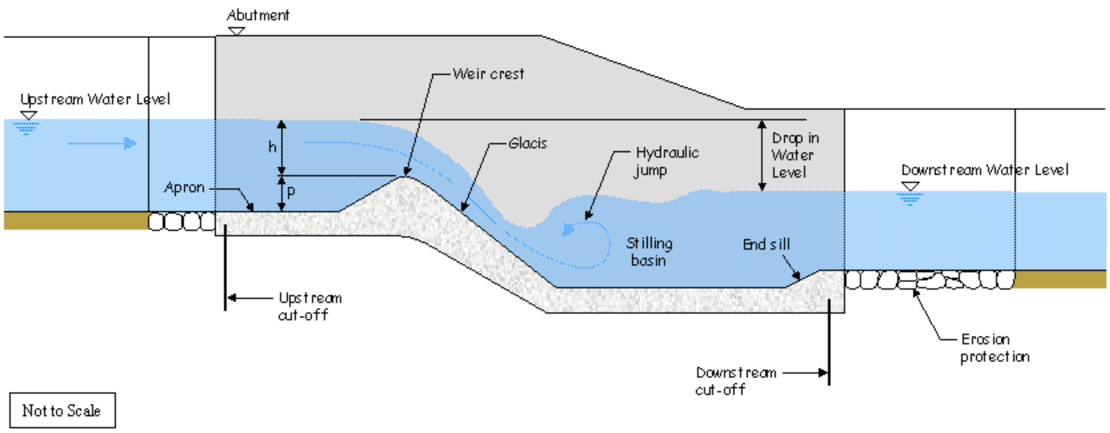
2.3.1 Introduction

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

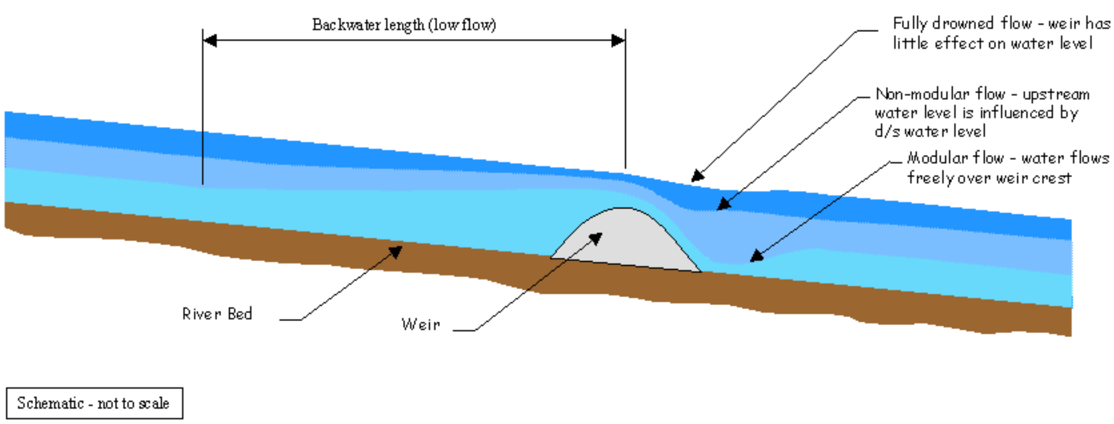
Weirs are often provided for purposes other than simply raising water levels; whether this is for navigation, flood defence or habitat improvement. One of the primary reasons that weirs have been installed over the past 50 years is for the purpose of gauging flow (discharge) in rivers, and in the UK 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

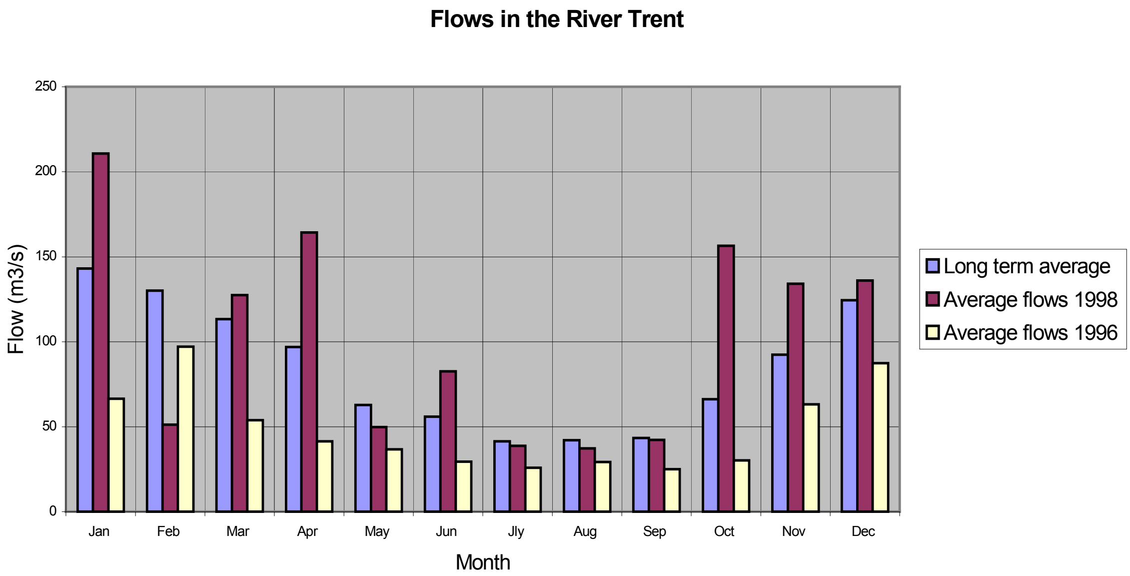


Once a flow gauging weir becomes 'drowned' it is unable to provide accurate flow measurement, unless specific arrangements have been made. As downstream water levels continue to increase still further, above the minimum levels that caused drowning, then the impact that the weir has on upstream water 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

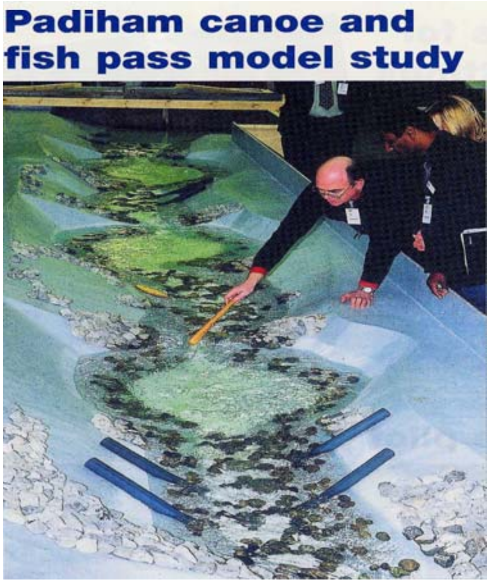
The ideal weir for a canoeist would have the following features:

- 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.