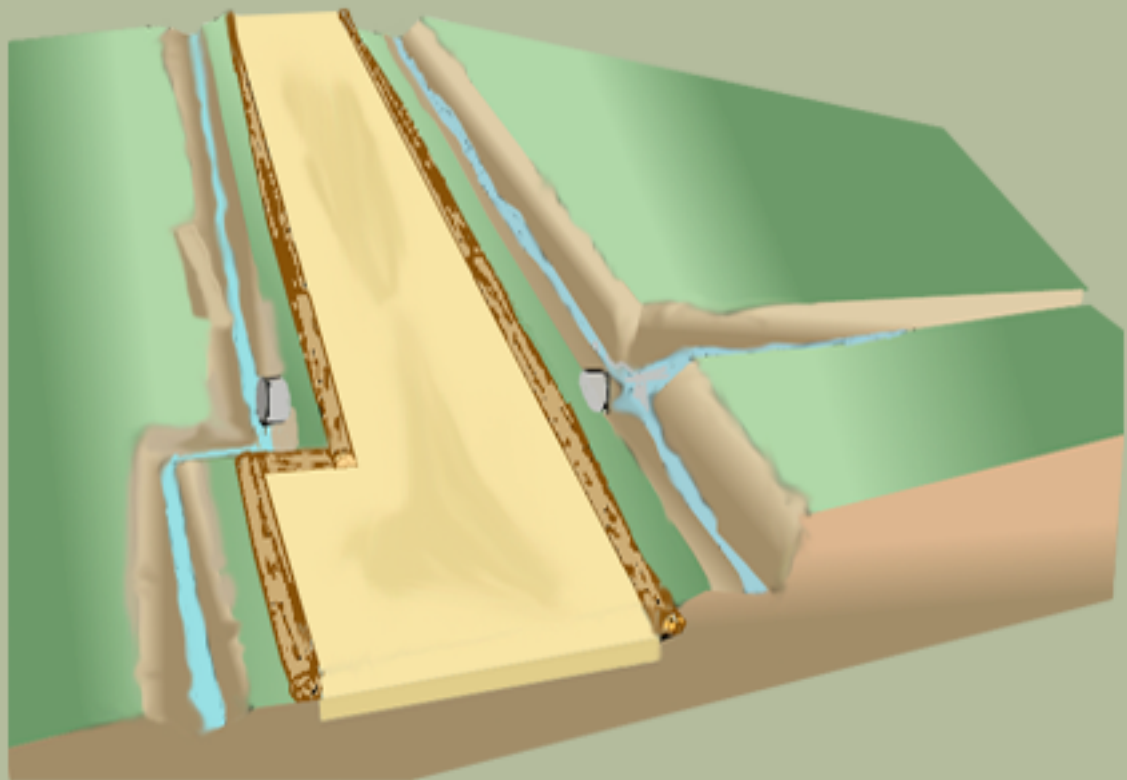


# Design and Maintenance of Culverts



Guide for designers  
and managers



David Croft

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# Design & Maintenance of Culverts

## Scope

Culverts are one of the most important features of a path network. If their structure and placement is not properly designed and maintained at the beginning managers can look forward to major works in the future.

Three methods are recommended for crossing a stream: bridges, pipe culverts, and fords. Water bars, broad-based dips, and open top and pole culverts should never be used to cross streams especially where disabled people are probable path users. These methods are used to improve drainage but can be a barrier and hazard to some path users.

This guide introduces the design and maintenance of culverts and their use in drainage and erosion control.

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# Design & Maintenance of Culverts

## 1 Design & Construction

### 1.1 Typical materials and sizes (mm)

Materials can be galvanised corrugated steel, reinforced concrete, or corrugated polyethylene pipe. the polyethylene pipe double wall (smooth interior) is preferred, standard steel pipe (potential corrosion problems) use of perforated pipe is encouraged.

- Concrete – 300, 450, 600, 900, 1100, 1800mm.
- Corrugated Steel ('Armco') – 300mm – 10m. (preferably galvanised to reduce corrosion)
- PVC single wall – 100, 150, 225, 300mm.
- PVC Twinwall – 225, 300, 450, 600, 900, 1100mm.

Care should be taken to select diameters which will not allow children or dogs to enter and become trapped. It is suggested that diameters between 400 and 900 mm have guard gratings fitted. (see notes on fish migration)

### 1.2 Selection of Culvert Diameter

Visit the site in wet weather with very heavy rain and see what flows and diameters are typical in the area. Speak to local land owners and find what they construct. (note: the same basis is used for square and rectangular culverts)

Look at the location where you are going to install the culvert and assess the flows e.g. the average cross-section of the ditch x the water depth. The diameter of your culvert pipe(s) should be capable of carrying 50-100% greater flow than the flows you have witnessed. Typically a culvert should never be expected to be more than  $\frac{2}{3}$ <sup>rd</sup> full in the worst weather.

For deep slow moving water the diameter should be at least 200% of the measured channel and water depth as these are typically area collection streams.

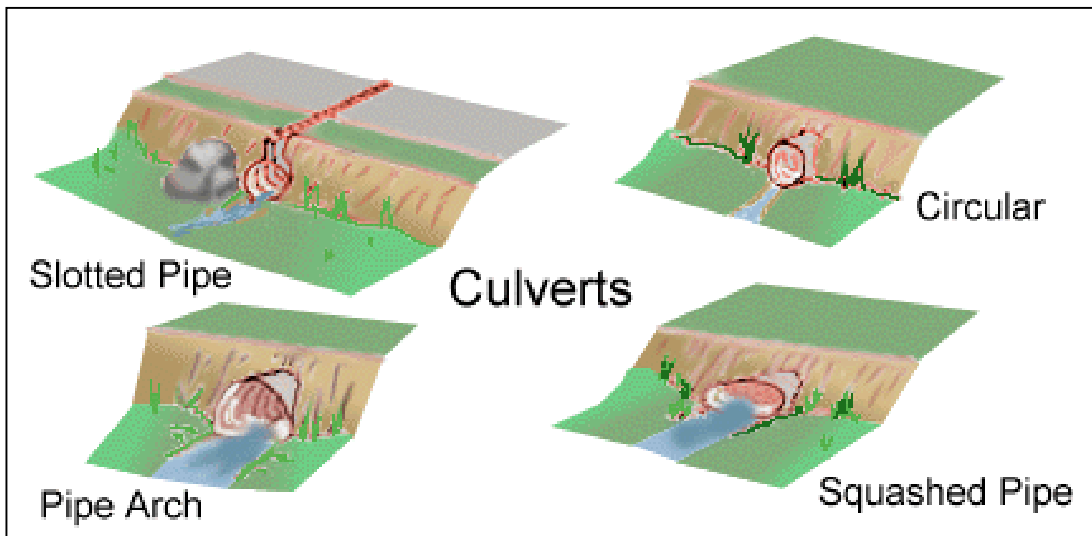
For land/path ditch system culverts use several 150mm diameter water pipes set at regular intervals of 10 to 20 metres depending on amount of water flowing into ditches. This prevents build up of water, reduces flow through any one place and compensates for any blocked cross-culverts. For road culverts 450+ mm diameters at 15 metre intervals are more probable.



If one large pipe culvert would create too much of a vertical break in the path/road alignment, two smaller culverts should be considered as an effective alternative. Compaction is even more critical with dual installations. Ensure that the culverts are placed with at least 1.5 times the width of the excavator bucket apart, to assist in the compaction efforts between the pipes and around the low side (haunches) of the culverts. To ensure fish passage consider placing one pipe at a lower elevation for regular/low flows, and a higher pipe for peak flows.

### 1.2.1 Common Types

Although the standard corrugated-round or round pipe culvert is the type most commonly used, it is the least desirable for fish passage. The width constriction from stream channel to culvert is usually severe in round pipes, and the gradient of the pipe should be less than 2 percent to keep water velocities within an acceptable range for fish passage. This type of culvert is also the most likely to be installed with its outlet end elevated above the tailwater level, producing an outfall barrier. Elevated outfalls must be avoided or mitigated. See Outfall below.



The pipe-arch culvert is less desirable than the structural plate-arch, but can usually be installed to allow fish passage. Fabricated in smaller sizes, the pipe-arch culvert can be used in smaller, lower fills where structural steel arches would not fit. Wherever a pipe arch is used, the gradient must be kept below 1 percent to minimise water velocities. During periods of low flow, the water in this type of culvert can be spread so thinly across the bottom that fish passage is impossible. Baffles may be needed to increase the flow depth through the pipe arch.

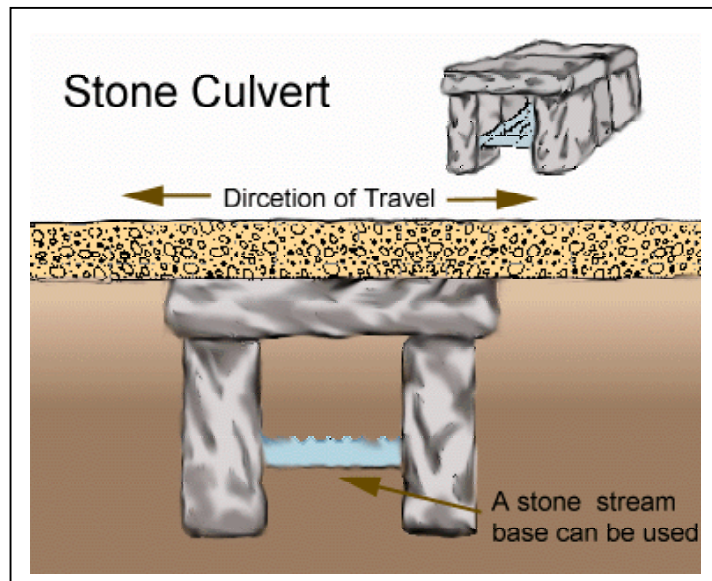
The structural plate-arch set in concrete footing is the most desirable culvert type for fish passage because the natural



streambed is left mostly unchanged. Little narrowing of the flow occurs at either end of the culvert, and there is no significant change in water velocity. Where concrete footings are not practical, split, wide-flanged, buried steel footings have been used successfully. Many fisheries biologists believe the structural plate-arch is the only acceptable culvert type where fish passage is required.

A stone culvert is built from flat(ish) stones or concrete pavers. These are robust and simple construction for use as small culverts.

These have been used for thousands of years and have long life spans with little maintenance required. Where erosion could be a problem the stream bed can be reinforced by use of flat stones set into the bed. At least 30% of the stone height should be below the stream bed to allow for scouring action.



**Note: Headwater Depth** - The total flow depth from the inlet invert of the culvert to the water surface at the inlet. Culverts may constrict the natural stream flow and cause a rise in the water surface level at the culvert entrance. This may increase water flow rates above those a fish can swim against.

### 1.3 Construction Sequence

Culverts should be installed as the path/road work progresses. The culvert and its related drainage features should be installed in the following order:

- Place debris and slash to be used as a filter system, if needed.
- Construct sediment ponds, if needed.
- Complete downstream work first, such as energy dissipating devices and large rock riprap.
- Route stream around work area until pipe is installed. Use erosion protection fabric to reduce sedimentation.
- Construct pipe inlet structure.
- Install culvert pipe.



The following are additional guidelines for installing culverts in streams:

- Limit construction activity in the water to periods of low or normal flow.
- Minimise use of equipment in streams.
- Use soil stabilisation practices on exposed soil at stream crossings. Seed and mulch and install temporary sediment control structures, such as silt fences made of straw bales or geotextiles immediately after road construction, to minimise erosion into streams
- Maintain these practices until the soil is permanently stabilised.
- Use materials that are clean, non-erodible, and non-toxic.
- To prevent erosion and under-cutting of the inlet end of the culvert, provide a headwall. Sandbags containing some cement mixed with the sand, durable logs, concrete, or hand-placed riprap are suitable
- When replacing damaged culverts which handle the flow adequately, use the same size, shape, and type of pipe. Changing any of these criteria may adversely effect the established stability of the ditch, stream, and/or path/roadway.

Note: where concrete is poured as part of the construction process the water will be contaminated. This contamination should be limited as well as can be achieved. Pouring during the dry season and outside fish and water bird breeding seasons helps limit damage due to contamination.

### 1.3.1 Maintenance

Inspect culverts often, especially in the spring and autumn, and after storm events, checking them for signs of corrosion, joint separation, bottom sag, pipe blockage, piping, fill settling, cavitation of fill (sinkhole), sediment build-up within the culvert, effectiveness of the present inlet/outlet inverts, etc. Check inlet and outlet channels for signs of scour, degradation, aggradation, debris, channel blockage, diversion of flow, bank and other erosion, flooding, etc.

Keep culverts clear and free of debris so water can pass unimpeded at all times. Culvert failure is caused by blockage with debris as often as by the culvert's capacity being exceeded. For this reason, avoid leaving excess amounts of woody debris in stream channels where it can float downstream and lodge in culverts. Therefore, when inspecting culverts it is necessary to inspect up stream and remove fallen branches etc. which could float downstream when water levels rise. All culverts should be checked after major storms and at least twice per year — in spring and autumn.

Practice preventive maintenance to avoid clogging of pipes and other situations which may damage the culvert or diminish its design function. If a culvert is plugged with sediment, flush it from



the outlet end with a high pressure water hose. Take measures to reduce downstream sedimentation and clean debris and sediment from the outlet ditch afterwards.

It should be noted that any culvert which crosses a 'highway' will need to be professionally designed, drawings, material specifications and work procedures for construction and maintenance will have to be submitted to the Highways department of the LA or the Highways Agency. Construction and maintenance of the culvert will have to be carried out under the control of these departments or possibly by contractors appointed by them. Similar conditions may apply to culverts on private land.

## **2 Design**

### **2.1 Support & Cover**

Culvert pipes should be bedded using either the natural soil (stone free to prevent damage to the pipe wall) or by using fine gravel, pea gravel, screened bank gravel or path sub-base material. This bedding should be below the stream bed level.

The sides of the pipe should be packed with found soil or fine gravel. The top should be covered with fine gravel or sub-base materials 50-100% the diameter of the pipe thick. On polythene pipes the bedding should be carried to a height of  $\frac{3}{4}$  of the pipe diameter.

It is recommended that the pipe should be longer than the width of the usable surface (the width of the path plus the extended width for construction/maintenance vehicles). The culvert should extend past the path/verge by 4 times the depth of the culvert. This reduces the chance of collapse when heavy vehicles use the route.

A headwall should be constructed around the inlet and outlet ends of the pipe, to retain fill and conceal the pipe end. This wall can be loose or mortared stone or brick. Loose stones must be tight fitted. Either a long flat stone lintel should be placed above the pipe or close packed stones should form an arch.

The lowest level of this wall should be bedded below the stream bed level and into the banks to prevent erosion. Where walls are greater than 1000 mm consider placing a footing or gravel bed below the wall.

Walls should be 150–450 mm thick dependant on height.



## 2.2 Features

### 2.2.1 Inlets

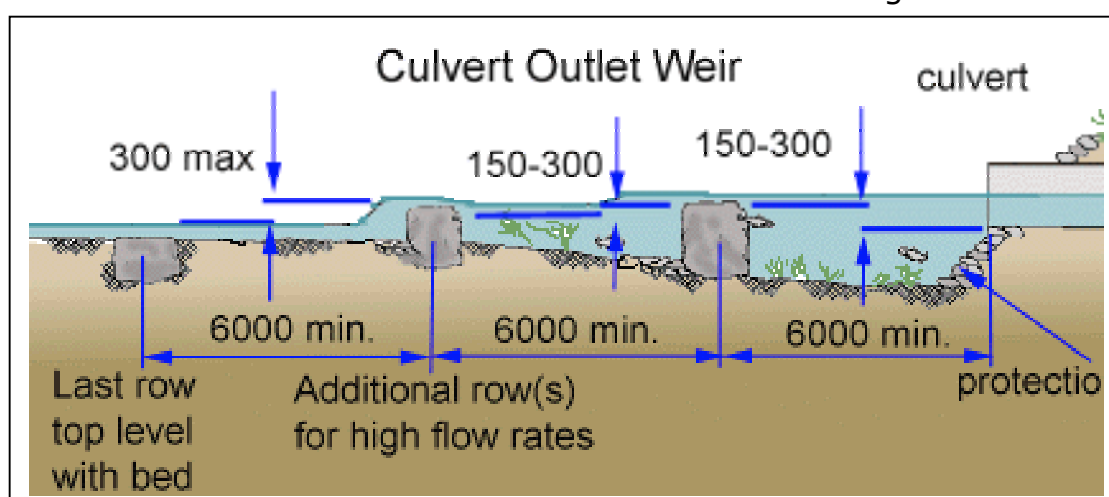
Place an apron of flat stones in the bed of the stream at the entry. Where there are high flow rates a retaining wall or abutment may be needed for a couple of metres upstream of the culvert.

Where there are multiple pipes place vertical flat stones to act as water splitters at the joins between pipes to divert the water.

### 2.2.2 Outlets

Place a flat stone below the outlet where the main water will fall. Surround this with an apron of flat stones to reduce scour and erosion.

If the outlet is in a ditch and has a bank facing it consider facing the bank with a stone wall to reduce erosion if there are high flow rates.



If experience shows erosion of the bank immediately after the outfall consider lining the bank with a stone or concrete wall.

When new culverts are to be installed on streams with migrating fish, every attempt should be made to avoid constructing outfall barriers. Putting a new culvert outlet below the tailwater elevation is sometimes not possible, and many existing culverts form outfall barriers.

One way to correct an existing outfall barrier is to provide for one or a series of low-end weir or dams below the culvert outfall. These weirs may be nothing more than hand-placed rock "reefs," wire basket gabions filled with local rock, or concrete sills. These downstream dams raise the tailwater elevation and flood the culvert. Access by fish is not only enhanced, but water velocity in the culvert is decreased. The downstream dams should not create outfall barriers. Rocks should be selected to form notches for fish. A

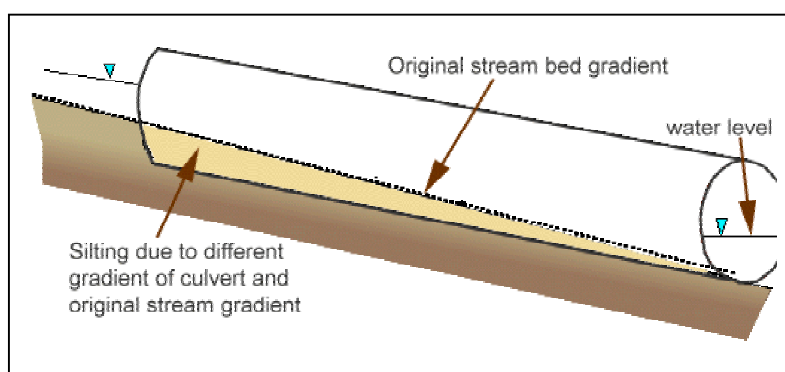


number of weirs can be used to control fast water or to step down additional height in the form of a pool and jump fish ladder.

In some streams, the range of flows is so great that it is impossible not to have the culvert outlet above the tailwater at some time. Also where severe fluctuations in flow require large culverts, fish passage may be impeded during low flows because of shallow flow over the broad culvert bottom. In such cases, stacked- or multiple-culvert installations can be used to provide fish passage. Placing the stacked culverts at different elevations ensures adequate discharge capacity as well as fish passage over a wider range of flows.

### 2.2.3 Culvert Sedimentation

Poor laying and slope control of culverts can cause them to become partially blocked or reduce the depth of water flow in a culvert. The culvert should maintain the original angle of the stream bed as closely as possible.



By reducing the water depth the stream may become too shallow or increase flow speed preventing fish swimming through.

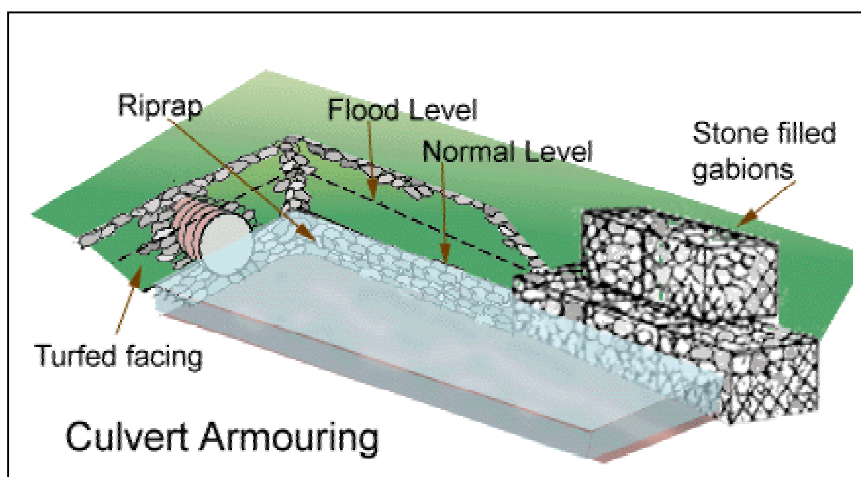
### 2.2.4 Armour

On both inlet and outlet approaches additional protection may be needed to prevent scour.

It should be angular and well graded,

and 50% should be 10% bigger than the biggest rocks moved by peak flows. Look downstream and see what rocks are visible and obviously moved by the water at some time.

Place armour below scour depth and force it into the soil with the excavator bucket.





Simply "sprinkling" rock around intake and outlet is very ineffective and expensive. Avoid using round river rock as armour if possible as this is easily moved when water flow rates are high.

Stone filled wire gabions are a cheap low maintenance method of protecting banks from scouring.

### 2.2.5 Inspection pits

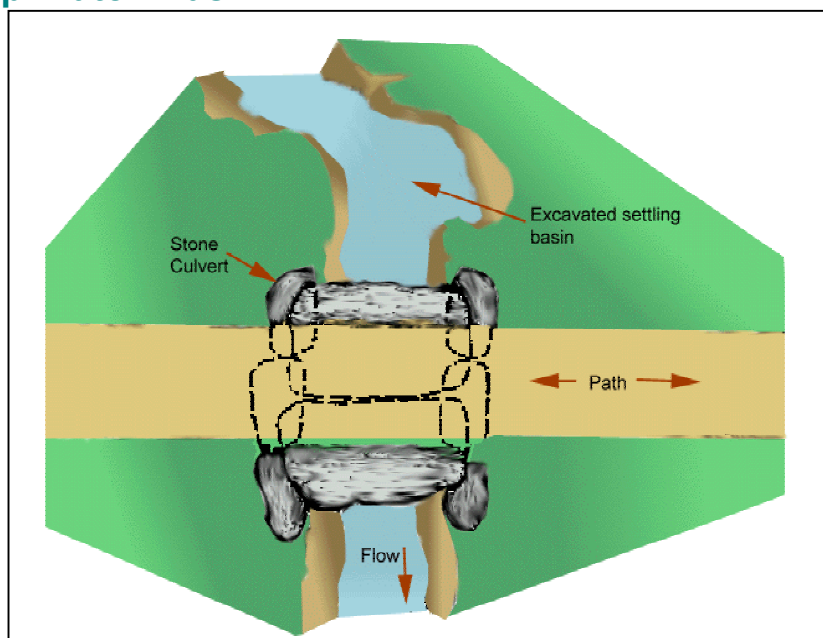
On longer culverts which are too small for personnel access it will be necessary to construct inspection pits and manholes to allow access or clearing jambs and removing silt.

Where culverts are expected to run for long distances underground consider fitting inspection and cleaning pits every 15-20 metres. These should be deeper than the pie base to act as silt collectors.

### 2.2.6 Silt Trap/ Catch Basin

Consider having a silt trap/settlement catch basin before the culvert inlet apron (deeper section of stream bed) when culverts are to be long.

On long lengths of drain ditches you might also consider



installing silt traps periodically especially in soils where there is high erosion. These should be provided every 60 metres.

### 2.2.7 Filter grating

Where branches and similar debris are likely to be washed down streams or ditches consider fitting a filter grating about a meter before the inlet to prevent blocking of the pipe(s). This is necessary before long culverts where any jammed branch could require excavation of the pipe.

Filter gratings or debris grids can be detrimental to fish passage. The storms that often bring debris downstream are those in which many fish can move up to spawning areas. Although the protected culvert may not be a velocity or outfall barrier, a debris-laden filter



grating can be impassable to fish. Therefore, debris-catching structures should be avoided on streams used by migrating fish, and crossings should be large enough to transmit debris downstream. However, increasing the culvert diameter may be impractical because of the increased cost.

To compensate for the absence of culvert protection from avoiding debris-catching structures, the culvert should be large enough to allow debris to pass through it. Passing debris through the culvert is a valid alternative to intercepting debris above the culvert inlet, and should not be overlooked.

### 2.2.8 Guardrails

As with any drop of over 300 mm (on hard surfaces) or 600 mm (For soft surfaces) or where there is water over 300 mm deep, a guardrail should be provided at the side of the path, on bridges and at culverts to prevent people falling into the ditch or stream.

## 3 Construction Phase Culverts

Following use on temporary routes, they should be carefully removed to minimise soil and stream bed disturbance. It is important that these culverts be of adequate diameter to handle above-normal water flows, long enough to extend slightly upstream and downstream from the crossing. They should be installed with a 1:50 to 1:25 downstream angle to aid in flushing out debris. A single culvert, sized to handle the water flow, is less likely to clog than several smaller stacked culverts and provides more opportunity for fish passage.

Temporary culverts on construction routes help control water and keep the route open for work. If working during high rainfall periods it may be worthwhile having a pump available or know where one can be obtained quickly. It is cheaper to pump water clear than pay workers to sit in a cabin while water levels fall.

Remember 300 to 600 mm diameter pipes pose a trapping danger to children and dogs sized animals and should not be used where these groups may become stuck.

## 4 Fish Habitat

Protection of fish habitat is necessary for stream crossings where fisheries exist. The choice of crossing location is important in terms of both sedimentation effects and fish passage. For fish passage, preferred locations are those that do not cause large increases in velocity and have no abrupt changes in gradient or alignment of the channel. Sections of a stream with uniform alignment, good bank



stability, and uniform gentle gradients are easier to cross with provisions for fish passage.

Determine the type and extent of fish habitat before selecting drainage structure design. The incorporation of fish-passage facilities at stream crossings should be based on assessments of the life-cycle requirements of fish species, of habitat quality, and of the accessibility of sites to fish. Natural barriers downstream or immediately upstream from the site may eliminate the need to provide fish-passage facilities. Usually, a fisheries biologist must be consulted to assess the habitat.

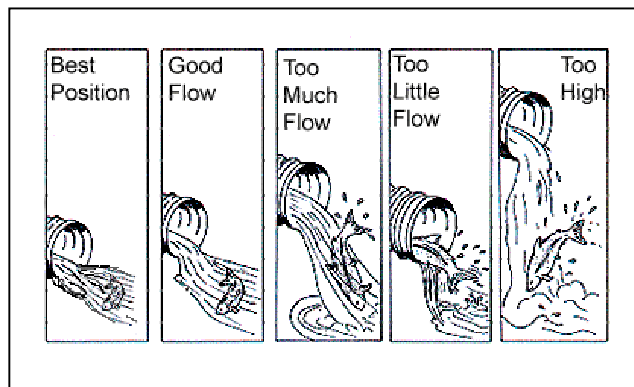
Bridges and arch culverts are preferred for crossing streams with migratory fish. Bridges are preferred because they usually cause less modification of the stream than do culverts, and are often the best way to ensure fish passage. Culverts are by far the most common type of crossing device and the most likely to cause barriers to fish migration.

Culvert crossings have been installed in thousands of streams with little or no thought to their effects on fish populations. A single, poorly installed culvert can eliminate the fish population of an entire stream system.

The following are some important considerations for culvert installation (Furniss et al. 1991, Yee and Roelofs 1980):

- The two most important considerations for fish passage through culverts are maximum acceptable water depth for the migrating species, and outfall.

- The culvert should be placed at or below the original streambed elevation, and water depth and velocity at low and high flows should be integrated into the design. Fish jumping pools can be used to help flow control and outlet design



- the water flow is important, too low or sediment build up and the fish cannot swim. Too high a flow and poorer swimmers cannot move against the flow. Where it is necessary for the outfall to be positioned higher than the stream level (flood levels in high water season) the outfall should be no more than the jump height local sedentary fish can handle. The best solution has the outlet below the surface of the lower stream.
- Control scouring at culvert outlets with energy dissipators such as heavy rock riprap consistent with fish passage considerations.
- At stream crossings, avoid channel width changes and protect embankments with riprap.



- Align culverts with the natural course and gradient of the stream. Locate valley-bottom paths/roads to provide a buffer strip of natural vegetation between the road and stream.
- Select periods of low flows for construction to limit disturbance. Design and construct a stream crossing so that if the culvert should fail, the stream flow will not be diverted out of the original channel
- Ensure erosion-control measures are completed before the wet season in your area. Locate fuel storage areas away from the stream.
- Construct dikes to contain the largest possible spill.
- If gravel removal operations are permitted in the streams, co-ordinate the removal with a fisheries biologist who can give beneficial information to protect your fisheries.
- The diameter of culverts must be adequate to allow maximum flows and the expected debris to pass. Washing out of culverts and their earth fills damages the path and is a source of sedimentation. Channel bank stability upstream and downstream of culverts should be provided for. Road and path crossings alter the hydraulics of streams above and below the crossings for considerable distances, sometimes making stream banks more susceptible to erosion. Severe erosion can alter the configuration of the stream and crossing, and can eliminate the design components that provide for fish passage.
- A single large culvert is better than several small ones because it is less likely to become plugged, and carries water at low velocities.
- Where culverts are installed in stream sections with steep gradients, it is important to create or improve resting pools, cover, and bank protection along the stream above and below the culverts. Maintaining a stable stream bottom through the culvert-influenced area is essential.

### 4.1 Resting Places

Resting areas immediately downstream of and upstream of the culvert (or ford) are desirable with the requirements being:

- an area of water of adequate depth (e.g. at least 300 mm for trout, 450 mm for salmon);
- an area of deeper water with adequate cover for resting;
- rocks or overhanging vegetation; and
- moderate flow conditions (well within the cruising speed of the fish – see table).
- Resting pools within the culvert are not recommended as they are likely to collect silt and debris and would be difficult to maintain

Several North American reports present guidelines for the design of low stone weir installations intended to raise tailwater height. It is recommended that weirs should be a minimum of 6 metres apart



and have a maximum fall of 300 mm between successive weir crests, and that the most downstream structure should have its crest level with the stream bed to act as an erosion control mechanism. This is suitable for salmon and trout but may be too high for more sedentary species.

## 4.2 Planning

There are many other potential effects arising from poor planning and design which include the following:

1. The loss of genetic diversity in an upstream reach for resident fish as fish can go downstream but not back upstream.
2. The loss of range for juvenile (anadromous) and resident fish that may migrate upstream at certain times of the year.
3. The loss of nutrients (from the anadromous spawning adults) to reaches upstream of passage blockages.
4. Changes in fish genetics or community assemblages upstream of fish passage impediments because certain stronger swimming fish species or life stages can pass upstream while the weaker swimming fish can not.
5. The loss of resident fish on small streams after extreme flood or drought events that evacuates fish from the reach and fish are not able return.

**Table 1 Design Criteria for Salmonids**

	Notes	Brown Trout 15cm	Sea Trout 25cm to 50cm	Salmon > 55cm
Maximum Water Velocity:	a,b,c			
Culvert Length <20m		1.25m/s	1.6m/s	2.5m/s
Culvert Length 20-30m		1.0m/s	1.5m/s	2.0m/s
Culvert Length >30m		0.8m/s	1.25m/s	1.75m/s
Minimum Diameter of Pipes		0.3m	0.3m	0.5m
Minimum Depth of Water	d	0.1m	0.15m	0.3m
Maximum Water Level Drop	e	0.2m	0.3m	0.3m
Trash Screen (minimum gap)	f	0.05m	0.1m	0.2m
(From Scottish guidance on river crossings migratory fish passage – Note: it relates to adult migratory fish and not the needs of juveniles or local sedentary fish)				



## Notes

- a) Mean velocity of cross-section (there will be areas of lower and higher velocity).
- b) The velocities for the shorter culverts approximate to the burst speed achievable by each species at 5°C, and the velocities for culverts > 30m approximate to the cruising speed.
- c) These velocities should not be exceeded at any flow within the passage design flow range.
- d) Minimum depth acceptable at the lower end of the passage design flow range.
- e) Maximum drop at either intake or outlet.
- f) The minimum gap a fish can pass through will depend upon the size of the fish - these gaps are for typical large adults. Trash screens should be avoided whenever possible but if this is not possible a grid of sufficient size to allow fish passage should be used.
- g) These water speeds and depths apply to culverts, bridges and fords.

See also our guide Fish Passage for alternatives and discussion of fish needs.



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