6.0 Guidelines for the construction of instream structures

All stream crossings have the potential to adversely affect the aquatic habitat and its biota. It is therefore essential that the number of in-stream crossings be minimised through proper planning. When a stream crossing is shown to be essential, bridges are the best means of ensuring fish passage. Where these are not practicable, the correct choices of appropriate in-stream structures and correct installation will reduce the impact on the habitat and ensure fish passage.

6.1 Culverts

Most of the culverts installed in the Auckland Region have been designed to optimise flow/flood passage; they generally do not have the roughness and variability of a natural stream channel and therefore do not dissipate energy as readily.

The two most common faults found in Auckland culverts were:

1) Vertical drops at the end of outlet aprons that several fish species would not be able to overcome during low flows, and large concrete aprons that dissipate flow so that water levels are too low for fish to swim through (Plates 3, 4 and 13);
2) High culvert barrel velocities and downstream channel scour that create perched outlets that fish cannot surmount at low and medium flows (Plates 3 and 4).

Generally these faults were caused by poor positioning of the structure at construction and/or subsequently through downstream erosion.

To minimise the length (and therefore the cost) of a culvert it is possible to skew the structure relative to the alignment of the stream. Although this reduces the length of culvert fish need to negotiate, this action often results in bank erosion at the inlet and/or outlet. Also relevant, is the potential increased turbulence at the upstream and downstream end of culvert, and the important loss of energy dissipation capacity caused by the shortening of the channel. Therefore, wherever possible, culverts should be larger than the stream width, be on the same slope, have the culvert invert buried and have contoured inlets and outlets.

Plate 14: A fish friendly culvert with invert countersunk below the natural streambed.

6.1.1 *General culvert design*

The following guidelines should be applied when installing new culverts or retrofitting existing culverts:

- ❍ The culvert should be positioned so that both its **gradient** and **alignment** are the same as that of the existing stream;
- ❍ culvert **width** should be equal to or greater than the average streambed width at the point where the culvert intersects the streambed;
- ❍ the **culvert invert** should be set well below the current streambed (minimum of 20% of culvert diameter at downstream end) (Plate 14);
- ❍ bed material should be assessed to determine the potential for erosion. If erosion is likely, a **weir** or series of weirs should be provided downstream of the outlet (Plate 15 and Figure 3). Such a weir could also provide pools as resting areas, reduce culvert velocities by backwatering, and eliminate elevated outlets. However, it is important to remember that a poorly designed weir can also prevent passage and therefore it is essential that the weir be notched to provide passage at low and medium flows;
- ❍ **armouring** of the banks with riprap at the outlet and inlet may be required to prevent erosion (Plate 16);
- ❍ the **average barrel velocity** should ideally be **below 0.3 m s^{-1}**, however where this cannot be achieved, a **50-100 mm** zone should be provided on either side of the culvert with velocities below 0.3 m s^{-1};

Plate 15: Series of rock weirs built to drown culvert outlet.

- ❍ where average barrel velocities are greater than 0.3 m s^{-1}, rocks cemented onto the barrel floor (Plate 17) or even smooth culvert walls provide a more **suitable surface for climbing** indigenous species than ribbed walls (note, however, that ribbed culverts of the Polyflo™ [1] type are useful for reducing barrel velocities, while still providing a climbing surface);
- ❍ **spoilers and some types of baffles** are useful for reducing barrel velocities and providing resting areas (Plate 18 and Fig. 4). Such structures should only be installed where they will not cause obstruction of the culvert through accumulation of debris, and where site and engineering restrictions leave no other options;

[1] Polyflo™ is the trademark of Promax Plastics, Maruata Rd, R.D.3, Glenbervie, Whangarei, New Zealand. Phone (09) 437 6864.

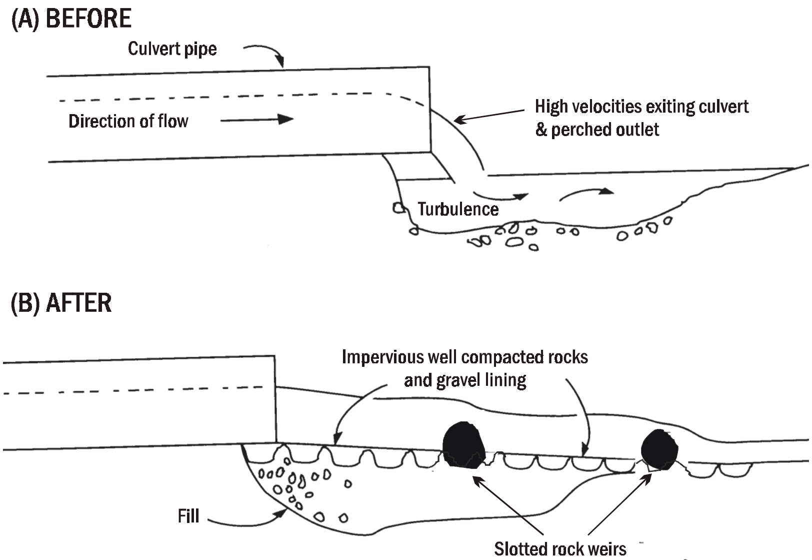


Figure 3: A retrofitting option for perched culverts using rock weirs and fill (modified from Clay 1995).

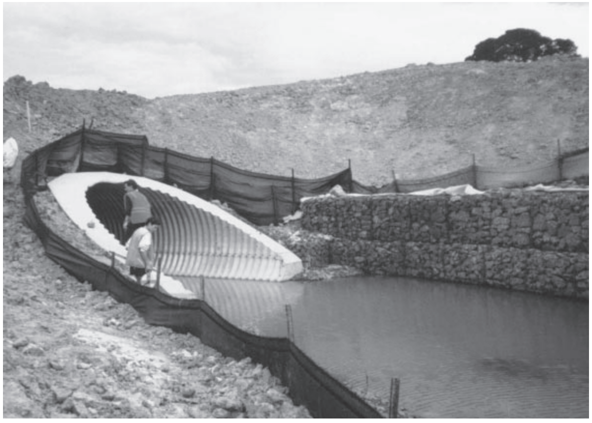


Plate 16: Erosion control at culvert outlet.

- ❍ **baffles** can ease passage of larger swimming species but to ensure an uninterrupted pathway for small indigenous species, they should not cut across the entire floor of the culvert;
- ❍ where low flows (and therefore shallow water depths) are a feature of the site, the apron, weir, or barrel floor should be **dished or sloped** to concentrate flows;
- ❍ all the **ends and junctions** of the culvert should be rounded to allow climbing species to pass;
- ❍ where the flow regime of the stream permits, to ensure the maintenance of a wetted margin, **water depth** should be no greater than 45% of the culvert height for the majority of the September to February main upstream migration period (Table 1).

6.1.2 Fish-friendly culvert designs

The process of installing or retrofitting culverts requires the consideration of several important issues, including, fish passage requirements, hydrological and physical characteristics of the site.

The various fish species present in the Auckland Region all have different swimming and climbing abilities. It is therefore possible to "custom build" instream structures to cater for the fish species present. Four basic designs are proposed (Fig. 5):

- ❍ No-slope (stream slope),
- ❍ Stream simulation,
- ❍ Hydraulic design,
- ❍ Climber design.

The no-slope (stream slope) design option (Figs. 6 and 7) requires few, if any calculations however it may result in the installation of a very conservative structure. In practice, this option will be limited to relatively short culverts in low gradient streams. The stream simulation design option (Figs. 8 and 9) creates flow conditions inside the culvert that are similar to that of the natural stream channel found upstream and downstream of the structure. The hydraulic option (Fig. 10) is designed using the velocity and depth requirements of a target fish species and requires more complex calculations. Finally the climber design option (Fig. 11) makes use of the ability of many indigenous freshwater species (e.g. elvers and koaro) to use the wetted margin to progress upstream. In terms of design, the climbing species option is the least restrictive but is only useful in high gradient streams where fish diversity is already limited.

Plate 17: An example showing how rocks could be used to increase the channel roughness of a culvert.

Plate 18: Spoiler design installed in an Auckland culvert.

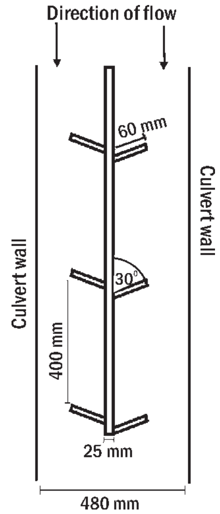


Figure 4: Baffle design that allows passage of NZ species. The height of the baffle in this example was 60 mm (from Boubée et al. 1999).

Figure 5: Fish friendly culvert design options.

Species that require passage	**Culvert design** (in order of preference)	**Culvert specifications**	**Special requirements** of design	**Additional structures** that may be required
All species (swimmers, anguilliforms, jumpers and climbers)	**No-slope** (Fig. 6)	**Length:** short (<20 m?) **Width:** >average channel width **Water depth:** specific to largest fish needing passage **Slope:** same as stream (normally flat) **Alignment:** same as stream **Water velocity:** mean ≤ 0.3 m/s **Culvert invert:** below stream bed	None	None
Species known to be **present** only	**Stream simulation** (Fig. 8)	**Length:** moderate to long **Width:** >average channel width **Water depth:** specific to largest fish needing passage **Slope:** low to moderate (similar to stream) **Alignment:** same as stream **Water velocity:** same as stream **Culvert invert:** below stream bed	**Rocks** arranged and on culvert floor to simulate held the natural streambed	**Bed retention** devices (inside culvert) and **water/bed level control devices** (inlet and outlet)
Targeted species only	**Hydraulic** (Fig. 10)	**Length and width:** length and distance between resting areas calculated to achieve passage **Water depth:** specific to largest fish needing passage **Slope:** **calculated to achieve passage)** **Alignment:** straight **Water velocity:** ≤ 0.3 m/s (50-100mm on sides) **Culvert invert:** at or below stream bed	**Spoilers or rocks** may be required on culvert floor to provide resting areas and reduce water velocities	**Low flow channel** and **water/bed level control devices** (inlet and outlet)
Climbing species known to be present only	**Climber** (Fig. 11)	**Length:** moderate **Width:** any as long as wetted margin provided **Water depth:** wetted margin required **Slope:** <40^{0} **Alignment:** straight **Water velocity:** low velocity, moist margin **Culvert invert:** at or below stream bed	Ensure that the **entry and exit** of the culvert are **smooth. No breaks** along culvert. **Climbing media** may need to be installed within culvert	**Water/bed level control devices** (at inlet and outlet)

Figure 6: No-slope design assessment diagram for culverts. All conditions need to be met before the design can be considered acceptable.

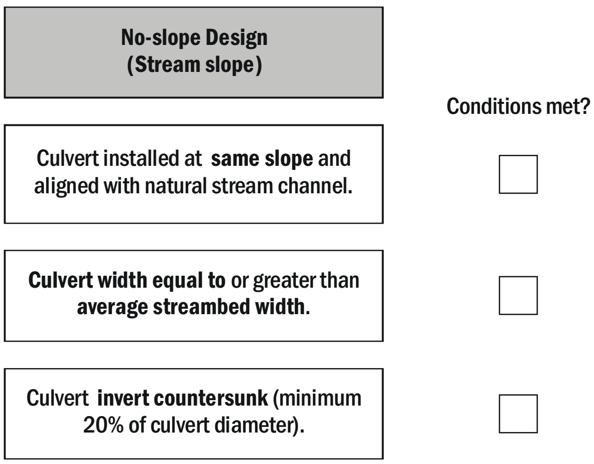


Figure 8: Stream Simulation design assessment diagram for culverts. All conditions need to be met before the design can be considered acceptable.

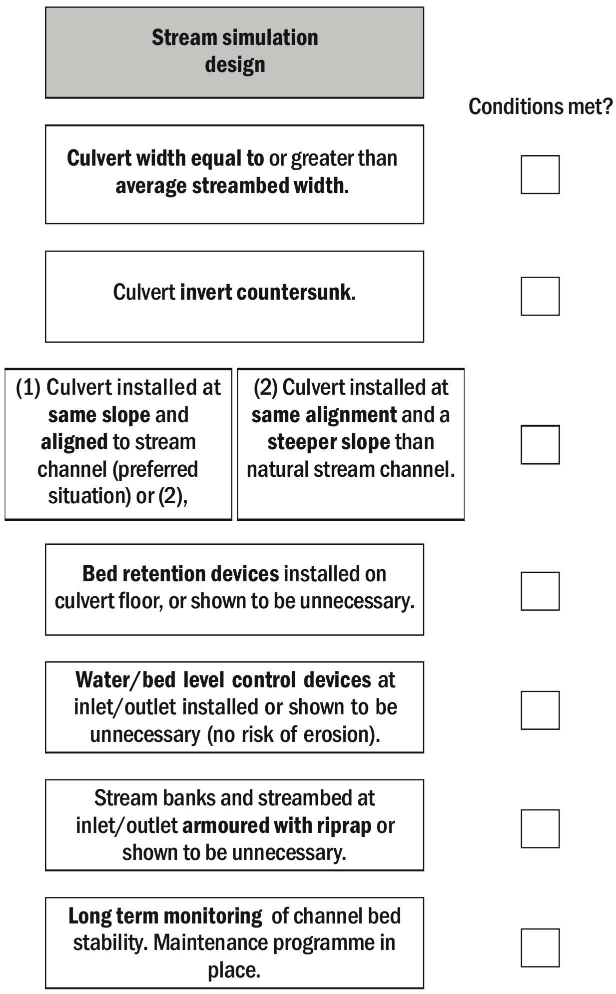
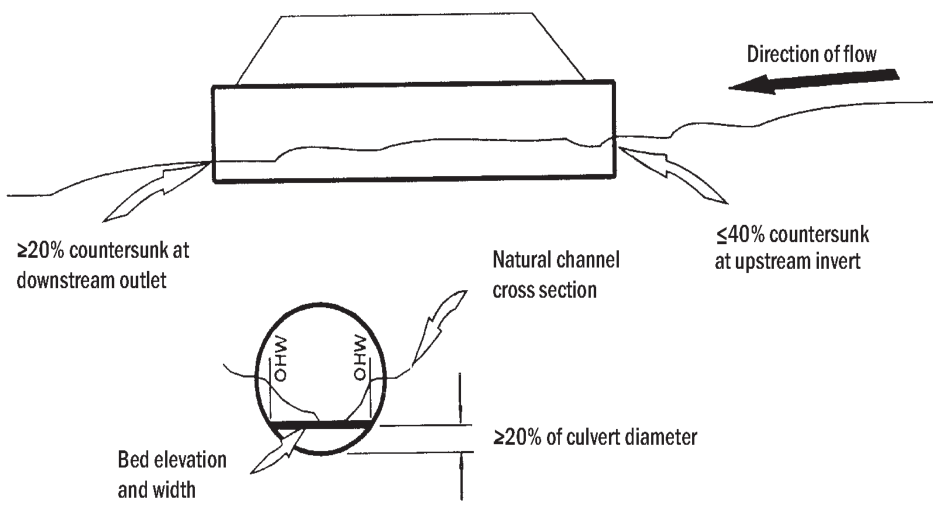


Figure 7: No-slope culvert design. OHW = ordinary high water marks (taken from Bates 1999).



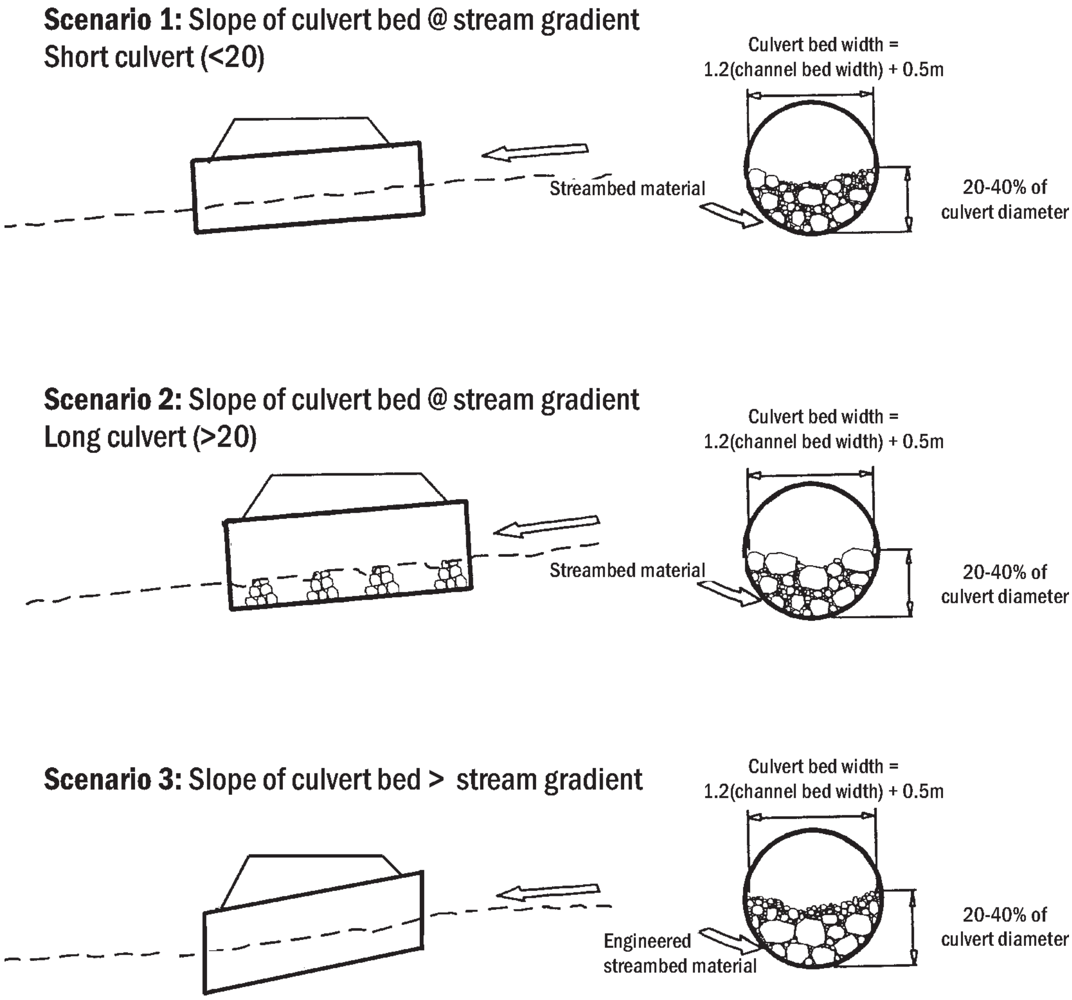


Figure 9: Stream simulation culvert design scenarios (modified from Bates 1999). Care needs to be taken when inserting rubble onto the floor of the culvert as at low flows all the water can disappear into the substrate. In the above diagram we stipulate that 20-40% of the culvert diameter should be filled with stream bed material, however, the % fill can be reduced if the culvert is running <10% full during the migration period.

Figure 10: Hydraulic design assessment diagram for culverts. All conditions need to be met before the design can be considered acceptable.

Hydraulic design	Conditions met?
Information on **diameter, slope, and length** provided.	☐
Information on minimum and maximum **flows, barrel velocities**, fish **species present** and fish **swimming capabilities** provided.	☐
Velocity and water depth estimate made and culvert **shown to be negotiable** by target species. If **Spoilers, baffles** or **rocks** inserted on barrel floor to increase bed roughness and provide resting areas, include design.	☐
Low flow channel in culvert floor provided or shown to be unnecessary.	☐
Water/bed level control devices at inlet/outlet included.	☐
Armouring of stream banks and streambed at inlet/outlet included.	☐
Short term monitoring plan devised, to determine if culvert is providing passage as predicted.	☐
Long term monitoring and maintenance plan designed to ensure integrity of structure and to ensure passage retained over time.	☐

Figure 11: Climbing species design assessment diagram for culverts. All conditions need to be met before the design can be considered acceptable.

Climber design	Conditions met?
Entry and exit of culvert **smooth** (no breaks).	☐
Smooth, even surface within culvert with **no breaks.**	☐
Climbing media within culvert barrel installed or shown to be unnecessary.	☐
Water/bed level control devices at inlet/outlet installed.	☐
Armoured stream banks and streambed at inlet/outlet.	☐
Short term monitoring plan devised to ensure that the culvert is providing passage as predicted.	☐
Long term monitoring and maintenance plans devised to ensure integrity of structure (including erosion control ensure passage measures at inlet/outlet) and to retained over time.	☐

Plate 19: Notched weir constructed from large rocks.

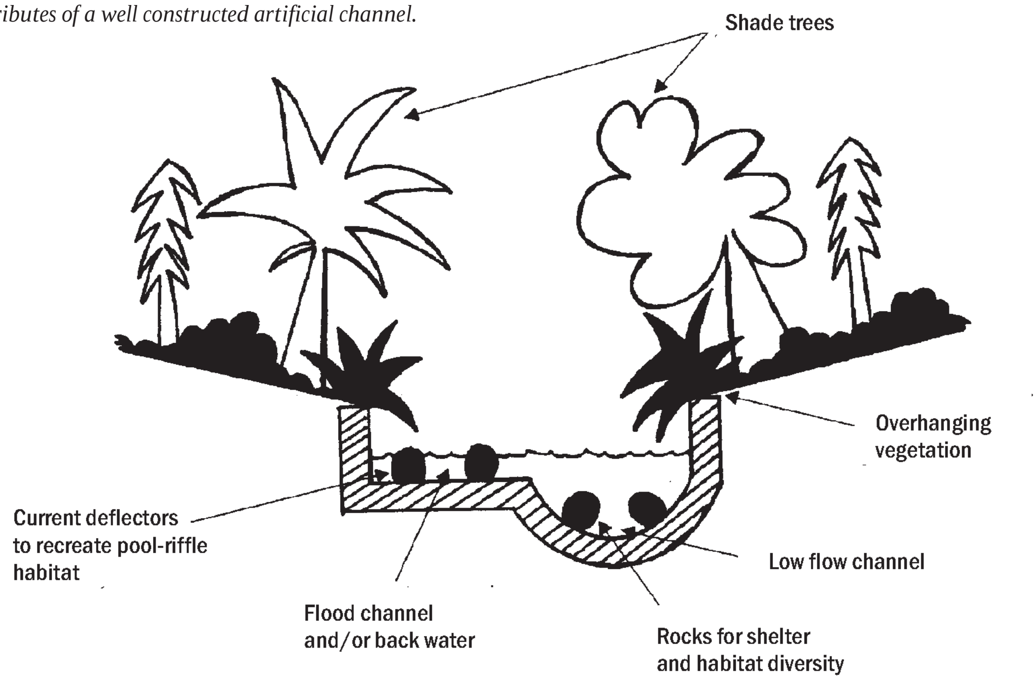
6.2 Low weirs and water/bed level control devices

Weirs should be slotted and/or notched and impermeable so that a well defined pathway(s) over and through the weir is/are present at all flows. Large rocks can be arranged to form a weir and are visually more pleasant than concrete structures. Where large rocks cannot be anchored on the stream floor, it is possible to position the rocks so that each rock leans on the one downstream to ensure stability. With such constructions, the central rock should be submerged so as to create a notch in mid channel (Plate 19).

6.3 Channels

Artificial channels which either bypass obstacles, or are built as part of an instream structure, are now considered one of the most effective means of ensuring passage of non-salmonids fish (Jungwirth and Schmutz 1996). Although habitat preferences and velocity preferences of some indigenous fish species are available (e.g. Jowett and Richardson 1995), this information has not yet been compiled into criteria for the construction of artificial channels. Until this is done, standard overseas concepts will need to be adopted (e.g. Swales 1989, Hauer and Lamberti 1996).

Figure 12: Attributes of a well constructed artificial channel.



In general, the channel needs to be well armoured and as diverse as possible and should include pools, riffles, runs and backwaters. In catchments prone to extreme water fluctuations, a low flow channel and a flood channel should be provided (Fig. 12). Wherever possible, different size of material (including woody debris) should be used in the construction. Pool and riffle spacing of six times the channel width and a meander of 12 times the channel width have been recommended (Newbury 1996). The banks should be planted to provide shade as well as maximise food production and instream cover. Until overhead vegetation is dense enough to reduce plant growth, the instream vegetation may need to be controlled to ensure that the channel is kept open.

6.4 Fish passes

Structures and by-pass channels that are constructed to assist with the upstream migration of fish stock are termed fish passes, fishways or fish ladders. For new in-stream barriers, provisions for upstream and downstream fish passage need to be included at the concept stage. For existing structures, retrofitting is possible.

Fish passes need to account for complex interactions between fish behaviour, fish swimming ability, and engineering constraints. As such it is best to use proven designs and consult an expert on the choice of type and best position. As all newly constructed fish passes require adjustments, a monitoring and maintenance programme is essential.

6.4.1 General requirements of fish passes

The success of a fish pass depends largely upon:

a) position/site;
b) attraction flow;
c) design of entrance and exit;
d) operating schedule;
e) flow, velocity and turbulence;
f) floor design;
g) maintenance.

a) Position/Site
The fishway entrance must be located where fish can find it (usually where fish are naturally attracted). In a river channel, this is often near an undercut bank. At hydro dams or where there is a compensation flow, it is best to position the entrance adjacent and close to the turbine outlet or discharge point.

b) Attraction flow
To find the fish pass entrance, fish must be able to perceive the attraction flow. This flow must be higher than that of the river and the turbulence must be low. Wherever possible, the flow out of the fish pass must be aligned to the existing current.

c) Design of entrance and exit
The entrance and exit of the fish pass must be accessible under a wide range of flows. Fish must be able to leave the exit easily, without danger of being entrained back downstream. Screens, or trash racks must be included to prevent the pass becoming blocked by debris and must be regularly cleaned.

d) Operating schedule
The pass must operate for the entire migration season (because the different species have different migration periods, this usually means that it must operate for the entire year). Continual 24-hour operation during the main migration period must be guaranteed. However, fish passes do not necessarily need to operate during extreme high (flood) and extreme low flow periods.

e) Flow, velocity and turbulence
Velocities in the fishway must cater for the fish with the poorest swimming ability. The hydraulic conditions must be constant throughout the fishway to ensure passage over the entire length of the pass.

f) Floor design
In traditional fish passes, a minimum 0.2 m layer of coarse substrate should be included on the floor of the fish pass to reduce flow velocities close to the bottom, and provide a pathway for invertebrates. The material used must be of variable size and shape to provide shelter for small fish as well as invertebrates (notably shrimps and

koura). Where the preferred design does not allow for the insertion of a gravel floor (e.g. Denil fishways), a combination of fishway types should be considered (Plate 20).

g) Maintenance

The pass must be able to be easily maintained. A maintenance schedule and monitoring plan must be in place to ensure that the pass is not only working to design, but also that it continues to be effective. Most fish passes will require some modifications after construction to ensure that maximum effectiveness is achieved.

6.4.2 Types of fish passes

Three different types of fish passes can be differentiated. These are:

1. traditional fish passes;
2. nature-like fishways;
3. fish lifts and fish locks.

Combinations of these systems can be installed in situations where species with different requirements are present (Plate 20).

1) Traditional fish passes

These passes have traditionally been designed for salmonids, but are now commonly used for all species. The design and installation of these fish passes is a complex task and should be left to an expert. Computerised expert systems are available to recommend the most suitable fishway type for given design conditions (e.g. Bender et al. 1992). The most common types are:

- weir (pool) type fishways (Fig. 13);
- vertical slot fishways (Plate 21 and Fig. 14);
- Denil fishways (Plate 22 and Fig. 15);
- eel ladders (Plate 23 and Fig. 16).

Plate 20: Combined Denil and nature-like fishway installed to allow passage of trout and indigenous fish species. The netting on top was included to prevent predation by birds.

Weir (pool) type fishways

In weir (pool) type fishways the fish travel upstream by jumping or swimming from pool to pool. The pools are separated by weirs, which control the water level in each pool (Fig. 13). Most weir (pool) type fishways have a slope of <10% and are sensitive to water level fluctuations when no other type of flow control is provided (Bates 1992, Office of Technology Assessment 1995)

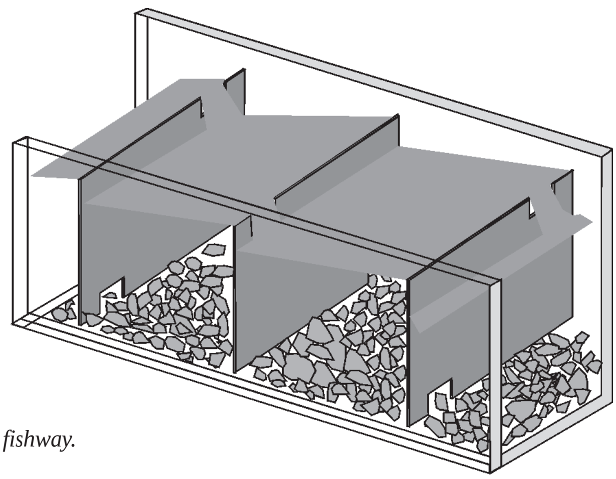


Figure 13: Diagram of weir (pool) type fishway.