11 River and canal structures

11.1 Overview

This chapter considers the design issues that apply for the common types of structure encountered in the fluvial environment. Although civil, mechanical and electrical engineering aspects need to be fully integrated in the design process, they are more conveniently dealt with separately here.

The chapter begins by describing the application of the basic concepts that need to be considered in the civil engineering design. This is followed by a series of information sheets on the principal types of structure and then a description of the specific considerations that apply to their rehabilitation. The chapter continues by considering mechanical and electrical design, power supplies, and instrumentation, control and automation (ICA).

This chapter draws on information presented in almost every other chapter of this guide but has particularly close links with Chapter 3 (Fluvial geomorphology), Chapter 4 (Fluvial ecology) and Chapter 7 (Hydraulic analysis and design). Importantly, it relies on Chapter 8 (Works in the river channel) and Chapter 9 *(*Floodwalls and flood embankments*)* as these structures are often combined as part of river and canal works, and it is the connections between the two that are most often points of failure.

Considerable research into flood risk management is underway in the UK and Europe. Readers are encouraged to keep abreast of the latest research and development initiatives by consulting the following websites:

- Joint Environment Agency/Defra Flood and Costal Erosion Risk Management R&D Programme (FCERM) (http://www.defra.gov.uk/environ/fcd/research);
- Flood Risk Management Consortium (http://www.floodrisk.org.uk);
- Floodsite (http://www.floodsite.net).

11.2 Basic concepts in civil engineering design

11.2.1 Introduction

Structures are placed in rivers and canals in order to:

- control water levels and flows;
- facilitate the abstraction of water;
- maintain navigation;
- control flooding;
- measure the discharge.

Rivers – and to a lesser extent canals – experience fluctuating water levels and flows that depend on the runoff from its catchment, together with any other sources such as catchment transfers or artificial releases from storage.

Any structures placed in this environment are required to function in a wide range of hydraulic conditions. Other important variables include the transport of suspended material (type of material and the volume carried).

11.2.2 Design in a uncertain environment

Design flows

The first steps in designing a river or canal structure are to:

- define its function (what the structure is expected to do);
- identify the range of conditions that it will operate in.

The most fundamental of operating conditions is generally the range of flows to which the structure will be exposed. But, depending on the type of structure and its location, there may also be a need to consider sediment load, trash and debris load, boat impact and vandalism. It is also essential to consider the safety of operatives and members of the public who may have access to the structure.

Chapter 2 provides details of the principal methods used for estimating discharges.

There is an inherent uncertainty when choosing design flow values for structures in rivers. Flows can and do exceed design expectations. Designers need to manage this risk in the face of uncertainty. Creating a structure that copes with this uncertainty, while retaining economy in its design, requires an assessment of the damage that may be caused to it or its elements under exceptional circumstances. The level of damage that can be accepted for different loading conditions needs to be assessed. Such damage should not result in an increased threat to life and property compared with the situation before the structure's construction.

River transitions

River structures are static elements in a dynamic system and, as such, they can disturb the natural equilibrium of the river channel. This disturbance can be minimised by:

- avoiding sudden changes of flow direction (from channel to structure, and structure to channel);
- providing transitions between the natural channel and the rigid structure.

These transitions are often formed using flexible revetments (see Section 8.3.5).

Integration in the design team

Many of the structures covered in this chapter involve a mix of civil, electrical and mechanical elements, requiring a multidisciplinary design team.

A common root cause of problems in such cases is a lack of integration of concepts and detailing between different designers. To ensure an effective design, early and regular communications between the various discipline teams are vital to discuss:

- input parameters;
- functional requirements;
- revisions during the design process (particularly important).

Interaction with the public – safety

Rivers and canals are often public places. The potential for danger to the public can be minimised through a design process that is based on a full understanding of how people will interact with the works (both during and after construction work). Appropriate design can minimise the risks – not least of all by making people aware of them.

Although warning signs may be adequate to alert the public to specific dangers, handrails can serve to reinforce the designation of some areas as out-of-bounds and potentially dangerous. When handrails are designed sensitively – with the character of the local area acting to guide the choice of materials and construction methods – they present minimal visual impact.

Trash screens have a double function when used on a culvert entrance. As well as keeping trash out of the culvert, they also keep people out of what could be a potentially dangerous space. Screens that are designed exclusively to inhibit access are generally referred to as security screens. Both trash screens and security screens present a risk of blockage by debris and hence risk causing or aggravating local flooding (see also Section 8.6.3).

Interaction with the public – vandalism and theft

Members of the public have access to many of the structures placed in rivers and canals. Thus there is always the possibility of:

- accidental or wilful interference;
- damage to the structure;
- theft of potentially portable components.

Designers need to consider how best to render key infrastructure invulnerable to the actions of ill-intentioned people and protected against disturbance. A general rule is that, if a structure looks weak and vulnerable in a place with public access, then someone may well attempt to exploit such weakness. Figures 11.1 and 11.2 illustrate how a vulnerable structure can be turned into a resilient one.

Figure 11.1 Example of vulnerability – a floodwall under construction, awaiting capping slabs

The construction method used here leaves large voids between bricks and sheetpiles, and uses brick-to-pile ties at 1200mm centres. The bricks are there to disguise the unattractive sheetpile wall.

The wall gave a hollow 'ring' when knocked. This may encourage a harder knock resulting in damage to the cladding (though it would be difficult for vandals to damage the defence itself, which is provided by the steel sheetpiling).

Figure 11.2 Example of resilience – a floodwall that survived a vandal attack

This wall is constructed as in the previous example, but with concrete infill of the voids. It has had the coping slabs pinned with dowel bars cast into the concrete.

After an attempt to remove a slab and after damaging a dozen more, the vandals have given up. Should this type of attack occur on the wall in the previous example, it would be severely damaged.

Since coping stones are often the subject of vandalism – and, as this illustration demonstrates, even dowelled fixings are not secure – it is common to assume that the coping does not contribute to the flood defence level.

Common vandalism targets include:

- gabions;
- sandbags;
- single-course blockwork walls;
- other semi-hard structures.

When specifying such features, consider whether the public will be attracted to the area. If so, avoid vulnerable features or move the structure elsewhere.

Common targets for theft include:

- metals;
- items that can be manhandled (such as precast concrete units and stone slabs);
- solar panels;
- cabling.

Theft and vandalism can be reduced by making materials securely composite with each other and with other parts of the structure. This has implications for the ease of recycling at decommissioning, so both aspects need to be considered by the designer (see Figure 11.3).

Figure 11.3 Sliding scale of vulnerability to theft and vandalism versus ease of recycling

Design criteria - accessibility	Public congregation area	Public access route	Inaccessible to public
Design resilience to theft and vandalism	High ◄	Medium	Low ►
Ease of recycling	Impossible to separate materials at decommissioning	Materials may be separated at a cost	Elements designed for ease of separation when decommissioning

11.2.3 Fluvial processes

The effect of the fluvial processes described below should be considered carefully when determining the loads applied to the structure.

Erosion and scour

Water is well known for its erosive properties. In the fluvial environment, this usually occurs when water flows are fast or highly turbulent. In general, finer sediments become mobile at lesser velocities than larger particles, but the shape of the individual particles and cohesion also have an effect on their vulnerability to erosion.

Scour initiation mechanisms

Where a flow velocity increases, it can cause an area of scour. Two main mechanisms interact to suspend the sediment and move it in the direction of flow.

Lift — The velocity of the water flowing over the top of a bed of sediment creates lift forces on the particles. Once the lift force on a particle exceeds the downwards force of its buoyant weight, it is lifted from the bed into the flow of water.

Momentum — Water striking the surface of a sediment particle is deflected around it. Some portion of the water's momentum is passed to the sediment particle as an applied force. Once this force is greater than the ability of the particle to resist that force, the particle becomes mobile.

Turbulent eddies that move faster than the main flow are a significant factor which increases the potential for scour. Such eddies are created by river structures of all types, as well as by natural obstacles.

Transport mechanisms

Once in motion, there are two main mechanisms for the transport of sediment:

- bedload – rolling and sliding along the river bed;
- suspended load – in suspension in the water.

Under normal flow conditions, smaller particles are usually suspended while the larger pebbles, cobbles and boulders are likely to form the bedload. In very fast flows, particles up to the size of large cobbles can form a part of the suspended load.

Scour caused by structures

As scour is likely to be increased around structures placed in flowing water, an understanding of the potential extent of such scour is required to ensure their continued operation. The CIRIA publication, *Manual on scour at bridges and other hydraulic structures* (May *et al*, 2002) describes the following three main types of scour.

Natural scour	This includes scour due to bed degradation, channel migration, confluences and changes to flow conditions. Can be of human cause.
Contraction scour	A result of confining the channel, for example between bridge piers or abutments.
Local scour	A result of increased turbulence and velocities due to obstructions in the flow or energy dissipation at weirs, drop structures and hydraulic jumps, etc.

The total scour experienced at a location can be thought of as the sum of all these. Designers should aim to control or contain these causes individually to reduce the sum effect.

Scour as a cause of failure of structures

Scour can present a particular problem for structures placed in rivers as it can lead to:

- undermining and instability of the various elements of the structure;
- failure of the complete structure.

Some important methods to reduce this effect include:

- streamlining of structures to avoid the onset of turbulent eddies;
- scour protection on vulnerable surfaces;
- establishing the structural foundation and support below the anticipated depth of scour.

Groundwater flows bypassing a structure can also lead to washout of material around or under the structure, leading to instability. Techniques to reduce this include:

- incorporation of filters to retain particles;
- lengthening of the flowpath for seepage flows (see Section 9.9.2).

Sediment deposition (sedimentation)

When the flow velocity falls below certain thresholds (which depend on the particle size and density), bedload ceases and sediment is dropped from suspension. This is called deposition. If the deposition occurs in a spatially defined area, it can produce bedforms on many scales from ripples through to bars, spits and islands. Deposition produces a corresponding reduction in flow cross section and is therefore self-limiting and often cyclic.

Deposition presents an issue for the performance of fluvial structures by restricting the potential flow capacity and by blocking intakes. In canals and navigable rivers, sedimentation can reduce the draught available for navigation.

Waterborne debris

Debris transport is a natural function of rivers. Debris consists of organic matter (leaves, trees, decaying plants and the like) and man-made waste (such as litter, grass clippings and shopping trolleys) that are carried as bedload, as suspended load or floating on the surface.

The volume of debris in the watercourse often fluctuates in response to increased flow rates; runoff from the land washes debris into the water and stationary riverside stores of debris are mobilised. Debris can obstruct flows, reducing the discharge capacity of a channel and causing a rise in water level. This is especially troublesome in locations that are enclosed or hard to access, and at structures where the flow depth is restricted or surface flows are obstructed such as at weirs and gates. These problems can sometimes be mitigated by using trash screens and floating booms to collect the debris. Such units require continued maintenance.

Another issue presented to structures by both debris and sediment transport is abrasion. This leads to damaged finishes and surfaces, or loss of section. Such damage can be classed as a serviceability failure of the structure and is likely to require repair.

Afflux

Another factor that needs to be considered at structures is afflux (see Chapter 7), which is defined as the maximum rise in water surface elevation above that of an unstructured stream due to the presence of a structure such as a bridge or culvert in the stream (see Figure 11.4). When choosing a site for a structure, consideration should be given to the effect of afflux on upstream land, buildings and other assets. Afflux can be estimated using the afflux estimation system (AES) developed under the joint Defra/Environment Agency flood and coastal erosion risk management programme (Mantz, 2007).

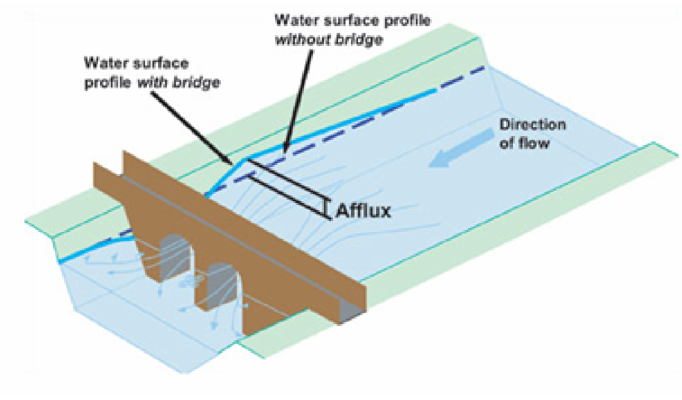


Figure 11.4 Illustration of afflux

Afflux is the difference between the water level before the bridge was built and the maximum water level upstream from the bridge after its construction, with all other things being equal.

11.2.4 Flow measurement

Some hydraulic structures are specifically designed for flow measurement, but many others – because their hydraulic characteristics are broadly predictable – provide opportunities for flow measurement, provided that water levels are monitored or observed at suitable locations.

Flow gauging is a specialist subject, but Box 11.1 gives some outline guidance.

Box 11.1 Options for flow measurement

Suitable hydraulic structures – or components within hydraulic structures – for flow measurement include:

- orifice with machined edges;
- thin-plate weir (rectangular or vee-notch);
- Crump weir;
- critical-depth flume.

To maintain their performance, these devices require:

- brushing the surfaces to remove slime and algae;
- removing sediment that may affect the hydraulic behaviour.

Thin-plate orifices and weirs can be prone to leakage. They also require occasional renewal or refurbishment if the machined edges are starting to show wear.

In addition, flows within channels and culverts can be measured using various ultrasonic devices that employ time-of-flight or Doppler effect technology. These need to be carefully designed and installed, and the method of processing velocities and depths to obtain the discharge needs to be properly understood and verified.

Water level monitoring nowadays is normally by ultrasonics or pressure transducer. A means should be included to allow operations staff to readily check that the device datum is correct.

Further information on flow and level measurement structures is given by Bos (1989) and in the relevant British Standards.

11.3 Types of structure

Information sheets are presented below for:

11.3.1	Gated control structures
11.3.2	Weirs
11.3.3	Drop structures
11.3.4	Bridges
11.3.5	Culverts
11.3.6	Flumes
11.3.7	Siphons
11.3.8	Outfalls
11.3.9	Screens
11.3.10	Pumping stations and intakes
11.3.11	Locks
11.3.12	Fishpasses

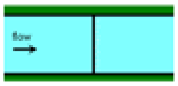
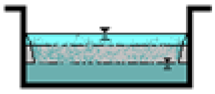
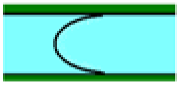
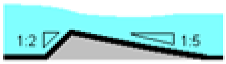
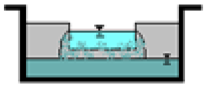
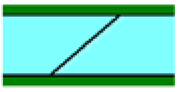
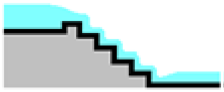
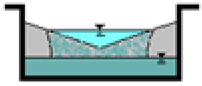
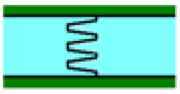
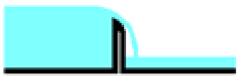
Each sheet contains:

- a description of the structure and its purpose;
- illustrations of a selection of different forms;
- specific design considerations;
- references for design guidance;
- common faults.

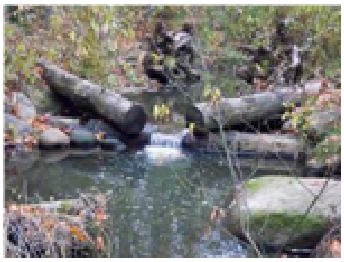
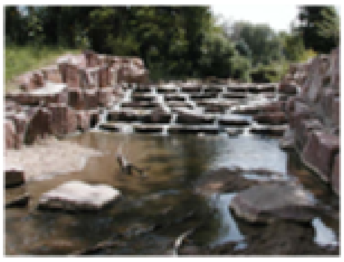
11.3.1 Gated control structures

<table>
<tr><td>Description and purpose</td><td colspan="2">Used to control water levels in rivers, sluices or canals, for water flow management, flood control and navigation.
Gates can be undershot (for example, a sluice gate) or overshot (that is, acting like a weir). An undershot gate can be fully closed (allowing no flow), partly open (see radial gate illustration) or fully open (lifted clear of the water surface).
Undershot gates produce a jet of water which can pose a significant erosion risk. This is normally addressed by the provision of a stilling basin.
Often used with multiple gates in parallel to enhance redundancy.</td></tr>
<tr><td colspan="3">A selection of different forms
Common types not illustrated: bottom hinged, rising sector</td></tr>
<tr><td>Radial gates
Light weight reduces power of required plant
Moving parts above waterline
</td><td>Vertically hinged (mitre) gate
Operated by either water pressure (passive) as a non-return gate, or powered
Directional flow control only if passively operated
</td><td>Vertical lift (sluice) gates
Require a gantry structure to lift them free of the water
May use counterweights to aid lifting
Smaller units can be hand operated
</td></tr>
<tr><td>Specific design considerations</td><td colspan="2">Purpose – flood defence or water level control
Navigation – draught, height and beam restrictions may already be in place on waterway
Scour – most gates generate fast and highly turbulent flow in operation and require a concrete stilling basin, as well as local erosion protection in the channel
Ease of maintenance
Failure to operate – redundancy and bypass
Aesthetic and architectural issues – character of local area
Ecological – impassable to migratory fish during some operations</td></tr>
<tr><td>References for design guidance</td><td colspan="2">US Army Corps of Engineers manuals:
▪ Vertical lift gates, EM 1110-2-2701
▪ Radial gates, EM 1110-2-2702
See http://140.194.76.129/publications/eng-manuals/</td></tr>
<tr><td>Common faults</td><td colspan="2">Excessive scour leading to undermining and instability
Lack of maintenance provision
Inadequate redundancy</td></tr>
</table>

11.3.2 Weirs

<table>
<tr><td>Description and purpose</td><td colspan="3">Used to control grade and water levels in rivers or canals, for offtakes, and for flow gauging (see Section 11.2.4 and Box 11.1), amenity and navigation.</td></tr>
<tr><td>A selection of different forms</td><td colspan="3">All combinations of plan, elevation and section can be used and have advantages in particular applications.</td></tr>
<tr><td>Plan (flow from left)</td><td>Section (flow from left)</td><td colspan="2">Elevation (flow towards reader)</td></tr>
<tr><td>Orthogonal
Minimum material use
</td><td>Broad crested
</td><td colspan="2">Straight
Used for simplicity and for moderate flows
</td></tr>
<tr><td>Curved
Greater crest length results in less variation in upstream water level for a given range of flows
</td><td>Crump
Standard design that is highly versatile, usually in concrete
</td><td colspan="2">Stepped
Useful for varied flow rates
</td></tr>
<tr><td>Diagonal
As curved, but stilling basin design is more difficult
</td><td>Stepped
Water feature and aid to energy dissipation
</td><td colspan="2">Flat-vee
Accurate gauging over a greater variation of flows
</td></tr>
<tr><td>Labyrinth
As curved in low flows, but behaves like orthogonal crest in high flows
</td><td>Sharp-crested
Mostly used for temporary measuring structures
</td><td colspan="2"></td></tr>
<tr><td>Specific design considerations</td><td colspan="3">Material use – suitability for setting
Effects on ecology – fragmentation of habitats, migratory fish
Potential for deposition upstream – effects on intakes
Potential for scour of bed and banks downstream – affecting the stability of the weir and adjacent infrastructure
Foundations – especially under-seepage and uplift pressures
River or canal users – canoeists, anglers and navigation by larger boats</td></tr>
<tr><td>References for design guidance</td><td colspan="3">River weirs – good practice guide (Rickard et al, 2003)
Case study from Manual of river restoration techniques (RRC, 2002): 5.1 Bifurcation weir and sidespill
(http://www.therrc.co.uk/pdf/manual/MAN_5_1C.pdf)</td></tr>
<tr><td>Common faults</td><td colspan="2">Accumulation of trash on the weir crest
Foundation failure
Excessive scour
Undermining</td><td>Inappropriate materials and finishes
Inadequate fencing
Outflanking of flow measurement weirs in flood conditions</td></tr>
</table>

11.3.3 Drop structures

Description and purpose	Used to control grade, water levels and flow. Also for erosion reduction and to provide diversity in a watercourse. Less predictable hydraulic performance than weirs, but greater aesthetic versatility and environmental sensitivity.
A selection of different forms	
Local materials Shown is a log drop structure, but can be of various construction materials or methods. Used to enhance ecological diversity in rural settings with riffle pool stepped morphology. Is applicable only to small streams. Reduces channel incision and brings incised channel up and into contact with its floodplain. Requires a higher level of maintenance and more liable to flood damage than hard engineered structures (see below). Photograph courtesy of Washington Department of Fish & Wildlife, (http://wdfw.wa.gov/hab/ahg/)	
Baffle block – reinforced concrete with baffles Good energy dissipation in high flows – good for controlling steep drainage channels in flashy urban catchments. Difficult to landscape. Dangerous for 'paddling'.	
Baffle rock – rocks grouted into place Moderate energy dissipation in high flows, but water may flow through the structure in low flows. Can utilise local rock to enhance visual appearance. Can be detailed to allow safe access to waterside for 'paddling'.	
Specific design considerations	Material use – suitability for setting and for the hydraulic loads Effects on ecology – some fragmentation of habitats (less than a weir) Potential for scour of bed and banks affecting the stability of the structure River users – canoeists, anglers Migratory fish – species and numbers
References for design guidance	Case studies from *Manual of river restoration techniques* (RRC, 2002): 5.2 Drop-weir structures (http://www.therrc.co.uk/pdf/manual/MAN_5_2C.pdf) 5.3 Restoring and stabilising over-deepened river bed levels (http://www.therrc.co.uk/pdf/manual/MAN_5_3.pdf)
Common faults	Not strong enough to resist hydraulic loads in floods and therefore vulnerable to severe damage, scour of bed or banks undermining the structure Inappropriate materials and finishes

11.3.4 Bridges

Description and purpose	Carry transport routes over rivers and canals and come in a very wide range of structural forms.

A selection of different forms

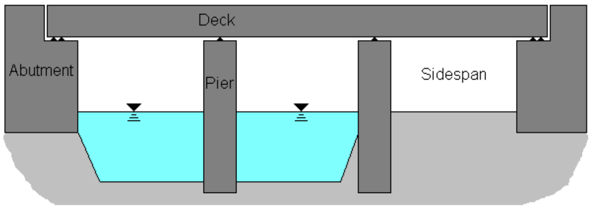
Most bridges that cross rivers are formed of the following three main components that interact with a watercourse.

Piers

Can be formed from many different sections, generally streamlined to some extent to reduce local and contraction scour. Simple cylindrical and rectangular sections tend to shed vortices, which travel for large distances causing scour, and should be avoided. Scour protection may be needed.

Abutments

Abutments form the hard ends of the bridge. They contain flows and should be wide enough apart to function under design conditions. Additional side spans can be used for extra capacity in flood flows. Scour protection may be needed.



Deck

Usually designed to be well above even extreme flood levels. If close to the water level, route and depth markers can be used to guide vehicles across the bridge safely (where the bridge is so designed) in the event of the deck being submerged by shallow flood flows

Arch bridges – a special case

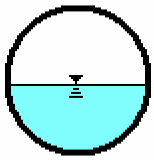
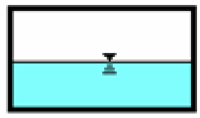
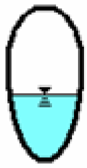
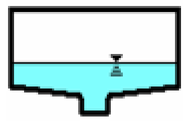
Due to their geometry, traditional semi-circular arch bridges can restrict flow increasingly as the flow through them rises. This can cause increased afflux and hence problems.

Additionally the risk of blockage by debris increases as water-levels rise (see right). As debris volumes tend to be raised in high flows, this can lead to blockage and, in extremis, failure of the structure.

Photograph by kind permission of Mr B Drinkwater

Specific design considerations	Potential for scour at abutments, piers and adjacent banks Afflux – flood risk upstream Pier design – large piers in the waterway can increase afflux and scour; need to consider longer span or streamlined piers Navigation – headroom and beam. Also signage and 'traffic lights' on busy reaches Obstruction of the floodplain by approach embankments – need for flood arches
References for design guidance	*Scour at bridges and other hydraulic structures* (May *et al*, 2002) *Conservation of bridges* (Tilley, 2002) For a detailed description of the hydraulics around bridges, see Section 6-13 of US Army Corps of Engineers manual, *River hydraulics*, EM 1110-2-1416 (http://140.194.76.129/publications/eng-manuals/)
Common faults	Excessive afflux Blockage by large debris; scour – local and contraction Sediment deposition in the outer spans Inadequate environmental sensitivity in location Obstruction to floodplain flow

11.3.5 Culverts

<table>
<tr><td>Description and purpose</td><td colspan="2">Provide closed passages for flow through transportation embankments and for rivers passing under urban areas. Most commonly made from precast reinforced concrete, but plastic and steel are occasionally used. Historically, brick-lined culverts were common and many are still in active service.</td></tr>
<tr><td colspan="3">A selection of different forms</td></tr>
<tr><td colspan="2">Round
Precast circular pipes function satisfactorily in consistent flows; simple geometry and standard fittings.
Some capability of self removal of sediment build-up.
</td><td>Box
Standard precast units can provide a simple solution.
Can use multiple culverts in parallel with different invert levels to suit a range of flows.
Liable to suffer sedimentation in low flows.
</td></tr>
<tr><td colspan="2">Elliptical
Limits build-up of sediment and debris.
A non-standard design and requires fabrication by specialist.
</td><td>Complex/specialist
One-off designs to suit individual site-specific constraints, such as large flow variation, underground obstacles or high sediment loads.

(… and others)</td></tr>
<tr><td>Specific design considerations</td><td colspan="2">Material use – refer to Figure 4.6 in CIRIA R168 (see below)
Hydraulic design – should generally be for free flow (as illustrated above). Complex flow conditions can arise, particularly with steep culverts and for culverts flowing close to full.
Sediment load – design so that sedimentation in the culvert is reduced, and make provision for cleaning out (e.g. manholes, access ramps at inlet and outlet).
Trash and debris in the flow – avoid design features that may trap debris in the culvert (e.g. bends and changes of cross section).
Inlet and outlet details – design against scour and blockage
Effects on ecology – fragmentation of habitats, migratory fish impacts</td></tr>
<tr><td>References for design guidance</td><td colspan="2">Culvert design guide (Ramsbottom et al, 1997)
US Army Corps of Engineers manual, Conduits, culverts and pipes, EM 1110-2-2902 (http://140.194.76.129/publications/eng-manuals/)
Case study from Manual of river restoration techniques (RRC,2002)
1.6 Opening up a culverted stream
(http://www.therrc.co.uk/pdf/manual/MAN_1_6.pdf)</td></tr>
<tr><td>Common faults</td><td colspan="2">Inadequate size
Blockage by trash
Excessive scour at inlet or outlet
New service obstructions in old culverts
Over-use of screens</td></tr>
</table>

11.3.6 Flumes

Description and purpose	Flow measurement structures that rely on channel contractions (see Section 11.2.4 and Box 11.1). Used where there is risk of blockage. They cause much less headloss than most weirs and are less affected by incoming flow velocity. Not suitable for large flows or on wide, shallow rivers. Can be used as a means of flow control, for example creating an elevated backwater which can be diverted into a flood storage area, taking the peak off the flood hydrograph.

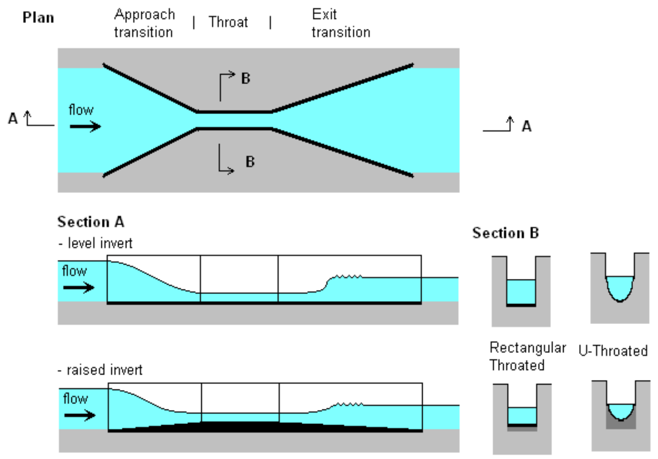
A selection of different forms

Flumes come in three standard types, as described in BS ISO 4359: 1983 (BSI, 1983), which is expected to be revised in 2010. These can all be of level or raised invert to suit conditions.

- Rectangular throated
- U-throated
- Trapezoidal

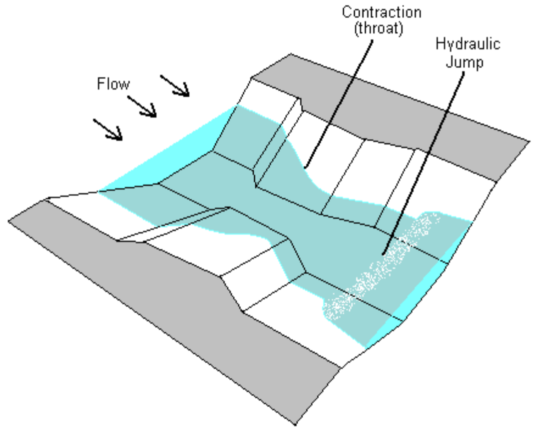
Rectangular and U-throated

Standard design with published discharge coefficients.



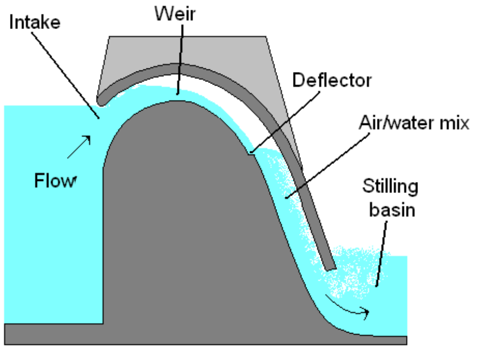
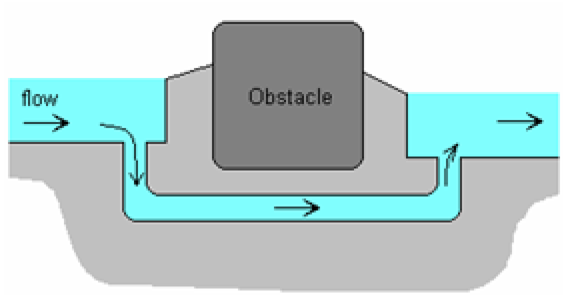
Trapezoidal

Designed for use in irrigation applications, this flume has the advantage of accurate flow measurement over a greater range of discharges.



Specific design considerations	Material – plastic or steel for smaller, temporary structures; or concrete (both precast and insitu) for larger, permanent ones Approach channel required to be streamlined and straight to ensure uniform approach flow for flow measurement structures Scour of all types can be associated with these kind of structures Trash load – type and frequency of occurrence (may require periodic removal of larger items) Standard dimensions allow use of standard discharge coefficients
References for design guidance	BS ISO 4359: 1983 (being updated)
Common faults	Foundation failure due to scour Inadequate environmental sensitivity in terms of location, materials and finishes

11.3.7 Siphons

<table>
<tr><td>Description and purpose</td><td colspan="2">Used for transferring water above or below an obstacle such as a river or road.
Siphons are strictly devices that involve the generation of sub-atmospheric pressures, but the term (or ‘inverted siphon’) has also become applied to culverts that run full and in which the invert level is below the bed level of the upstream and downstream channels.</td></tr>
<tr><td colspan="3">A selection of different forms</td></tr>
<tr><td colspan="3">Siphon
A ‘true’ siphon must include a means of priming (that is, expelling all or some of the air from its barrel). In fluvial siphons, this is normally achieved by including appropriate features that result in the air being entrained in the water flow, but it is also possible to prime a siphon by mechanical means of expelling the air such as a vacuum pump or ‘ejector’.
Some siphons have been designed to run either full-bore or not at all. These so-called ‘black-water’ siphons are not recommended because they alternately prime and deprime when the discharge arriving at them is less than their full-bore capacity. They can thus generate erratic conditions in the upstream and downstream channels.</td></tr>
<tr><td colspan="2">The recommended type of siphon for use in the fluvial environment is a self-priming air-regulated siphon. If well-designed, these can operated with a stable water flow that constantly matches the flow arriving from upstream.

</td><td>Inverted siphon
Not really a siphon, this type of structure is useful for passing under an obstacle such as a river, road or building with deep foundations.

</td></tr>
<tr><td>Specific design considerations</td><td colspan="2">Sediment load – both bed and suspended, settling velocities, material type
Trash load – quantity and quality, consider specification of trashscreen
Inlet and outlet details – design against scour and blockage
Sediment trap upstream of entrance – can reduce the need for maintenance
Ecology – generally impassable to migratory fish, so consider fishpass as auxiliary structure
Reliable means of priming and depriming (for true siphons)
Risks associated with sudden changes in flow (if a ‘black-water’ siphon or mechanical priming is proposed)</td></tr>
<tr><td>References for design guidance</td><td colspan="2">The detailed design of true siphons is a specialist activity due to the subtleties of priming and sealing, the effects of wave action and cavitation risks.
Design and operation of air-regulated siphons for reservoir and head-water control (Ackers and Thomas, 1975).
Design of small canal structures (Aisenbrey et al, 1978).</td></tr>
<tr><td>Common faults</td><td>True siphons:
▪ blockage by trash;
▪ excessive scour at inlet or outlet;
▪ ineffective arrangements for priming and retaining prime;
▪ cavitation.</td><td>Inverted siphons:
▪ inadequate provisions for sediment removal;
▪ need for security screens at inlet and outlet which create a maintenance obligation.</td></tr>
</table>

11.3.8 Outfalls

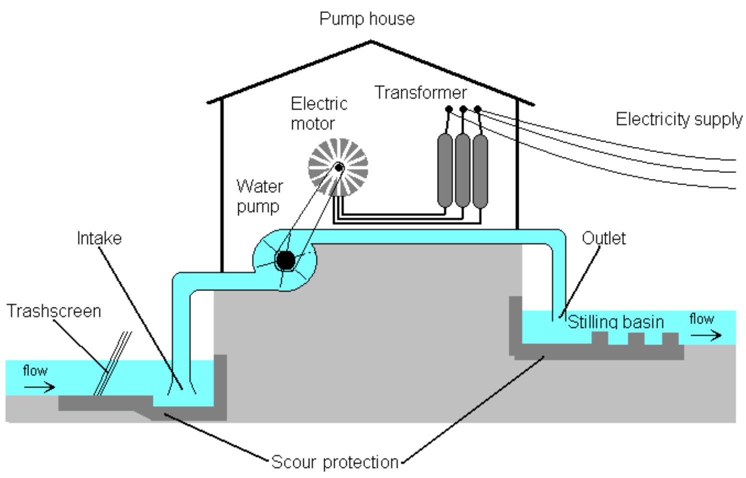
<table>
<tr><td>Description and purpose</td><td colspan="2">The structure at the point of a discharge into a river.
Can be above or below the normal water level.</td></tr>
<tr><td colspan="3">A selection of different forms</td></tr>
<tr><td>Common
Most outfalls require scour protection, but hard protection (below) often creates more scour problems than it solves. Scour is often worse at the edges of hard structures.
</td><td>Access restriction
Larger outfalls require access restrictions – these must be at both ends to ensure people are entirely excluded.
</td><td>Flapgate
Fitted to stop flow reversal during flood flows – a common cause of flooding – these should be accessible in design flows and not obscured from view by an overhang (see below).
</td></tr>
<tr><td>Specific design considerations</td><td colspan="2">Flapgate to stop reverse flow condition, although there remains a risk of operational failure due to blockage or obstruction. Consequences of failure should be assessed. Access to the flapgate for inspection and maintenance is vital.
Scour protection – will be required if flow from outfall has high velocity, or if the outfall obstructs flow in the receiving channel
Security screen to stop access into pipe. This must be at both ends of pipe or culvert or people entering the pipe may become dangerously trapped.
Differences in water quality – may require pre-treatment such as reed-beds, cooling structures, oil traps or sediment traps.</td></tr>
<tr><td>References for design guidance</td><td colspan="2">Case studies from Manual of river restoration techniques (RRC, 2002):
9.1 Surface water outfalls (http://www.therrc.co.uk/pdf/manual/MAN_9_1C.pdf)
9.2 Reedbed at Raglan Stream – reedbed treatment of an agricultural outfall (http://www.therrc.co.uk/pdf/manual/MAN_9_2C.pdf)</td></tr>
<tr><td>Common faults</td><td colspan="2">Over-engineered so that the outfall becomes an obstruction in the receiving channel
Inadequate scour protection
Faulty or damaged flapgate
Poor water quality matching of discharge with river water
Inadequate environmental sensitivity in terms of location, materials and finishes
Design excludes provision for dealing with trash caught on screen or obstructing flapgate</td></tr>
</table>

11.3.9 Screens

<table>
<tr><td>Description and purpose</td><td colspan="2">Screens are used for two reasons:
▪ A trash screen is designed to prevent debris entering a culvert or inverted siphon where it could cause a blockage.
▪ A security screen is designed to prevent unauthorised access to a culvert or inverted siphon, generally for health and safety reasons.
Environment Agency policy is to discourage the use of screens except where the benefits clearly outweigh the risks.</td></tr>
<tr><td colspan="3">A selection of different forms</td></tr>
<tr><td>Single stage
Suitable for smaller streams and rivers
Raking bars maximum length 2m
</td><td>Multi-stage
For areas where water level variation requires raking bars longer than 2m
Access platforms on each stage to allow safe cleaning by operatives

</td><td>Self-raking
Trash loaded into hopper/skip for disposal
Periodic or head-difference operated
For systems in continuous operation
</td></tr>
<tr><td>Specific design considerations</td><td colspan="2">The need for a screen should always be questioned as they are often themselves a source of problems (high maintenance requirement and the risk of blockage resulting in local flooding before the screen can be cleared – screens can block in a matter of hours in flood conditions).
The design must be based on an assessment of likely debris types and volumes, so that the area of screen and suitable bar spacing can be determined.
There must be safe access for cleaning and space for temporary storage of debris above flood level.
Implementation should proceed only once responsibility for routine and emergency cleaning has been established and the screen owner has confirmed that the required resources for this work will be available in perpetuity.
There may be ecological issues associated with fish and mammal passage.</td></tr>
<tr><td>References for design guidance</td><td colspan="2">Trash and security screens: a guide for flood risk management (Environment Agency, 2009)</td></tr>
<tr><td>Common faults</td><td colspan="2">Screen is not required.
Screen area far too small so that debris accumulation is rapid.
Bar spacing too small so that the screen becomes obscured by material that poses no risk to the culvert. NB For security screens, a standard clear spacing of 140mm is recommended.
Inadequate provision for safe raking and storage of debris removed.
Flimsy construction making the screen vulnerable to vandalism.</td></tr>
</table>

11.3.10 Pumping stations and intakes

Description and purpose	Pumping stations are used for a variety of purposes, but their main function in the fluvial environment is land drainage (raising water from low level drains into rivers and streams). Pumping stations are also be used to abstract water from a river for domestic or industrial use. Sometimes pumps may be used to empty flood storage reservoirs. Pumping station intakes are always below water level.
Major components in a pumping station	
	Power supply – often requires grid connection; backup diesel generator for critical locations Pump – various types (see USACE design manual below); often multiple pumps for redundancy and for continued operation during maintenance or breakdown Trash screens – specification should meet Environment Agency standards Scour protection and stilling basin – designed to protect against scour, dissipate excess turbulent energy and ensure subcritical flow of discharged water Pump house – should be sensitive to architectural character of area
Specific design considerations	Maintenance of minimum water levels for intake Range of pump capacity to cope with flow variability Scour and deposition due to changes in river flow Intake water free from trash, sediment and pollutants – trash screens and sediment/oil traps may be incorporated in design Ecology – fish may become trapped in intake (humane methods of removal should be investigated)
References for design guidance	US Army Corps of Engineers design manual: *Mechanical and electrical design of pumping stations*, EM 1110-2-3105 (http://140.194.76.129/publications/eng-manuals/) *Pumping stations – design for improved buildability and maintenance* (Wharton *et al*, 1998)
Common faults	Damage to the pumps from sediment, trash or weed 'Hunting', with pumps switching on for short periods only Operational failure of remote unmanned pumping stations

11.3.11 Locks

Description and purpose	Locks allow the passage of boats between water bodies or channels with different water levels. Can be used in series to traverse large inclines, or in parallel to reduce waiting times for vessels. Often used in conjunction with another means of water level control such as a weir, a flume or a gated control structure.

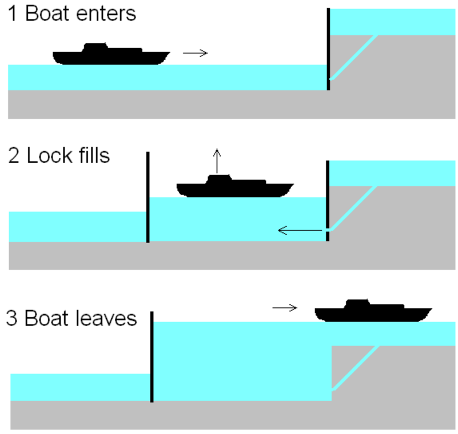
A selection of different forms

Single lock with side weir

Double locks in parallel

Stepped locks in series

Lock operation



Specific design considerations	Navigation – vessel traffic numbers, dimensions, frequency, etc Ecological – migratory fish routes and local ecological constraints Upstream and downstream water levels – effects on ecology and flood risk Potential for scour at bed and banks Foundations – especially under-seepage Stoplog grooves or similar for draining lock during maintenance Operational requirements – will there be a lock keeper?
References for design guidance	US Army Corps of Engineers manuals: *Hydraulic design of navigation locks,* EM 1110-2-1604 *Planning and design of navigation locks,* EM 1110-2-2602 See http://140.194.76.129/publications/eng-manuals/
Common faults	Instability of walls and base Scour downstream Boat impact Deterioration of rubbing strips Older structures suffer from deterioration of masonry in walls and base and leakage through lock gates.

11.3.12 Fishpasses

<table>
<tr><td>Description and purpose</td><td colspan="2">Employed to encourage movement of fish across obstacles such as locks, weirs and pumping stations that interfere with migratory fish routes. Success depends on selecting an appropriate type of pass, good positioning and the provision of an adequate ‘attraction flow’.</td></tr>
<tr><td colspan="3">A selection of different forms</td></tr>
<tr><td>Bypass channel
Simulates natural channel
Provides extra offline habitat
Not usually appropriate for large drops
Landscape feature
Requires large area
</td><td>Pool and traverse
Series of linked pools separated by notched traverses
Used for moderate to large drops (1–20m)
Suitable mainly for salmonid fish unless underwater orifices between pools are included
</td><td>Larinier
Open sloping channel with chevron-shaped baffles to floor only
Suitable for a wide variety of fish species, including non-jumping types
Can be made as wide as required using replicated units
Suitable for canoe passage when wooden baffles are used
</td></tr>
<tr><td>Specific design considerations</td><td colspan="2">Fish – species, behaviour, size and numbers, migration seasons
Geometry – available space, location of entry and exit, preferred fish routes, height of obstacle, water level variation and slope suitable for fish ascent
Water levels and flows expected during peak migration season
Previous experiences of passes with the same fish species and local practice
Provision of trapping and/or monitoring arrangements to measure their effectiveness</td></tr>
<tr><td>References for design guidance</td><td colspan="2">Information on fishpasses on the Environment Agency website (http://www.environment-agency.gov.uk/business/sectors/32651.aspx)
Environment Agency’s Fish pass manual (Armstrong et al, 2004)</td></tr>
<tr><td>Common faults</td><td colspan="2">Design not suited to passing required species or sizes of fish
Inappropriate positioning of downstream entrance (fish don’t find it)
Inverts not matched to water levels during fish migration season
Inadequate attraction flow
Injury to fish
Excessive maintenance
Lack of monitoring provision</td></tr>
</table>

11.4 Rehabilitation of structures

There are large number of existing structures on our rivers and canals. Each one requires consideration of how best to maintain it, in order to prolong its useful life, while planning for its eventual replacement or retirement.

The importance of this is recognised in work during phase 1 of project FD2318 (Performance and reliability of flood and coastal defences) under the joint Environment Agency/Defra flood and coastal erosion risk management R&D research programme (Environment Agency, 2005; Buijs *et al,* 2007). For full details of this project and links to the various project outputs, use the project search tool on the programme website (http://www.defra.gov.uk/environ/fcd/research/RandDcompproj.htm).

The second phase involving a performance-based asset management system (PAMS) to develop and demonstrate the methodologies is underway. This will lead to a third phase of supporting manuals and software. For information about the project see the PAMS website (http://www.pams-project.net/index.htm).

The principal steps in decision-making are discussed in the following sections.

11.4.1 Inspection and residual life

To aid decision-making when planning the management of assets on rivers and canals, it is essential to ascertain the residual life of the asset – usually through means of an inspection. Inspection often presents various access and safety issues, and problems associated with assessing the condition of buried structures and foundations.

Inspection for failure – serviceability and ultimate

An ultimate limit state is a limit beyond which a structure no longer serves its primary purpose. Emergency works may be required if the structure is failing, or about to fail in its primary purpose. This is especially true if the structure in question is a flood risk or navigational asset.

A serviceability limit state is one that affects functions of only secondary importance such as finishes or appearance. Such issues may be resolved with less urgency, although it is often more cost-effective to intervene sooner rather than later.

Inspection for residual life

There are many inspection methods available; some of the most important ones are listed in Table 11.1. Before interpreting any results that the inspection may yield, it is essential to understand the limitations of the inspection method.

Assessing residual life

The performance-based approach to assess residual life of structures developed with the concept of fragility curves as part of the joint Defra/Environment Agency flood and coastal erosion risk management R&D programme (Buijs *et al*, 2007) can be applied to river and canal structures. The fragility curve is a measure of the variation of the probability of failure of an asset with the range of loading conditions to which it is subjected.

Table 11.1 Inspection methods – applications and limitations

Method	Application	Limitations
Walkover/visual, with photographic record	Assessing structural form, condition, materials and access restrictions to site Identifying potential problems such as accumulations of sediment	Can only see what is visible at the surface
Diver survey	Assessing extent and condition of submerged structural elements Mapping bed levels Identifying scour hole locations	Health and safety issues Limited visibility in certain conditions
Trial pit	Finding structure footprint Assessing buried services and structures as a precursor to other surveys	Depth limited by excavator arm and stability of excavation
Borehole	Assessing soil conditions and geology	Small sample may not be representative, so may require several boreholes
Drilled core	Assessing concrete condition and extent Collecting samples for destructive testing	Small sample may not be representative, so may require several cores Drilling may cause damage to structure
Non-destructive materials testing	Can test different regions within a structure for comparative strengths Finding weak points Can be correlated with destructive testing results	Large margin for error
Destructive materials testing	Assessing material qualities, strength, type and chemistry	Small sample may not be representative Damage to structure
Geophysical methods	Assessing geology and soil structure Identifying weak points, voids, buried structures and services for further investigation	Limited penetration of hard surfaces Ambiguity of results
Total station survey	Mapping levels and locations of key features to a given accuracy	Level of accuracy Line of sight required
Laser survey	Mapping levels and locations of solid surfaces (for example, lock chambers) to a very high accuracy Identifying instability and movement	Relatively expensive Line of sight required

11.4.2 Intervention strategy

Choosing the correct strategy for rehabilitation of an asset requires a structured method of comparing a variety of options. Innovative options may present themselves, or be suggested, for specific structures. There are also various generic strategies that should be considered in every case. Strategy options are summarised in Table 11.2.

Table 11.2 Intervention strategy options

Option	Comments
Do nothing	The effects or risks arising from this option must be assessed to form a baseline by which other options are measured in a benefit to cost ratio.
Patch and repair	This approach entails simply fixing issues as and when they arise. Examples include: ▪ carrying out a localised repair to a damaged revetment; ▪ replacing a broken hinge on a flapgate.
Periodic significant maintenance	A schedule of major works that will replace whole structural elements that are obsolete or at the end of their serviceable life. Examples include: ▪ replacement of non-standard trash screens; ▪ substitution for a pumping station with newer, more efficient, electric motors.
Demolish and reconstruct	Demolition and replacement of the present structure with a new one designed to the same or similar design criteria.

11.4.3 Whole-life costing

A whole-life costs approach should be taken to appraising rehabilitation options. This involves accounting for design, planning, maintenance and decommissioning costs as well as the cost of the capital construction works to be undertaken.

To ensure carbon dioxide (CO_2) emissions are taken into account, carbon costs for options should be calculated and compared using the Environment Agency's carbon calculator for construction activities (http://www.environment-agency.gov.uk/business/sectors/37543.aspx).

Both cash and carbon costs require net present value discounting.

Details of methods of discounting financial costs can be found in *The green book* (HM Treasury, 2003).

For discounting carbon costs see the Defra guidance on the shadow price of carbon (http://www.defra.gov.uk/Environment/climatechange/research/carboncost/index.htm).

11.4.4 Repair and rehabilitation techniques

Seasonal working

Rehabilitation of river and canal structures is often constrained by:

- prevailing fluvial conditions;
- the need to avoid disrupting navigation;
- the requirements of stakeholders such as anglers.

These considerations may significantly reduce the period in a year when it is acceptable to undertake works (except, of course, in an emergency), as illustrated in Figure 11.5.

Figure 11.5 Penton Hook lock refurbishment

Works were carried out to refurbish the lock at Penton Hook. The work included sprayed concrete to resurface the walls and replacement rubbing strips and edge stones. This required draining the lock and therefore temporary lock closure.

As most of the boat traffic on the River Thames is during the summer, closure of the lock had to take place during winter months. The increased risk of flooding had to be reflected in the contract terms.

Dry working

Some operations are entirely possible without closure of the watercourse. Some require works to be carried out in the dry. This necessitates the construction of temporary works (see Section 8.7) such as:

- a cofferdam using techniques such as sheetpiling;
- water-filled dams;
- portable temporary dam (membrane supported by a steel A-frame and similar units).

11.5 Mechanical and electrical design

Mechanical plant for river and canal structures is usually associated with one of the following applications:

- locks for accommodating changes in the height of navigable waters;
- gated flow control structures;
- gravity inlets and outlets connecting to pipes, culverts or channels;
- pumped inlets and outlets connecting to pipes, culverts or channels;
- gated flood control barriers.

Details of the types of mechanical plant generally used in these applications are given below. For specific design considerations, please refer to the publications highlighted amongst the references at the end of the chapter.

11.5.1 Gates and similar

Vertical lift gates can be wheeled or sliding – of steel or composite construction – and vary in size from small sluice gates or penstocks for controlling water into pipes up to major steel constructions weighing in excess of 100 tonnes (see Figure 11.6).

Other variants of vertical lift gates include double leaf hook gates as installed on the Cardiff Bay barrage.

Figure 11.6 Examples of gates of varying sizes

Set of small bottom pivoted flapgates for river regulation. The flaps are raised when river flows are low, and lowered in flood conditions.

A large vertical lift gate which is lowered to prevent high tidal levels from flooding the city of Hull.

Mitre gates are the traditional installation for river and canal locks. Traditionally they are made of wood and hand operated (see Figure 11.7), but on larger and more frequently used locks, these have developed into steel construction and powered operation (see Figure 11.8). They are fitted with sluices within the gate or in the abutments for lock filling and emptying.

Figure 11.7 Traditional wooden lock gates

Figure 11.8 Modern steel lock gates

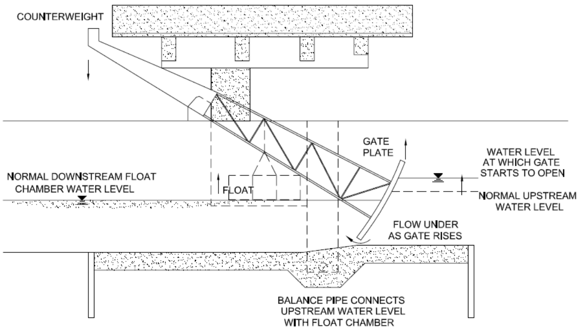
Sector and radial gates are of superficially of similar design, except for the orientation of the axis of rotation – vertical for sector gates (see Figure 11.9) and horizontal for radial gates (also known as Tainter gates) (see Figure 11.10).

Two pairs of sector gates can be used to form a lock, and sector gates are a more modern solution to dock gate design. They have advantages including low operating forces and the ability to withstand bidirectional head, but require more extensive civil works.

The drum gates on the Thames barrier are a variant of radial gates.

Figure 11.9 A pair of vertical axis sector gates used for a lock entrance

Figure 11.10 Automatic horizontal axis radial gate for automatic control of upstream river level



Other types of gate-like equipment include stoplogs, rymer weirs and inflatable weirs.

Stoplogs were traditionally made of wood as indicated by the name and are lowered into an opening registering in grooves in the walls to isolate a gate or structure to allow working in the dry. Larger examples are now made of steel.

Rymer weirs are an historic form of adjustable weir which still exist in some places despite serious health and safety disadvantages. A number exist on the River Thames, but are being phased out; they are mentioned here for completeness. An example at Northmoor Lock on the River Thames is described on http://www.the-river-thames.co.uk/locks.htm.

Inflatable weirs are of relatively modern design and made of a composite rubberised material in the shape of a long tube, which is inflated and deflated with air or water in order to control the crest height. They are common in Japan but have yet to be adopted in the UK.

11.5.2 Operating equipment

Operating equipment comes in many forms to suit the wide range of equipment being operated. It can be grouped essentially into:

- manual operation by handwheels, cranks, mitre gate balance beams and other means;
- electrical motors driving mechanical equipment such as winch drums;
- electric motors producing hydraulic power, utilised via cylinders for linear motion or hydraulic motors for rotational motion.

The final movement of the gate leaf can be achieved by direct mechanical linkage, hydraulic cylinder, rope or chain.

11.5.3 Trash handling facilities

When trash is a problem it either has to be repelled so as to pass further downstream by such methods as booms, bubble barriers and other techniques, or it has to be collected. Collection normally involves a static screen cleaned by manual or mechanical means, or a moving screen that is cleaned automatically.

11.5.4 Fish provisions

In a similar way, fish either have to be deterred – for example by preventing them entering intakes – or facilitated in their movement upstream or downstream.

Deterrence can be by screen or more elaborate systems involving ultrasonics, lights, acoustic effects, drum, electrified, etc.

Facilitation of movement can be by fish ladders or even a fish lift. For example, the Cardiff Bay barrage has a large fishpass aimed at facilitating the movement of migratory fish (http://www.cardiffharbour.com/harbour/barrage/fish%20pass.html).

11.5.5 Pumping plant

Pumping equipment for drainage purposes is normally either a centrifugal type or using an Archimedean screw. Individual pump flow rates may vary between a few litres per second for minor drainage works to pumps with capacities of several m^3/s.

Centrifugal pumps

Centrifugal pumps are generally considered to be any pump with an impeller producing radial or mixed flow, although axial flow pumps are also often referred to as centrifugal type.

The output flow from any centrifugal pump depends on the head against which the pump is discharging. The pump therefore has to be selected to suit the particular head and flow requirements. In most cases a centrifugal pump delivers its maximum head at zero flow. As the flow increases so the head reduces, and the pump operating efficiency increases until the peak efficiency is achieved; this is known as the best efficiency point (BEP). If the pump flow continues to increase, then the efficiency begins to reduce. If the flow is allowed to increase further as a result of falling head, the net positive suction head (NPSH) required by the pump begins to increase to the point where the NPSH required exceeds the NPSH available. At this point cavitation occurs, resulting in damage to the pump impeller.

The selection of a centrifugal pump must therefore consider the hydraulic conditions.

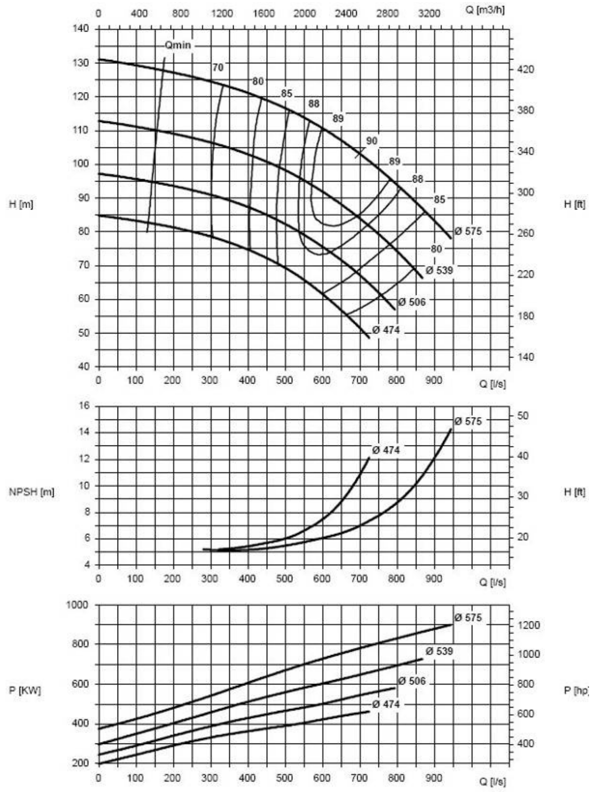


Figure 11.11 Typical pump performance curve

An example of a typical pump performance curve for a centrifugal pump showing how the head varies with flow.

The efficiency curves are also shown on the *H* v *Q* curve.

The four lines represent different impeller diameters.

The other curves show the NPSH and power absorbed by the pump.

If the pump is required to work over a very large range of heads, consideration must be given to throttling the discharge flow either using a control valve or resorting to a variable speed drive. Throttling wastes energy and is generally used only in exceptional cases. Where there is a wide variation in pump head, a variable speed drive is often used. This is achieved by changing the supply frequency of the driving motor using an electronic inverter. The pump flow varies proportionally to the change in speed, and the pump head varies as the square of the change in speed.

Figure 11.11 shows a typical pump performance curve.

Pumps can be deployed in either a dry well or a wet well. Wet-well pumps, as their name implies, are installed directly in a pump chamber. Dry well installations still require a 'wet' inlet chamber, but the pumps are installed in a dry chamber and have piped inlets from the adjacent inlet chamber. Figures 11.12 and 11.13 show examples of dry well pumping installations.

Figure 11.12 Dry well pumping installation

In this example, there are vertical shaft pumps driven through drive shafting from vertical axis motors at ground level.

Figure 11.13 Dry well pumping installation

In this example, horizontal split-casing pumps are directly coupled to their driving motors.

Over the last 20 years, submersible pumps – where both the pump and the driving motor are submerged in a wet well – have been widely used, particularly for the smaller flow rates.

For larger flow rates (generally in excess of 1 m^3/s), vertical wet well type pumps are normally used. In such installations, the pump impeller and volute are submerged and supported by a pipe which acts as the discharge pipe through which the pump drive shaft passes (see Figure 11.14).

The pump motor is located at the top of the discharge pipe and bend, normally at ground level.

Although wet well installations usually have a lower capital cost, they are more difficult to maintain. Dry well installations have the advantage that the pumps are always accessible and, after closing isolating valves on their suction and discharge mains, they can be dismantled insitu without having to remove the entire pump.

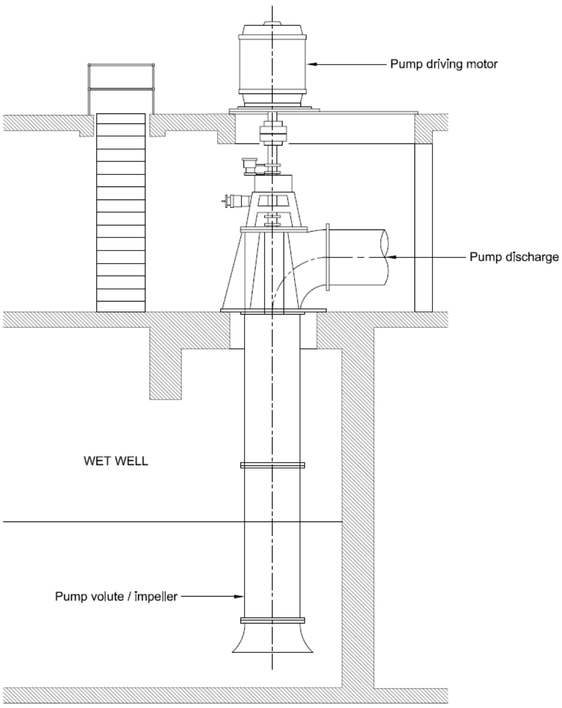


Figure 11.14 Wet well pumping station

Typical cross section through a wet well pumping station

Centrifugal pumps are not self-priming and require the pump volute to be filled with water before starting. Having the pump submerged ensures it remains fully primed and avoids having to provide a separate system for priming the pump. Failure to prime a centrifugal pump properly is one of the most common problems associated with pumping plant. A centrifugal pump is not capable of operating dry – it must always have water available to pump.

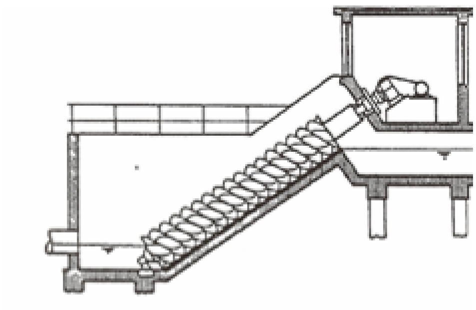
Other potential problems with centrifugal pumps can be as a result of debris in the water. It is essential to provide adequate protection to prevent the ingress of weed and other material that can get carried into pump intakes such as wood and plastics. Smaller pumps are more susceptible to debris, as the water passages through the impeller are smaller, so are more likely to get blocked – although any pump is at risk. Normally, as a minimum, a bar screen with 25mm spacing should be provided, with the facility to rake it periodically to remove any build-up of debris. Where weed or other debris is a known problem, then finer screening should be employed – possibly with automatic cleaning such as a rotating band screen, clog-resistant 'vee-wire' screen or similar.

In most instances, pumps are driven directly from electric motors. Where a mains power supply is not available, one option is to provide a diesel generator to supply electrical power. Alternatively the pump could be driven directly from a diesel engine, rather than having a diesel generator and an electrically driven pump. In special situations, other methods of pump drive such as hydraulic motors can be used, although these are not common on drainage applications.

Archimedean screw pumps

The Archimedean screw pump is probably one of the oldest type of pump and consists of a large screw located in an inclined channel (see Figure 11.15). The channel is usually cast concrete but, for smaller pumps, can be steel. The main advantage of the screw pump is that the flow remains almost constant, irrespective of the change in head. The flow is still proportional to the speed of rotation.

Figure 11.15 Archimedean screw pumping station



A screw pump can also operate even when there is little or even no water to pump. For drainage applications this makes the Archimedean screw pump an ideal choice. The main drawback of this type of pump is that their discharge head is limited. A head in excess of 10m is unusual due to the span of the screw required for high-head applications. Where higher heads are required two-stage lifts using two pumps in series can be used.

The main disadvantage of screw pumps is the size of the installation and the cost, which is usually significantly higher than the cost of a centrifugal pump of the same head and flow.

11.6 Power supplies

11.6.1 Selection of power supplies

The main sources of electrical power for operating equipment are as follows:

- mains electrical power from local power supply company;
- local generation using diesel or petrol generators;

- renewable sources of power such as wind or solar generation.

11.6.2 Mains electrical power

Mains electrical power is the most usual means of providing power for most of the larger gates or pumping installations. Normally the mains supply is very reliable and is adequate for most applications. Where additional security of supply is required, duplicate supplies from separate circuits can sometimes be obtained or, where this is not possible, a standby generator is normally installed, which would start automatically in the event of a mains failure.

In most instances, the source of power for operating equipment is to take a supply from the local electricity supply company.

For small installations where there is already an existing low-voltage (400V three-phase 50Hz) distribution system, a metered supply could be made available in the same manner as any other commercial consumer.

Where the power demand is much higher (such as a large drainage pumping station or where the location of the equipment is some distance from any existing low voltage distribution network), the local electricity supply company would provide a high voltage (HV) supply, probably at either 33kV or 11kV. This would normally require a local transformer (substation) to reduce the voltage to 400V.

On large drainage pumping stations where power demand is high, the probability is that the driving motors would require a HV supply. In general, it is more economic to use HV motors at 3.3kV or 11kV for any drive in excess of 350kW. In such cases, it may be possible to operate the drive motors at the supply voltage in order to avoid having a large substation. It would still be necessary to provide a small substation to provide low voltage supplies to ancillary equipment and for single phase small power, lighting and heating.

11.6.3 Local generation

Local generation is usually uneconomic for continuous operation, due to the high costs of providing fuel, as well as increased maintenance. But where equipment is located a long way from an existing power supply and the cost of installing a mains supply becomes prohibitively expensive, local generation should be considered.

Small diesel, petrol or even gas-fuelled generator sets can be used to provide power at remote locations.

Where occasional operation is required (such as an adjustment to a regulating gate or emergency drainage pump), the generator can be arranged to:

- start automatically whenever the gate or pump is required to operate;
- shut down when the equipment is no longer needed.

Local generation is never as reliable as mains power and requires considerably more maintenance and manual intervention.

11.6.4 Renewable energy

Although renewable energy sources such as wind and solar energy are becoming more widespread as the technology advances, their use is usually limited to low wattage applications such as instrumentation, monitoring equipment, and associated remote telemetry outstations. Their use for providing power for operating electrical drives is still very limited.

Renewable energy sources are ideal for remote instrumentation such as level and condition monitoring. They can also been used to operate small drives such as small pumps and gate drives, though the problem is in providing sufficient storage capacity in batteries to ensure reliable operation.

11.6.5 Motor control panels

If power is provided to a site of a pumping station or gate installation, local controls are required to operate the equipment.

Where simple manual operation is required, a local panel is required containing the necessary protective devices as well as manual controls to enable the equipment to be operated. This can be as simple as on/off pushbuttons or switches.

Where simple automatic operation is required, the control system is incorporated in the control panel. This automatically starts pumps or alters gate positions depending on signals from level sensors or flow controllers. The panel also provides manual override of the automatic controls for testing or other operational reasons.

On sophisticated installations where a number of parameters are monitored and controlled, a local programmable logic controller (PLC) might be incorporated to provide the necessary functionality. The PLC might also be integrated into a global system control and data acquisition (SCADA) system, whereby a number of installations can be controlled from a central control room using telemetry systems.

Examples of motor control panels are shown in Figures 11.16 to 11.18.

Figure 11.16 Typical examples of motor control panels

Figure 11.17 Control desk at small pumping station

The local control desk provides the facility to manually operate the plant locally in the pumping station. It also interfaces with the automatic controls.

Figure 11.18 Central control room for larger scheme

This control room covers the remote operation of a number of pumping installations. Overall status is shown on the wall mounted mimic diagram that gives the operators an overview of the entire system.

11.7 Instrumentation, control and automation (ICA)

11.7.1 Forms of control

Ideally, gates and pumps should have only local manual operation for the following reasons.

- This is safer for staff and the public in the area.
- It is technically simple and economical.
- It ensures that an operator is by the equipment for and during its operation. This allows items to be checked and ensures that signs of distress in the equipment can be observed and appropriate action taken.

In practice, remote and automated operation is frequently required. Remote operation can be:

- within a short distance of the equipment, but where the operator is more comfortably housed and can probably see the equipment to some degree – in such cases remote operation may well be achieved by hard wiring;
- truly remote from the site, where there is no visual contact (unless by CCTV) and where control links are achieved by telemetry or similar.

Considerable attention must be paid to safety when remote operation is adopted and local control facilities must be retained for maintenance purposes. Specific requirements are laid down when remote and automated operation is used for Environment Agency projects (Environment Agency, 2006).

Typical examples of where automatic operation is appropriate include:

- drainage pumps;
- gates that control the water level in a river or canal.

For gates, mechanical means of achieving automatic operation are possible – either as one-off designs such as the Pulteney weir in Bath or by traditional proprietary designs. These have the advantage of limited or zero energy consumption, and lack of dependence on a power supply.

For gates and pumps, automatic operation can be achieved readily in forms that range between:

- those based on simple level switches and limit switches;
- systems using PLCs to allow operation in accordance with sophisticated and readily changeable operating criteria.

11.7.2 Alternatives for remote linking

In most situations it can be uneconomic and/or environmentally unacceptable to provide traditional hardwired instrumentation and control systems over a distance of more than, say, one kilometre. Clearly exceptions to this can occur, for example on a large site where multi-function service corridors are provided.

For remote operation where such hardwiring is inappropriate, the principal options for the communication of instrumentation information and operating commands are described below. Combinations of these are also common.

Extended local area network (LAN)

Control and monitoring equipment is frequently connected using a LAN. Network distances can be extended by the installation of fibre optics, which can extend the traditional distance of an Ethernet network, for example, from 100m to several kilometres. They can be installed in ring configurations for redundancy.

Fibre optic networks are suitable for large sites where access is available to lay cables in service corridors and ducting without interruption.

Radio system

The use of radio systems is declining, as other systems achieve higher reliability and flexibility. Where the use of telephone systems or similar is difficult, such a system could be considered for linking over a distance of a few kilometres.

In principle, radio systems are suitable for a central site communicating to one or more outstations. The limitations are down to radio reception and usually require line of sight between the transmitter and the receiver for communications to work.

Public switched telephone network (PSTN) system

This analogue alternative is also declining in use, superseded by more comprehensive and advanced systems (see below). This system uses modems to allow transmission and receipt of digital signals through either dedicated lines rented from BT and others or on-demand dial-up arrangements.

PSTN or leased line communications are suitable for small amounts of data that are not required to be updated very frequently. Such systems can be expensive and slow.

Broadband-based system

These use the traditional wired telephone system at both the site of the equipment being controlled or monitored and the remote location, connected via a modem or a router. This arrangement can provide access from anywhere with an internet connection, provided that the correct security privileges are used. A virtual private network (VPN) can be configured in addition, providing a dedicated connection between systems if required.

Broadband-based systems are suitable for connecting several different locations that can be large distances apart, nationwide or even worldwide.

Successful use of this technology relies on a good broadband connection.

3G cellular telephone system

This uses the 3G (third generation) cellular telephone network to achieve broadband data communication between sites without the need to use the traditional wired telephone system. This system is not suitable for permanent connections as connection time can be expensive. It is suitable for remote outstations, provided they have good 3G cellular telephone coverage.

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