Scottish Environment Protection Agency

Engineering in the Water Environment
Good Practice Guide

Construction of River Crossings

First edition, April 2008

Your comments

SEPA is committed to ensuring its Good Practice Guides are useful and relevant to those carrying out engineering activities in Scotland's rivers and lochs.

We welcome your comments on this Good Practice Guide so that we can improve future editions. A feedback from and details on how to send your comments to us can be found in Appendix 2.

Acknowledgements

This document was produced in association with Royal Haskoning.

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(Document reference: WAT-SG-25)

Contents

1 Introduction

This document is one of a series of Good Practice Guides produced by SEPA to help people involved in the selection of sustainable engineering solutions. The Guide is intended for use by those considering engineering activities in rivers or lochs to provide solutions that:

- reduce the impact on the physical habitat (morphology) of rivers and lochs;
- reduce the need for long-term maintenance, helping to reduce cost.

Any engineering works must be designed to suit site-specific conditions. The Guide is not intended as a technical design manual but focuses on the environmental aspects that should be considered when undertaking a project.

Using the Guide will help with the process of obtaining an authorisation for works under the Water Environment (Controlled Activities) (Scotland) Regulations 2005 (CAR) (see www.sepa.org.uk/wfd for more information).[1]

1.1 What's included in this Guide?

SEPA expects all applications for new engineering activities under CAR to follow good practice. Good practice is defined as the course of action that serves a demonstrated need and is sustainable (i.e. the work is justified and the chosen design is effective), while minimising ecological harm, at a cost that is not disproportionately high.

Applicants proposing to undertake an engineering activity will be expected to demonstrate to SEPA that good practice has been adopted (Box 1).

Box 1: Summary of SEPA good practice tests

1. Have you demonstrated a need for the proposed activity?
2. Have you considered appropriate alternative approaches?
3. Does the proposal represent the best environmental option?
4. Is the activity designed appropriately?
5. Have all necessary steps been taken to minimise the risk of pollution and damage to habitat or flora/fauna during construction?

This Guide is designed to help applicants follow the steps outlined in Box 1 to:

- select sustainable river engineering solutions;
- provide the information required in the CAR application form

[1] Under CAR, new engineering activities in Scotland's rivers, lochs and wetlands require and authorisation. Authorisations take various forms and more information is available in the CAR Practical Guide available from www.sepa.org.uk

To help applicants through the process, the guidance is divided into four stages (Figure 1).

Figure 1 Key sections of this Guide

Section 3 Demonstrated need	The first step when identifying a sustainable engineering solution is to determine whether new engineering work is necessary. This section will help applicants assess the need for new engineering.
Section 4.1 Identification of options	There are often multiple solutions to a river engineering problem. This section provides information on relevant engineering options.
Section 4.2 Selecting best option	This section provides guidance to help you select the most suitable and sustainable engineering option.
Section 5 Design and implementation	Successful river engineering requires selection of a suitable option followed by appropriate design and implementation. This section provides guidance on design and implementation considerations.

Colour-coded boxes in the Guide highlight key information.

Blue boxes provide details of other useful sources of information

Green boxes provide summaries of important points

Orange boxes provide summaries of regulatory information

1.2 Basic terminology

Figures 2 and 3 give details of some basic structural components of crossings. Descriptions of these components are given in the Glossary (Section 7).

Figure 2: Basic components of a bridge

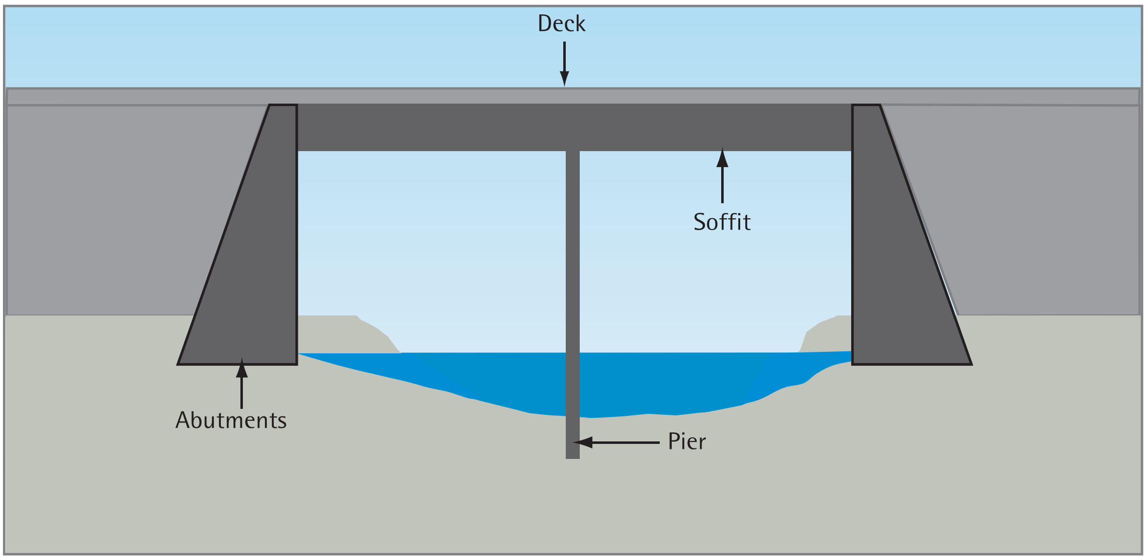
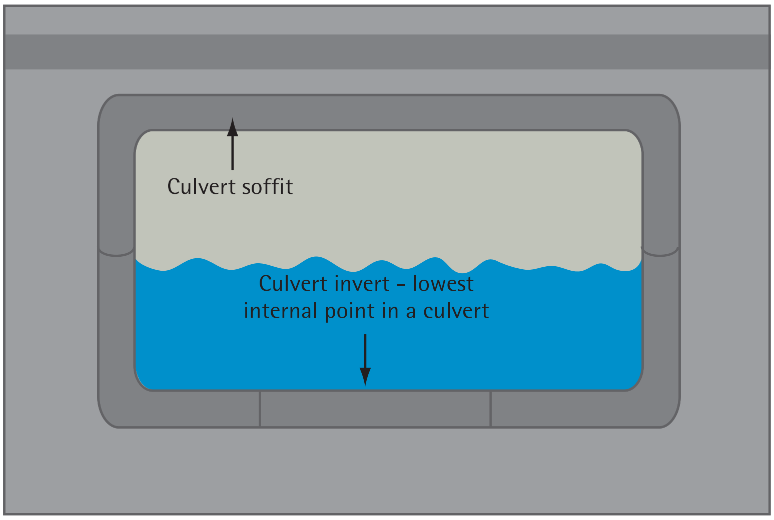


Figure 3: Basic components of a culvert



2 Impact of crossings

If poorly designed, river crossings can have significant impacts such as increasing the erosion of river banks and creating a barrier to fish passage. These impacts are explained below and summarised in the box at the end of the section.

2.1 Barrier to fish passage and other wildlife

Migration throughout the river catchment is essential to the survival of many species of fish. For example salmon travel as adults from the sea up river to spawn and then, as juveniles, migrate back downstream to the sea. Other fish such as brown trout use the whole river catchment throughout their life cycle, migrating upstream to smaller headwaters to spawn and moving downstream to feed and grow in the larger rivers where more food may be available. Other fish species that make significant migrations are sea trout, eels, sea lamprey and river lamprey.

Poorly designed river crossings can be a significant barrier to fish movement. Barriers can arise from:

- undersized crossings that increase the speed of water flowing through the structure;
- perched culvert outfalls (drop at outfall) (Figure 4);
- over-wide culverts that create flows that are too shallow to allow fish passage.

A complete barrier can lead to loss of migratory fish upstream and, depending on the provision of spawning gravels and rearing habitats, may also lead to a decline in populations throughout the river system.

Culverts typically present the greatest hazard to migration as they are frequently undersized and often form a drop at the culvert outlet (perched), requiring the fish to jump into the culvert section (Figure 4).

Figure 4: Perched culvert creating a barrier to fish passage

River continuity is essential not only for fish but also for other wildlife such as otters and water voles. These species not only depend on a healthy river ecology (fish and invertebrates), but also on good bank-side (riparian) habitat where they live and feed.

Culverts and other crossings that do not maintain the riparian corridor can create barriers for these mammals as well as preventing them from reaching feeding grounds and establishing populations elsewhere. Especially in more urban environments, the riparian habitat is often the only corridor they have left in which to move around.

Road accidents are one of the major causes of otter death in Scotland. During spate conditions at water crossings where no ledges have been provided, the high water velocities mean they cannot swim through the structure and thus use the road – greatly increasing their chance of being killed.

The cumulative impact of all the crossings that form potential barriers to fish and wildlife within a catchment can lead to significant problems.

2.2 Erosion

Poorly located structures such as bridge piers and abutments can cause turbulence and deflect flows, resulting in erosion of the bed and bank (Figure 5).

Figure 5: Abutment extends into channel, causing erosion of the left bank (photo courtesy of Royal Haskoning)

Where crossings lead to a narrowing of the channel, this can result in the bed being eroded and deepened (channel incision). This causes direct damage to the habitats where the erosion takes place.

In addition, river beds sometimes have a naturally occurring compacted layer of gravel on their surface (bed armour). If this layer is breached by bed scour, the soft underlying sediment is eroded very rapidly, leading to major damage in a short time. This destroys habitat and increases the amount of fine sediment supplied to downstream reaches. This sediment can smother habitats important for fish spawning, aquatic invertebrates and aquatic plants (macrophytes).

Erosion provides an input of coarse sediment (gravels) to the river from the bed and banks. This may have knock-on effects downstream leading to bed levels being raised (bed aggradation). This in turn reduces channel capacity such that the banks may erode, compounding the problem.

Localised erosion around the structure itself can lead to the structure being damaged.

2.3 Barriers to sediment and wood transport

Where crossings are poorly designed, sediment can deposit at bridges and culverts causing damage to the structure and increasing local flood risk (Figure 6). This leads to the need for regular dredging at the structure, which can have impacts on the ecology and water quality of the river.

The removal of dredged material directly impacts habitat, e.g. gravels provide spawning habitat for many species of fish and shelter for invertebrates. Dredging can also release finer sediments that can smother downstream habitats. If the dredged sediment is removed from the river system, this reduces the amount available for reaches downstream. This process of sediment transport downstream is vital to the creation and maintenance of many of the important habitats on which river ecology depends.

Figure 6: Increased deposition at a bridge

Figure 7: Large woody debris trapped at a bridge (photo courtesy of Royal Haskoning)

Large woody debris (LWD) is important for river ecosystems as it provides food for organisms and its presence increases the physical diversity of the channel. Woody debris is often trapped at bridges (Figure 7); this can increase flood risk and threaten the structure leading to failure in high flows. This woody debris is often removed from the system to stop such impacts.

2.4 Preventing the lateral migration of rivers

Many rivers move naturally across their floodplain (lateral migration). This movement – or migration – creates varied and constantly shifting habitats (see Channel migration/active zones in Section 5.1 for further information). Very active rivers can therefore be extremely valuable biodiversity hotspots. Crossings located on such rivers need very careful placement.

If a structure is placed poorly, it may prevent lateral movement (Figure 8). This will not only interrupt the natural river pattern and damage the habitat, but it will also undermine the structure (Figure 9). This can result in the need for engineering works to stabilise the structure or the river, which can lead to even more damage and can be very costly.

Figure 8: River migration affected by roads and river crossings (photo courtesy of Aberdeenshire Council)

Figure 9: Bridge structure at risk of failing due to inappropriate location on an active river

2.5 Flooding and floodplain connectivity

Poorly designed structures can increase flooding upstream due to a lack of channel capacity beneath the structure. Other structures may have sufficient capacity to take even the highest flows but, if they block the floodplain (e.g. through embanked causeways – see Figure 10), an increase in upstream flooding can still occur.

Figure 10 Road embankment crossing floodplain (photo courtesy of Aberdeenshire Council)

Floodplains are very important parts of a river; they provide storage for water and, under natural conditions, can act as storage areas for finer sediment and nutrients. They also provide important food sources and nursery areas for fish and other aquatic plants and animals. Floodplain woodland is one of the most biologically diverse and active habitats found anywhere. Crossings that block the flow of water on floodplains damage habitats directly and disrupt downstream floodplain connections.

Main impacts of river crossings

- Barrier to the movement of fish and other wildlife
- Increased erosion of river bed and banks
- Barriers to sediment and wood transport
- Prevent natural river movement
- Impact on flooding and floodplain connectivity.

Following good practice will help reduce the risk of these impacts

3 Demonstrated need

The first step in identifying a sustainable engineering solution is to determine whether new engineering work is necessary. This section will help you assess the need for new engineering.

A significant number of engineering activities are undertaken to address a perceived rather than real problem (e.g. bank protection on river bank that is not eroding or gravel removal from a pool that has not filled in).

Activities that are carried out without proper justification can:

- have a negative impact on ecological quality;
- tie up capacity in the water environment that is no longer available for activities associated with real problems.

Therefore, to demonstrate good practice, you must show that your application is associated with a real need to carry out the works.

3.1 Is there a demonstrated need?

There are some important points that should be considered to determine if a new crossing structure is necessary. Think about the questions in Box 2 before deciding if a new crossing structure is necessary.

Box 2: Is a new crossing structure required?

- Can route be chosen that minimises the number of crossings?
- Can existing structures be used and/or upgraded?

It is essential that these considerations are taken into account in the early stages of the planning and design process.

When replacing an old crossing, remove the old structure rather than building a new structure at a different location and leaving the old crossing in place. However, there may be exceptions to this where structures need to be retained for access purposes, or have some historical or local significance. In such instances, Historic Scotland (www.historic-scotland.gov.uk) and the local authority planning department should be consulted.

4 Options appraisal

It is a basic principle of good practice to consider a range of appropriate alternatives in addressing any river engineering problem or need. Without considering alternatives, it is not possible to determine if the approach chosen represents the best option.

This section describes possible engineering options and provides guidance to help applicants select the most suitable and sustainable type of crossing.

4.1 Selecting appropriate alternatives

This Guide identifies six generic forms of crossing (Box 3). Information is also provided on pipeline or cable crossings.

A range of suitable options should be considered when planning a new crossing structure. The guidance given in Section 4.2 will help you determine the range of options that may be suitable for your circumstances.

Box 3: Types of crossing

- I Single span bridges
- II Bottomless arch culverts
- III Span bridges with in-stream supports
- IV Closed culverts
- V Fords
- VI Causeways

↓ increasing impact

The different types of crossing are described in detail in Table 1.

Table 1 Different types of river crossing

I. Single span bridges

As their name suggests, single span structures span the width of the channel with no intermediate support and do not affect the bed of the river, therefore reducing the impact on the river channel.

They can come in a variety of forms from pre-cast structures to bridges designed for site-specific requirements.

Panel bridge

Comes as pre-fabricated sections that can be joined together to form different span lengths. Foundations have to be constructed on-site. Pre-fabricated structures are often easy and quick to install.

Site specific single span bridge

Bridge that spans the channel with no intermediate support and is built to suit site-specific conditions.

Photo courtesy of Highland Council

II. Bottomless arch culverts

Bottomless arch culverts span the width of the channel with no intermediate support and do not affect the bed of the river, therefore reducing the impact on the river channel.

They come as a pre-fabricated arch structure. Some require foundations to be constructed at the site and others can have pre-fabricated foundations. Pre-fabricated structures are often easy and quick to install.

III. Span structures with in-stream supports

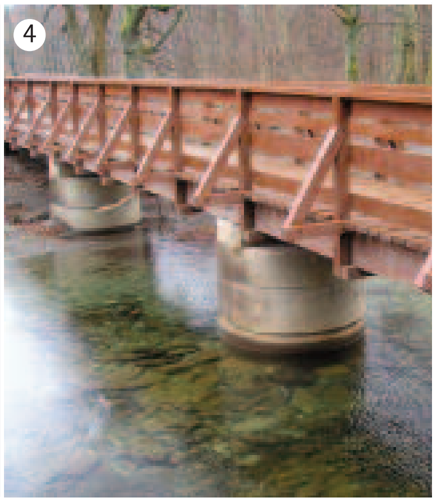
In-stream supports can be used to increase the crossing width where single span is not possible or prohibitively expensive.

Panel bridge

In-stream supports for panel bridges can be used to increase the crossing width where single span is not possible or prohibitively expensive.

Site-specific bridge with in-stream support

Bridge that spans the river with in-stream supports and which is built to suit site-specific conditions.



IV. Closed culverts

Closed culverts have an artificial floor and so have a greater impact on the bed and banks of the river. Closed culverts can be made from a variety of materials and come in a range of shapes and sizes from pipe, box and closed arch. Installation of a closed culvert causes significant disruption to the riverbed and, if not designed correctly, can cause a barrier to fish migration.

V. Fords

Fords are river crossings built at the level of the river bed. They can be made of natural materials (natural bed and bank material maintained) or they can be reinforced with artificial material (bed and/or banks).

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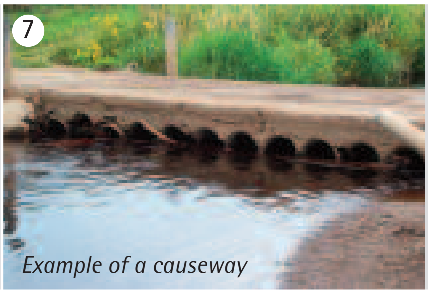
Ford created over river with no reinforcement

VI. Causeways

Causeways involve raising the crossing above the level of the bed, often using multiple pipes. The structure is normally inundated in medium flows.



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Example of a causeway

Figure 11 contains a flow chart to help you select a range or appropriate alternatives for your crossing. Guidance on selecting the best practical environmental option from this range of appropriate alternatives is provided in Section 4.2.

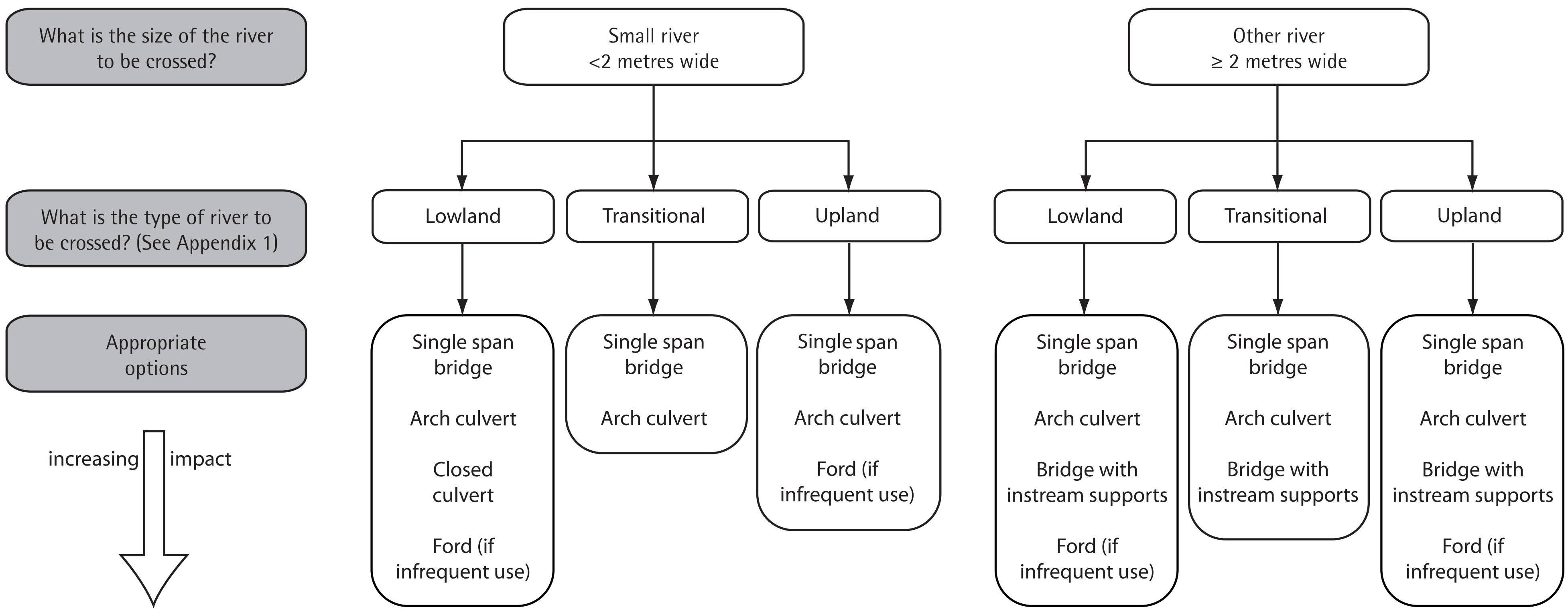


Figure 11 Identifying appropriate options

4.2 Selecting the best option

Once all the alternatives have been evaluated, the next step is to choose the best practical environmental option. This does not always mean adopting a low impact engineering approach. Best practical environmental option means selecting the approach that addresses the problem or need while minimising environmental impact as far as practical. It also has to be cost-effective (see Box 4) and achievable.

Box 4 Proportionate cost

The most cost-effective solution is the one that minimises environmental harm or maximises environmental benefit at a proportionate cost. In itself, large absolute cost does not constitute disproportionate cost. For example, incurring significant costs to prevent significant environmental harm or achieve significant gain would be considered proportionate. But incurring significant cost for minor environmental gain would be considered disproportionate and not cost-effective.

Table 2 summarises some considerations for selecting the best practical environmental option.

Table 2 Considerations for different types of crossing

Type	Impact	Considerations
Single span bridges & arch culverts	Least impact	• Preferred type of crossing. • May not be suitable for very wide rivers. • If properly designed has minimal impact on the river system. • Pre-fabricated bridges & arch culvets are generally cheaper than a site-specific design. • Span structures can take longer to install and may be more expensive than other crossing types as specialist construction techniques may be required.
Spanning structure with in-stream supports	Moderate impact	• Only appropriate where in-stream support is necessary to ensure structural integrity (i.e. very wide rivers). • Construction of in-stream supporting piers introduces a significant risk of damage to the water environment. As a result, the construction process may require specialist construction techniques. • In-stream piers can also significantly affect local channel hydraulics leading to impacts on channel stability (sediment erosion and deposition on both the bed and banks upstream and downstream) • Span structures can take longer to install and may be more expensive than other crossing types as specialist construction techniques may be required.
Closed culvert	High impact	• Only suitable for small streams in lowland rivers. • Not suitable for carrying pipelines or cables across rivers. • Culverts are generally cheaper that span structures because the design and construction process is generally less complex than for spanning structures.
Ford	High impact	• Only suitable where infrequent crossing is expected. If poorly designed/located can impede fish migration and cause pollution if overused, and induce bed and bank erosion or sediment accumulation. • A low cost solution.
Causeway	High impact	• Not suitable for permanent crossings. • May be suitable for temporary crossings during the construction phase where fish passage is not an issue. • Likely to create a barrier to fish passage/ sediment transport.
Pipeline or cable crossing buried below bed	Minimal impact	• Pipelines or cables should be carried above the river with a single span bridging structure of span structure with in-steam supports. • If they cannot be bridged over a river, they should be buried below the bed of the river and should not be laid in the channel. • Burying below the channel should be suitable for all types of river but may depend on ground conditions.

5 Design and implementation

Successful adoption of good practice requires selection of a suitable option followed by appropriate design and implementation. This section provides guidance on design and implementation considerations.

Many of the considerations highlighted in this Guide need to be taken into account in the early stages of the planning and design process. For larger scale projects, this includes consideration of the whole route as well as the crossing structures themselves.

5.1 Location

Selecting an appropriate location, or taking into account the characteristics of the location, is the first step in reducing:

- the impact of the river crossing on the environment;
- the risk of damage to the crossing structure itself and future maintenance costs.

Channel migration / active zones

Rivers are not static. The dynamic physical processes of rivers – including the movement of water, sediment and wood – cause the river channel in some areas to move around or 'migrate' over time. This is a natural process and allows the river to release energy and distribute its sediment load.

The area within which a river channel is likely to move over a period of time is referred to as the channel migration zone. Failing to recognise this process can damage natural river processes and habitat and lead to damage to, or loss of, structures (Figure 12).

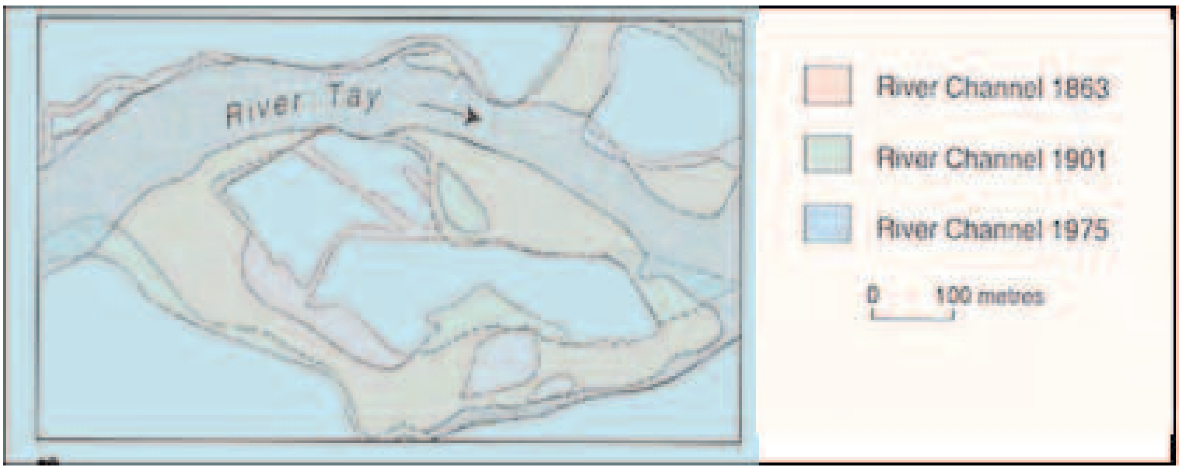


Figure 12 Route of the River Tay, 1863–1975 (diagram courtesy of Dr David Gilvear, University of Stirling)

Avoid crossings over active areas, particularly on the outside of meander bends, because there is a high risk that the structure will be damaged or fail due to river migration or localised scour. Extensive maintenance works to stabilise the structure and river may then be required, which will increase costs.

Active channels can be found in a variety of settings. The following information will help you determine if a site has the potential to be active. Active channels are often found in transitional type rivers (see Appendix 1 to help determine if your river is a transitional type).

Indications that a river is active include:

- evident signs of erosion especially on outside of meander bends (Figure 13);
- depositions of unvegetated larger sediment sizes – gravel, pebble, cobble (Figure 14);
- steeper river gradients (0.1–3%).

Figure 13 Erosion on the outside of a meander bend

Figure 14 Unvegetated sediment deposition

Locate crossings on straight/stable sections of the river (Figure 15).

Figure 15 Examples of a straight, stable section of a river

It is difficult to predict how a river may migrate and there are many different ways in which a river may move. If there are concerns that the river to be crossed has the potential to migrate significantly over time, ask a suitably qualified geomorphologist to assess the site to estimate rates of migration and suggest mitigation measures.

For information on appropriate assessment techniques see:

- Regulation of Engineering Activities, RM-02, SEPA, 2006
- Review of River Geomorphology Impact Assessment Tools and Post Project Monitoring Guidance for Engineering Activities, WAT-SG-30, SEPA, 2005

Depositional areas

As well as water, rivers also carry a significant amount of sediment. This is stored and transported throughout the river creating habitats for many species such as:

- spawning gravels for fish;
- gravel bars and islands essential for many invertebrates.

Avoid crossing rivers at depositional areas as there is a risk that sediment will accumulate at the structure and thus reduce flow capacity. Any modifications to the channel could lead to the bed level increasing (aggradation) and reducing flow capacity. This could lead to a need for regular dredging, which increases maintenance costs and affects the ecology of the river.

An appropriate assessment will provide an insight into the potential for sediment movement within a reach, i.e. it will help identify if the reach contains too much (or not enough) sediment, and therefore whether there will be problems with deposition (or erosion).

Depositional areas are widely found in lowland and transitional types of rivers (see Appendix 1 to determine your river type). Active depositional areas are the result of various factors including valley gradient, geology and sediment supply.

In many rivers, deposition occurs where there is a reduction in valley gradient. Where the slope is lower, the river has less energy and sediment is deposited. This may occur where relatively steep tributaries with high sediment loads join the main river to form alluvial fans (large areas of deposition at river confluences). Deposition also occurs downstream of areas that supply large volumes of sediment. Avoid these locations if possible.

Characteristics of depositional areas include:

- sediment accumulations in rivers such as gravel bars and islands present (Figure 16);
- smaller sediment sizes of gravel/sand/silt;
- low river gradients or where the gradient changes quickly from high to low.

Figure 16 Examples of gravel bars – indicators of a depositional area

Locate crossings in areas where sediment is not accumulating in rivers.

If it is necessary to cross a river in a depositional zone, ask a suitably qualified geomorphologist to assess the site. Sources of information on appropriate assessment techniques are given in the box above.

Make the crossing as wide as possible to maximise the space for the river to adjust.

5.2 Alignment

Making the crossing perpendicular to the river ensures that the crossing is as short as possible – reducing impact and, in some instances, cost. It also reduces the risk of localised scour at the structure.

To achieve this:

- avoid realignment;
- consider modifying the crossing point and alignment (Figure 17).

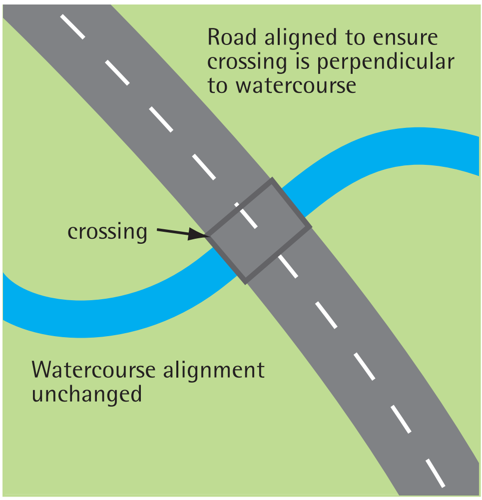


Figure 17 Crossing perpendicular to river, with no change to the river alignment

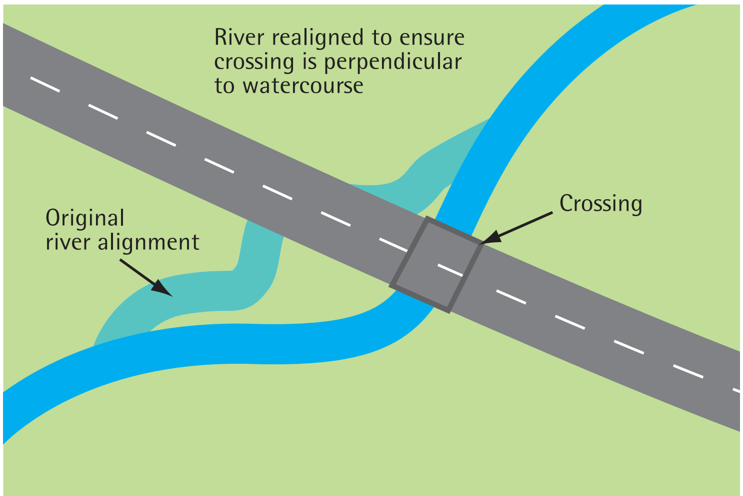


Figure 18 River realigned to ensure crossing is perpendicular

If river realignment is unavoidable, give careful consideration to the design of the new channel (Figure 18). Assess the channel dimensions to identify whether the existing channel is itself an appropriate size and shape (e.g. it may have been historically dredged and over-deepened), although under many circumstances it will be best to maintain the dimensions of the existing channel.

Design the new channel to replicate as closely as possible the original channel (if it is itself appropriate) or a more natural form (if the original channel was modified). This process will include:

- assessing the bank and bed materials of the new channel (which may be significantly different to those of the original);
- identifying appropriate channel dimensions (including variability in width and depth);
- identifying the features that should be found there (e.g. pool-riffle sequence, small-scale erosion on the outside of meander bends, point bars, appropriate bank-side vegetation).

In addition, a reduction in the overall length of the river (i.e. the river is straightened) will increase the slope and could lead to bed incision – leading to structure being threatened.

There are many possible scenarios and it is essential to understand how the river may respond.

If realignment of the watercourse is necessary, ask a suitably qualified geomorphologist to undertake appropriate modelling and assessment of the site to ensure the river will have a similar suite of processes to the original. Sources of information on appropriate assessment techniques are given in Section 5.1.

5.3 Crossing a floodplain

Floodplains are also very important functional parts of a river as they provide:

- storage for water;
- a sink for sediment and nutrients (under natural conditions);
- important food sources and nursery areas for fish and other aquatic organisms.

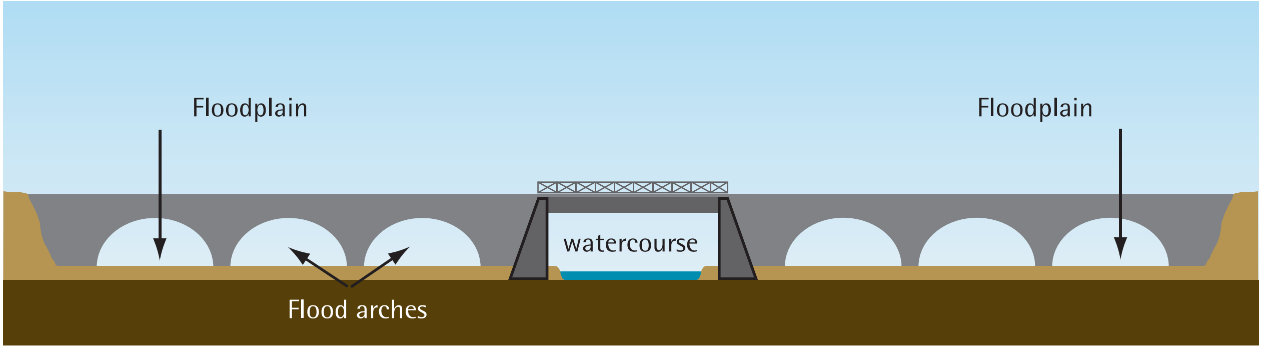
Crossing structures and their associated infrastructure such as embankments can:

- create a barrier to the passage of flood flows along the floodplain causing increased flooding upstream;
- significantly reduce floodplain storage (with implications on flooding downstream);
- disconnect floodplain habitat and alter the hydrologic regime of floodplain habitat;
- radically alter channel hydraulics as flood flow is forced through the relatively narrow opening at the crossing point rather than flowing freely along the much wider floodplain. This in turn can significantly alter channel processes such as bank and bed erosion and deposition of sediment.

Ideally, viaducts (a road deck spanning between piers) should be used to cross floodplains rather than embankments (Figure 19). This option greatly reduces the impact on the floodplain, but can have cost implications.

Where embankments are unavoidable, 'normally dry culverts' in embankments are sometimes used to connect the floodplain. There are, however, serious hydraulic design issues to overcome, which often result in structures that are very 'hard' in order to prevent scour around the culverts and embankment failure during high flow events.

Figure 19 Viaduct across a floodplain



5.4 Design of structure

Once the best type of crossing has been selected, the next step is to implement the design details necessary to minimise the environmental impact of the structure.

Good practice design sheets in this section provide information on each type of structure. Many different designs will fall into the generic types of crossing identified by this Guide and the diagrams shown below are intended merely as examples.

Box 5 Hydraulic capacity

The hydraulic capacity of crossing structures will vary depending on the location of the crossing and the purpose the crossing infrastructure serves.

Where crossing structures require planning permission they should conform to Scottish Planning Policy (SPP) 7 Planning and Flooding. This states that no new development should increase the probability of flooding elsewhere. SPP7 is available from the Scottish Executive website at www.scotland.gov.uk/Topics/Planning/PolicyLegislation/Policy

Further information on flooding and the different responsibilities in relation to flooding can be found on the SEPA website at www.sepa.org.uk/flooding

Where a crossing is in an urban area or is close to other development, the local authority should be contacted in relation to required hydraulic capacity.

These considerations must be taken into account in the early stages of the planning and design process.

Good practice design: I Single span bridges and arch culverts

The following principles should be followed for all types of single span structure.

Set back abutments from the river channel and bank to allow the continuation of the riparian corridor underneath the bridge. This helps to minimise/prevent the need for bank reinforcement (and allows for mammal passage) (Figures 20 and 21).

Bury foundations deep enough to minimise/prevent the need for bed or bank reinforcement or bridge weirs. This maintains the natural bed sediment and bed levels, protecting habitat and allowing fish passage (Figure 20).

The depth below the bed that the foundations should be buried will depend on site-specific conditions. Use appropriate methods to calculate this depth, taking into account scour during high flows.

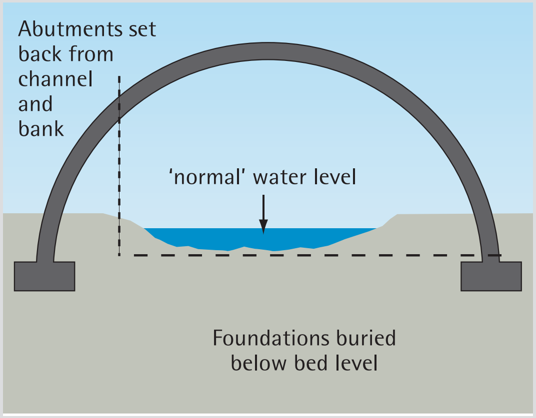


Figure 20 Pre-cast arch culvert showing set back abutments and deep foundations

Figure 21 Bridge showing set back abutments (photo courtesy of Highland Council)

Minimise the potential for localised bed and bank erosion (scour) around the crossing structure through careful consideration of the location and design as discussed above. Consider requirements for erosion protection only if the risk of erosion cannot reasonably be eliminated.

Where bank protection is necessary, 'softer' measures should be considered in lower energy, lowland environments (see Appendix 1). 'Harder' techniques may be required if the crossing is located in a higher energy upland or transitional environment (see Appendix 1) where there is high risk of erosion. Good Practice Guide: Bank Erosion Management SG-23 (www.sepa.org.uk/wfd) gives further information on bank protection.

Where a crossing affects a longer length of river, consider light penetration and soil moisture deficit. Lack of light and moisture can prevent the establishment of vegetation and could lead to bare banks under the crossing. This can weaken the banks, resulting in erosion under the crossing and potential exposure of the structure foundations.

Useful references

- River Crossings and Migratory Fish: Design Guidance, Scottish Executive, 2000. Available from: www.scotland.gov.uk/consultations/transport/rcmf-00.asp
- Good Practice Guide: Bank Erosion Management, WAT-SG-23, SEPA, 2007. Available from: www.sepa.org.uk/wfd/guidance/engineering
- Design Manual for Roads and Bridges, Volume 10 Section 4 Nature Conservation. Available from: www.standardsforhighways.co.uk/dmrb/index.htm

Good practice design: II Bridges with in-stream supports

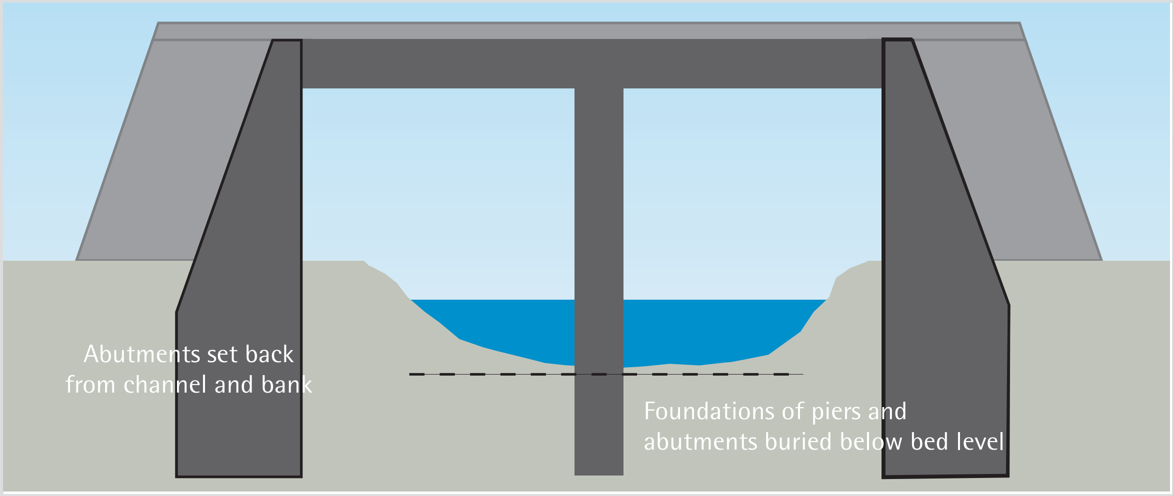
The following principles should be followed for all types of bridges with in-stream supports.

Set back abutments from the river channel and bank to allow the continuation of the riparian corridor underneath the bridge. This helps to minimise/prevent the need for bank reinforcement (and allows for mammal passage) (Figure 22).

Bury foundations deep enough to minimise/prevent the need for bed or bank reinforcement or bridge weirs. This maintains the natural bed sediment and bed levels, protecting habitat and allowing fish passage (Figure 22).

The depth below the bed that the foundations should be buried will depend on site-specific conditions. Use appropriate methods to calculating this depth, taking into account bed levels during high flows.

Figure 22 Bridge with piers showing set back abutments and deep foundations



Piers increase the risk of large woody debris (LWD) becoming trapped. This can increase localised flooding and can also put the structure at risk of failing. Design piers to facilitate the passage of LWD by streamlining the upstream facing side.

Minimise the potential for localised bed and bank erosion (scour) around the crossing structure through careful consideration of the location and design as discussed above. Only if the risk of erosion cannot reasonably be eliminated should requirements for erosion protection be considered.

Where bank protection is necessary, 'softer' measures should be considered in lower energy, lowland environments (see Appendix 1). 'Harder' techniques may be required if the crossing is located in a higher energy upland environment (see Appendix 1) where there is high risk of erosion. Good Practice Guide: Bank Erosion Management SG-23 (www.sepa.org.uk/wfd) gives further information on bank protection.

Where a crossing affects a longer length of river, consider light penetration and soil moisture deficit. Lack of light and moisture can prevent the establishment of vegetation and could lead to bare banks under the crossing. This can weaken the banks, resulting in erosion under the crossing and potential exposure of the structure foundations.

For further information see:

- River Crossings and Migratory Fish: Design Guidance, Scottish Executive, 2000. Available from: www.scotland.gov.uk/consultations/transport/rcmf-00.asp
- Good Practice Guide: Bank Erosion Management, WAT-SG-23, SEPA, 2007. Available from: www.sepa.org.uk/wfd/guidance/engineering
- Design Manual for Roads and Bridges, Volume 10 Section 4 Nature Conservation. Available from: www.standardsforhighways.co.uk/dmrb/index.htm

Good practice design: III Closed culverts

If not designed properly, closed culverts have a high risk of posing a barrier to fish passage. Following the advice given below will reduce this risk.

Design culverts so that they are passable under the normal conditions in which fish would be expected to pass. They should be passable to all fish species – even if some fish species are not present – because the culvert could affect future measures to improve passage in the catchment.

Successful fish passage requires the following factors to be acceptable:

- No physical obstructions to passage, e.g. avoid 'perching' this is where there is a drop or cascade at the culvert outlet (downstream end) due to erosion of the river downstream
- Adequate water depth
- Appropriate water velocity
- Adequate resting places above and below the structure.

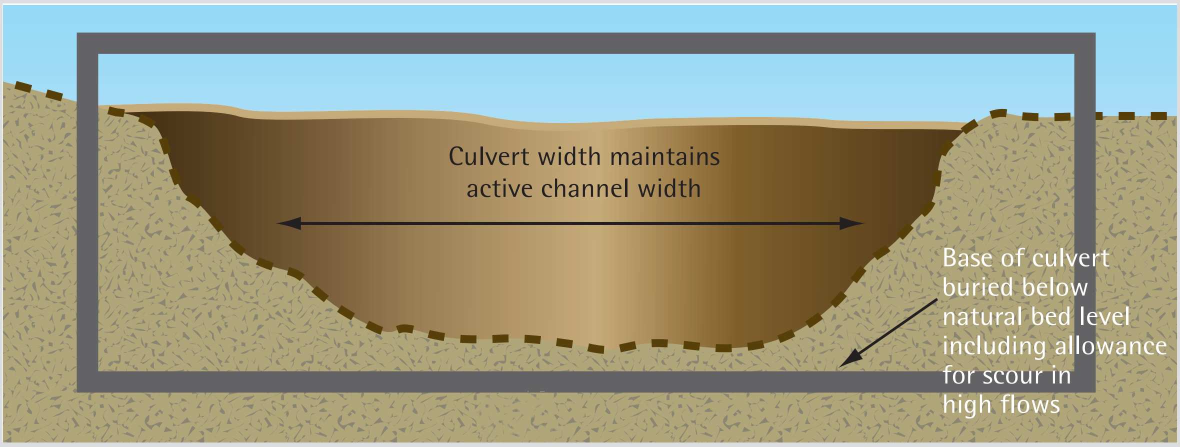
Specific requirements will depend on the species of fish. River Crossings and Migratory Fish: Design Guidance (www.scotland.gov.uk/consultations/transport/rcmf-00.asp) gives more information.

Following the guidance below will help ensure these factors are acceptable for fish passage.

Maintain natural bed level

Bury the culvert base below the natural bed level to allow this to be maintained (Figure 23). It should be buried sufficiently deep to allow a natural bed to be maintained during high flows. The culvert should be sized to carry both flood flows and bed material).

Figure 23 Culvert maintaining channel width and bed level



Also maintain the natural slope of the river. Burying the culvert base and maintaining the natural bed level will help retain the natural slope.

Maintain natural channel width

The culvert should maintain the natural channel width (Figure 23), as culverts that are too wide or too narrow can lead to an increased risk of erosion.

Ensure natural low flow depths are maintained through the culvert, if necessary by the use of a two-stage channel.

Use single barrel culverts as fish prefer larger barrel sizes and can be discouraged from entering smaller size diameters.

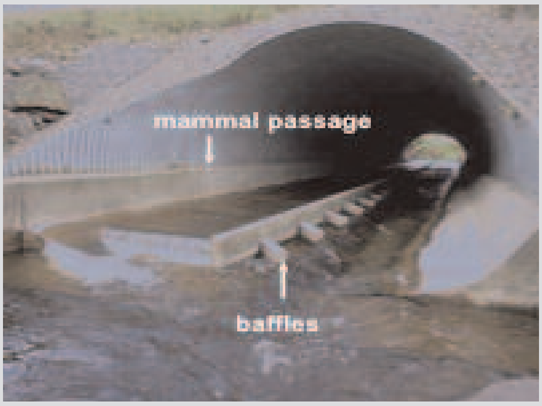
Other mitigation measures

The culvert soffit (top) should be higher that the natural bank height.

Check water velocities and depths in the culvert under different flow conditions (under which fish would be expected to seek passage) to ensure they are adequate for fish passage.

For longer culverts or culverts where depth/velocity is an issue, provide baffles or other mitigation measures (Figure 24).

Figure 24 Culvert with baffles and mammal passage



Where culverts are required, identify practical enhancement measures along the affected reach or elsewhere on-site in order to off-set some of the impacts caused by the culvert. For example:

- re-establish riparian vegetation where it has been lost;
- remove existing unnecessary man-made structures.

If trash screens are required, it is also necessary to take bar spacing and fish passage into account. Ensure at least 230 mm spacing between each bar.

Mammal passage

Also consider mammal passage (Figure 24). Mammals such as otter and water voles should be able to pass through the culvert on a dry area under high flow conditions.

Scour protection

Minimise the potential for localised erosion (scour) around the culvert through careful consideration of the location and design as discussed above. Having done this, consider requirements for erosion protection.

If bed reinforcement is deemed necessary, lay this below the natural river bed level so that the natural bed level can be maintained.

Where bank protection is necessary, consider 'softer' measures in lower energy, lowland environments (see Appendix 1). 'Harder' techniques may be required if the culvert is located in a higher energy upland or transitional environment (see Appendix 1) where there is high risk of erosion. Good Practice Guide: Bank Erosion Management SG-23 (www.sepa.org.uk/wfd) gives further information on bank protection.

For further information see:

- River Crossings and Migratory Fish: Design Guidance, Scottish Executive, 2000. Available from: www.scotland.gov.uk/consultations/transport/rcmf-00.asp
- Culvert Design Manual, CIRIA, 1997.
- Good Practice Guide: Bank Erosion Management, WAT-SG-23, SEPA, 2007. Available from: www.sepa.org.uk/wfd/guidance/engineering
- Design Manual for Roads and Bridges, Volume 10 Section 4 Nature Conservation. Available from: www.standardsforhighways.co.uk/dmrb/index.htm

Good practice design: IV Fords

Fords have the potential to cause pollution through the release of fine sediments. Where fords are constructed they can often lead to the widening of the river and lowering of water depth (Figure 25). Therefore it is important to ensure that an adequate water depth is maintained to allow fish passage.

Locate fords at 'natural crossing points', i.e. where the river is naturally wide and shallow (riffles). Do not move bed material from one location to another to form a shallow area for crossing.

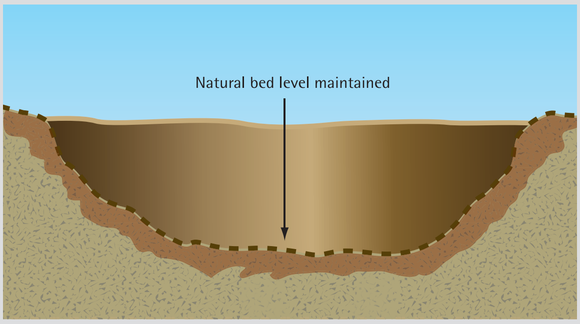
Bed rock areas (Figure 26) may also be suitable as this will limit erosion, reducing fine sediments that could be mobilised and will have minimal impact on the bed and banks.

Figure 25 Riffle section of a river showing a shallow crossing point

Figure 26 Bed rock section of a river showing a 'natural' 'natural' crossing point where erosion may be minimised

Figure 27 Ford crossing showing over-widened river and lower water depth

Figure 28 Ford crossing bed and bank reinforcement



Where a ford is located on a river where the bed/banks are not stable, consider bank reinforcement in order to stop excessive erosion and widening of the river (Figure 27), which may lead to decreased water depths.

Use non-grouted stone rip rap for bank protection.

Do not raise fords above bed level. Construct any reinforcement such that low flow depths are not changed to ensure fish passage is not affected (Figure 28).

For further information see:

- Good Practice Guide: Bank Erosion Management, WAT-SG-23, SEPA, 2007. Available from: www.sepa.org.uk/wfd/guidance/engineering

Good practice design: V Pipelines and cables buried below the bed

Where pipelines or cables are not carried over a watercourse by a single span structure or span structure with in-stream supports, bury them below the natural bed level of the watercourse.

Maintain natural bed level

Bury the pipeline or cable below the natural bed level to allow the natural bed level to be maintained (Figure 29). Bury it sufficiently deep so that it is not exposed during high flows.

Do not lay the pipeline or cable in the channel or where it would obstruct high flows (Figures 30 and 31). This increases the risk of:

- the pipeline or cable being damaged;
- erosion of the bed and banks of the river;
- local flood risk.

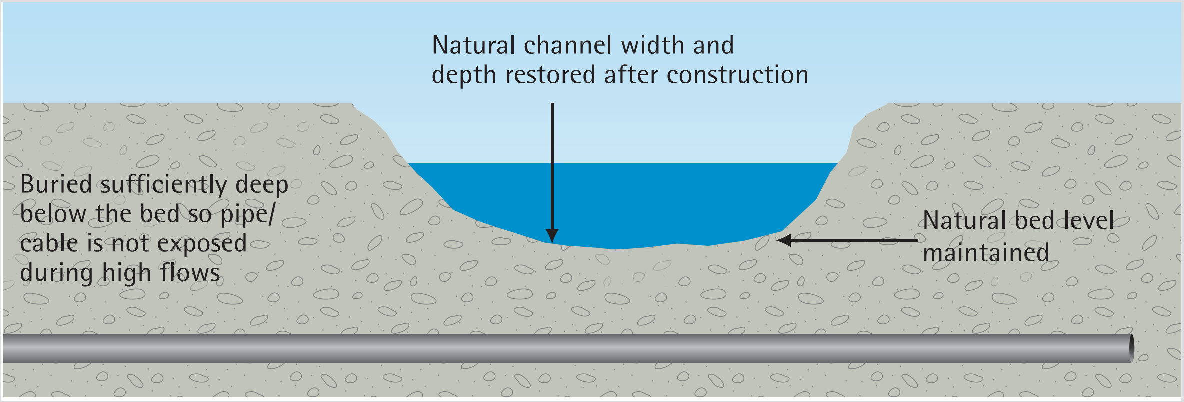


Figure 29 Pipeline/cable buried

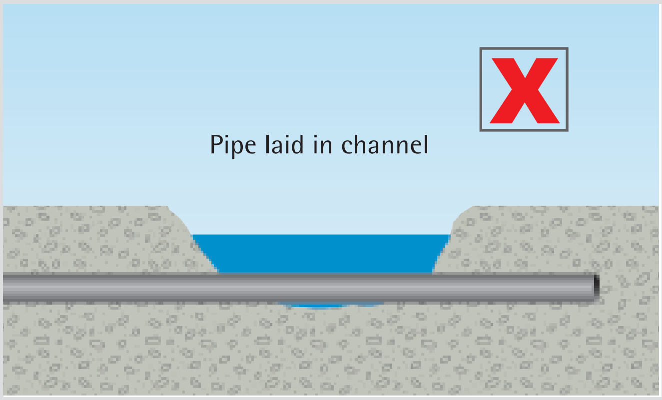


Figure 30 Pipeline/cable laid in channel

Figure 31 Pipeline/cable laid in channel at risk during high flows

It is also important to give careful consideration to the technique used to bury the pipe below the bed of the river. Boring underneath the river has the least impact.

Where the area to be crossed is kept dry by isolation methods (over-pumping, etc.) and a trench is dug, restore the natural width and depth of the river and re-establish the banks with native riparian vegetation.

Do not use river sediments to form temporary bunds to isolate working areas.

For further information see:

- Good Practice Guide: Bank Erosion Management, WAT-SG-23, SEPA, 2007. Available from: wwwww.sepa.org.uk/wfd/guidance/engineering

5.5 Construction phase

An important part of good practice is to ensure that all practical steps are taken during the construction phase to:

- minimise damage to habitats;
- reduce the risk of pollution.

Separate guidance is available from SEPA on construction methods (see the box below for details).

During the construction phase, store the bed material and keep it clean.

When construction is complete:

- use the stored bed material to restore the bed (but not if the natural bed material is silt/sand);
- restore any affected banks by re-establishing native riparian vegetation.

For further information see:

- Good Practice Guide: Construction Methods, WAT-SG-29, SEPA, 2007. Available from: www.sepa.org.uk/wfd/guidance/engineering
- Control of Water Pollution from Linear Construction Projects, CIRIA, 2006.

6 Sources of further information

6.1 Publications

Culvert Design Manual, CIRIA, 1997.

Manual on Scour at Bridges and Other Hydraulic Structures, CIRIA, 2002.

Control of Water Pollution from Linear Construction Projects. Technical guidance, CIRIA, 2006.

Design Manual for Roads and Bridges, Highways Agency [online]. Available from: www.standardsforhighways.co.uk/dmrb/index.htm [Accessed 15 May 2007].

Nature Conservation and Roads: Advice in Relation to Otters, Highways Agency, 2001. Available from: www.standardsforhighways.co.uk/dmrb/vol10/section4/ha8199.pdf [Accessed 15 May 2008].

Manual of River Restoration Techniques, River Restoration Centre, 1999. Available from: www.therrc.co.uk/manual.php [Accessed 15 May 2007].

River Crossings and Migratory Fish: Design Guidance, Scottish Executive, 2000. Available from: www.scotland.gov.uk/consultations/transport/rcmf-00.asp [Accessed 15 May 2007].

Good Practice Guide: Bank Erosion Management, WAT-SG-23, SEPA, 2007. See www.sepa.org.uk/wfd/guidance/engineering

Good Practice Guide: Construction Methods, WAT-SG-29, SEPA, 2007. See www.sepa.org.uk/wfd/guidance/engineering

6.2 Websites

Construction Industry Research and Information Association (CIRIA): www.ciria.org

Environment Agency: www.environment-agency.gov.uk

Highways Agency: www.highways.gov.uk

River Restoration Centre: www.therrc.co.uk

Scottish Environment Protection Agency (SEPA): www.sepa.org.uk

7 Glossary

Abutment	Support of a bridge at the banks of a river.
Active channel width	The width of a river is defined as the portion of the river channel characterised by open water and, if present, bare (unvegetated) river sediments.
Aggradation	Rising of the river bed due to depositional processes.
Alluvial fans	Large areas of sediment deposition at river confluences, often cone shaped.
Baffles	Structure placed inside a culvert to deflect the flow of water.
Bed armour	Top layer of river bed sediment that has been compacted and held together by finer sediments.
Catchment	Total area of land that drains into any given river.
Channel migration zone (CMZ)	Movement of river across the floodplain.
Deck	Component of bridge forming surface of road.
Embankment	Earth, gravel or similar material raised above the channel or floodplain to form a pond bank, stop flood waters from leaving the channel, or retain flood waters within a specified area.
Incision	Deepening of the channel due to erosion of the bed.
Invert	The lowest internal point of any cross section in a culvert.
Large woody debris (LWD)	Accumulations of trees and branches that have fallen naturally into the river system.
Meander	Bend in the river formed by natural river processes (erosion and deposition).
Perched culvert	Development of a fall or drop at a culvert outlet due to erosion of river.
Pier	In-channel supports of a multi-span bridge.
Riffle	Fast-flowing shallow water with distinctly broken or disturbed surface over gravel/pebble or cobble substrate.
Riparian	The area of land adjoining a river channel (including the river bank) capable of exerting physical, hydrological and ecological impacts on the aquatic ecosystem (e.g. shading, leaf litter input). In this standard, the term 'riparian zone' does not include the wider floodplain.
Rip rap	Angular stone placed to protect eroding banks.
Scour	Erosion of river banks or bed – often due to the presence of a structure.
Soffit	Underside of bridge deck or highest internal point of a culvert.
Viaducts	Road spanning a floodplain between raised supports.

Appendix 1 River typologies

River typologies have become a valuable tool for geomorphologists for identifying and interpreting river characteristics.

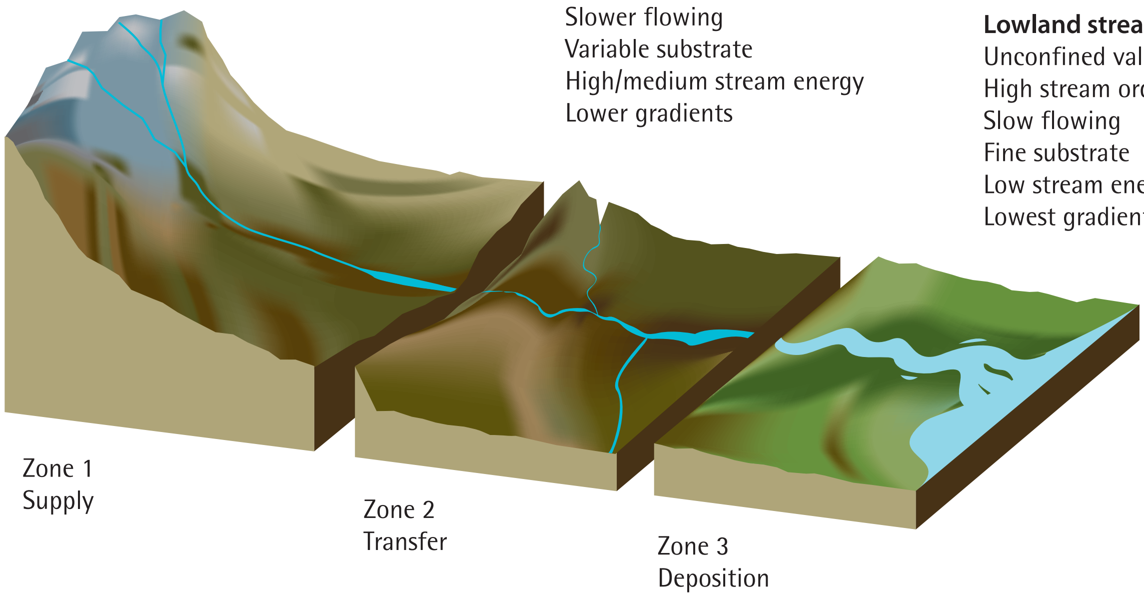
Different rivers (or sections of channel within a river) display distinct characteristics that can influence the considerations that need to be taken into account when installing a river crossing.

For the purposes of this guidance, rivers and streams have been divided into three categories as shown in Figure A1 and outlined below:

- upland;
- transitional (piedmont);
- lowland.

The different types of environment can be found throughout the catchment and Figure A1 gives a generalised overview of the different areas with a catchment.

Figure A1 Generalised diagram of different types of environment within the river catchment



River slope

One of the most important factors influencing river type is slope. If you do not know the slope, it can be determined by looking at the contour lines on an Ordinance Survey map.

Look at how many metres a river falls over a kilometre (e.g. a river falls 5 metres over 1 kilometre). To convert this to a percentage, divide the number of metres fallen over the distance and multiply by 100:

$$\text{Slope (\%)} = \frac{\text{Number of metres fallen}}{\text{Distance}} \times 100$$

In the example above, the slope percentage is calculated as follows:

$$\text{Slope} = \frac{5}{1000} \times 100 = 0.5\%$$

River categories

Upland

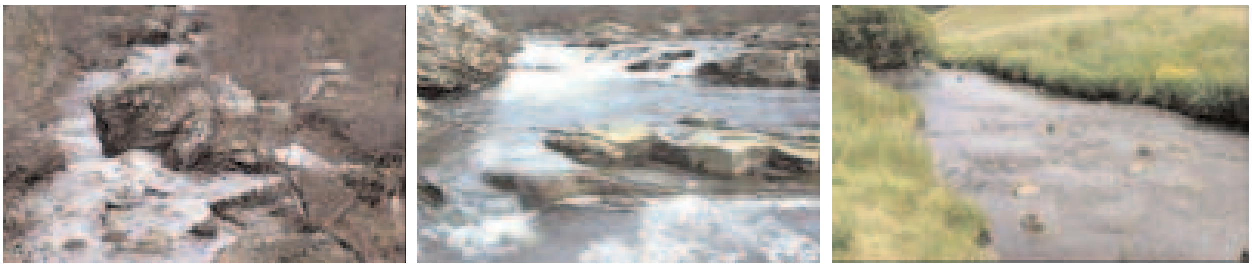
Upland streams (Figure A2) are generally fast, shallow streams. They typically have a slope greater than 1%. They are formed in steep high energy environments capable of mobilising and carrying cobbles or boulders during flood events.

The sides of the channel tend to be:

- steep with little, if any, floodplain development;
- relatively stable, i.e. they do not tend to migrate.

For the purposes of this guidance, straight channels with coarse (gravel, cobble substrate) and erratically placed larger boulders should also be considered as upland type channels.

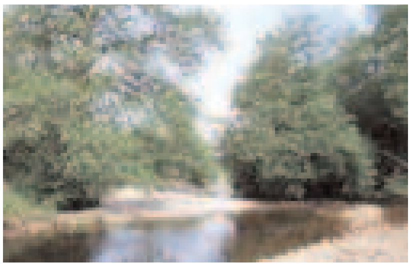
Figure A2 Examples of upland rivers



Transitional (piedmont)

The transfer zone receives much of the eroded material, although additional sediment enters through channel migration and associated bank erosion. Transitional rivers (Figure A3) generally have a slope from 0.1 to 3%. Such rivers are typically characterised by wide floodplains and meandering channel patterns. Riffle/pool sequences, braided systems and meandering are common morphological features of transitional and lowland rivers.

Figure A3 Examples of transitional (piedmont) rivers



Lowland

Lowland rivers (Figure A4) are typically low energy environments where particle sizes are generally a lot smaller than those in upland and piedmont streams (e.g. pebble and sand). Lowland rivers generally have a slope less than 0.1%.

The morphology of these river systems therefore tends to differ quite dramatically from upland streams. Meandering is a common morphological feature of lowland rivers.

Also included in this category are man-made or modified (e.g. straightened) rivers.

Figure A4 Examples of lowland rivers

Appendix 2 Feedback form – Good Practice Guide WAT-SG-25

SEPA is committed to ensuring our Good Practice Guides are useful and relevant to those carrying out engineering activities in Scotland's rivers and lochs.

We welcome any comments you have on this Good Practice Guide so that we can improve future editions.

After completing the short questionnaire, please detach it and post to the address below or fax it to 01355 574 688.

SEPA
WFD Administration Officer
5 Redwood Crescent
Peel Park
East Kilbride
G74 5PP

The aim of this Good Practice Guide is to set out the environmental aspects that should be considered when undertaking engineering works and to help applicants choose sustainable engineering solutions that reduce environmental impacts. This will also help them obtain an authorisation for works under the Water Environment (Controlled Activities) (Scotland) Regulations 2005.

1. Which of the following do you think describes how well the Guide meets these aims?

Excellent	☐	Good	☐	Average	☐	Poor	☐

2. How relevant was the content of the Guide to your activity?

Very relevant	☐	Sometimes relevant	☐	Not relevant	☐

3. What elements of the guidance did you find most useful?

4. What elements of the guidance did you find least useful?

5. Did you find the Guide clear and easy to follow?

Yes	☐	Sometimes	☐	No	☐

6. If there were areas that could be clearer, please let us know in the box below

7. Were there issues you felt should have been covered, omitted or dealt with differently in the Guide?

8. Please use the box below for other comments or suggestions on the Guide (continue on a new sheet if required).