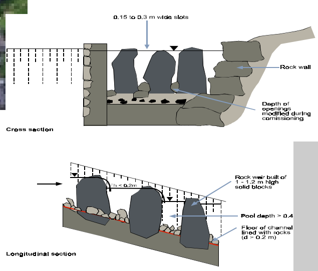
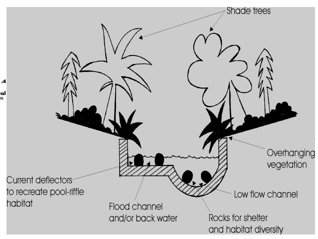
fish passage guidelines

for the **Auckland Region**

Auckland ***Regional*** Council



June 2000



Technical Publication No. 131

ISSN 1175 205X

Acknowledgements

Project Leader: Mace Ward

Authors[1]**:** J. Boubee
E. Williams
J. Richardson

NIWA Client Report ARC 90229

Contributors: Sediment Control Team
Stormwater Management Team
Water Allocation Team
Chris Hatton
Earl Shaver
Brent Evans
David Glover

Cover Photograph: Rod Morris

Printed on recycled paper

[1] National Institute of Water & Atmospheric Research Ltd

CONTENTS

Executive Summary

Of the 35 indigenous freshwater species currently recognised in New Zealand, 18 are diadromous and undergo migrations between fresh and saltwater as a necessary part of their life cycle. Apart from the degradation of adult habitats, one of the most significant causes of the decline in freshwater fish populations in New Zealand is the construction of structures such as dams and culverts that prevent fish from accessing otherwise suitable habitats. Management of the numerous freshwater resources has so far focused on avoiding, remedying, or mitigating the impacts of contaminants, physical activities and abstractions. However, these initiatives are significantly undermined if the resident aquatic biota do not have access to the resource.

The distribution of freshwater fish in the Auckland Region was analysed using data recorded in the New Zealand Freshwater Fish Database. In total, 15 indigenous and eight introduced fish species have been recorded in the Auckland Region. The majority of the indigenous species (13 species) are diadromous and fish migration barriers are therefore expected to have a major influence on fish distribution in the Auckland Region. Potential migration barriers like waterfalls, rapids, chutes and debris jams are natural, however the majority of instream obstructions are anthropogenic. These include badly positioned or undersized culverts, fords, dams and diversion structures, weirs (including flow measuring weirs), diversion channels, bed erosion control devices, and stream bed modifications.

This report provides guidance for the construction and retrofitting of in-stream structures to allow the upstream passage of fish. Although primarily aimed at road crossing culverts, solutions for the numerous low head weirs, artificial channels and dams present in the Auckland Region are also discussed.

As each potential barrier is different, and the species to be catered for are not always the same, passage solutions will tend to vary from site to site. For culverts four options are proposed. First, the no-slope (stream slope) design option allows passage of all species, but requires the installation of a very conservative structure. Second, the stream simulation design option recreates the natural channel within the culvert barrel and allows the passage of species present at the site. Third, the hydraulic option is designed using the velocity and depth requirements of a target fish species.

Finally, the climber design option makes use of the climbing ability of many indigenous freshwater species (e.g., elvers and koaro) to use the wetted margin to progress upstream. In terms of design, the climber design option is the least restrictive, but is only useful in high gradient streams where fish diversity is already limited. With all four options, bed control devices designed to minimise the risk of erosion are essential and potential solutions are therefore also discussed.

For barriers other than culverts, only general principles are described and potential solutions may need to be modified to suit the landscape features, the type of structure proposed or installed, as well as the habitat and fish species present. Options for low structures range from traditional designs like the vertical slot fish passes, to natural and rock-cascade fishways. For dams, fish lifts and/or catch and transfer operations are proposed. In all cases, it is recommended that only proven designs be used or that expert advice be sought. Inevitably, even with standard designs, adjustments and repairs will be required, and a monitoring and maintenance schedule should always be adopted.

As additional information is gathered, concepts and guidelines developed in this report will need to be reviewed. Users are therefore encouraged to submit comments for incorporation into future reviews and updates.

1.0 INTRODUCTION

New Zealand possesses a relatively sparse fish fauna, with only 35 or so indigenous species, at least another 20 introduced, and half a dozen marine wanderers that periodically enter estuaries and lowland rivers. Of indigenous freshwater species, 18 are diadromous and undergo migrations between fresh and saltwater as a necessary part of their life cycle.

Apart from degradation of the adult habitats, one of the most significant causes of the decline in freshwater fish populations in New Zealand is the construction of structures such as dams and culverts that prevent fish from accessing otherwise suitable habitat. Management of the numerous freshwater resources has focused on avoiding, remedying, or mitigating the impacts of contaminants, physical activities and abstractions. However, these initiatives are irrelevant if the resident aquatic biota do not have access to the resource.

This report was commissioned by the Auckland Regional Council to provide users with guidelines for the construction and operation of in-stream structures. As each potential barrier is different, solutions will also vary. Consequently, only general principles are described here and these will need to be modified to suit the landscape features, the type of structure proposed or installed, as well as the habitat and fish species present. In most cases it is recommended that only proven designs be used or that expert advice be sought. Inevitably, even with standard designs, adjustments and repairs will be required, and a monitoring and maintenance schedule should always be adopted.

2.0 DISTRIBUTION OF FRESHWATER FISH IN THE AUCKLAND REGION

The distribution of freshwater fish in the Auckland Region was assessed using data from the New Zealand Freshwater Fish Database (NZFFD). Approximately three quarters of the sites were sampled using electric fishing techniques which may have underestimated the occurrence of some species (e.g,. smelt). On 1 July 1999, the NZFFD contained 608 records for the Auckland Region dated from 1980 to the present (Fig. 1). Of these, there were 14 sites with no species present and five with only freshwater crayfish (*Paranephrops planifrons*). In total, 15 indigenous and eight introduced fish species were recorded from the Auckland Region (Table 1). Eels, both shortfinned and longfinned, were the most abundant species, but banded kokopu and common bully were also frequently recorded. Redfinned bully, Cran's bully (*Gobiomorphus basalis*) and inanga were found at about 10% of the sites. Apart from the introduced mosquito fish (*Gambusia affinis*), all other species were found at less than 5% of the sites. Other indigenous species that perhaps should be present but have not been recorded include shortjawed kokopu (*Galaxias postvectis*), bluegilled bully (*Gobiomorphus hubbsi*), and lamprey. Shrimps, which are not recorded in the NZFFD, are common throughout the region. More information on fish distribution is available on the NZFFD website at http://fwdb.niwa.cri.nz.

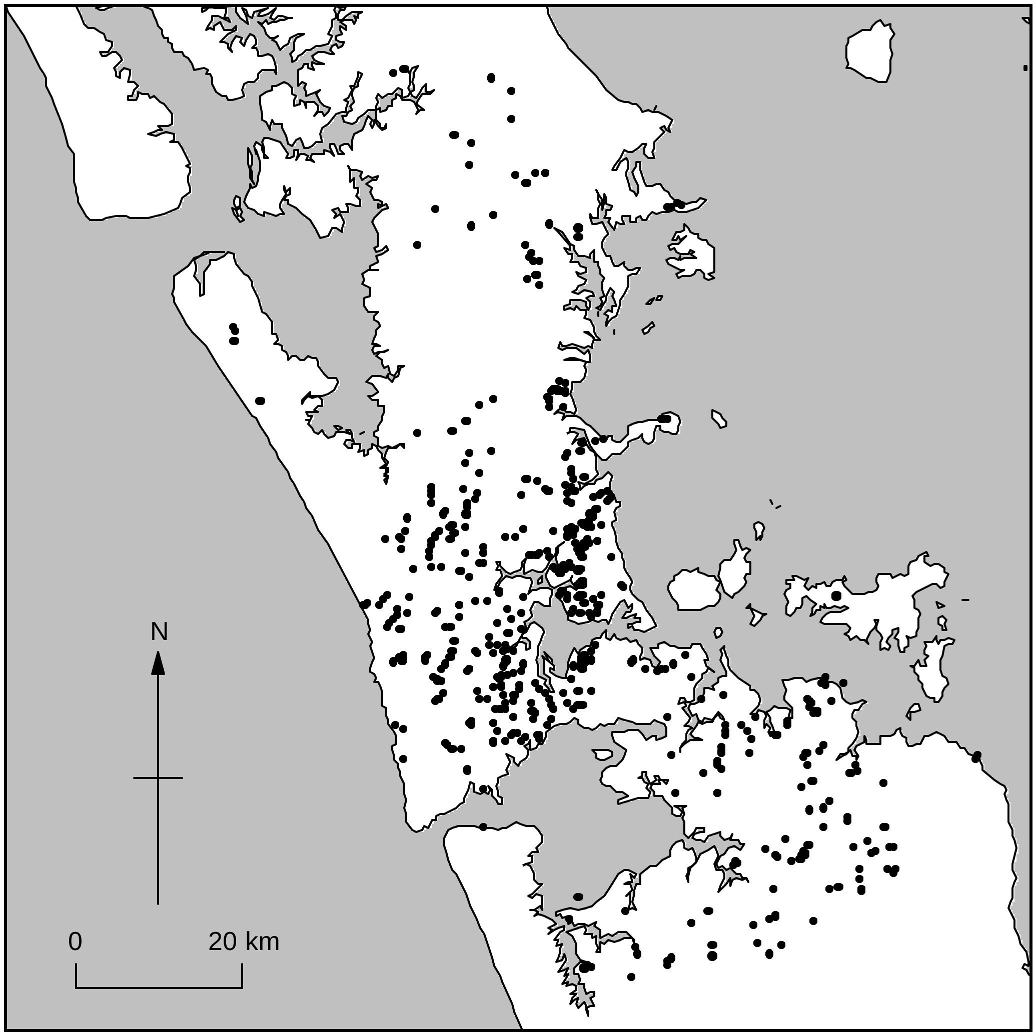


Figure 1: Location of sites within the Auckland Region where freshwater fish information is available on the New Zealand freshwater fish database.

Table 1: Freshwater fish species recorded on the New Zealand freshwater fish database for the Auckland Region. The total number of sites dated 1980 to the present that contained fish was 589. The majority of the information (77%) was collected by electric fishing which may have underestimated the occurrence of some species (e.g., smelt).

Common name	Scientific name	Frequency of occurrence (%)
INDIGENOUS		
Shortfinned eel	*Anguilla australis*	40.6
Banded kokopu	*Galaxias fasciatus*	35.6
Longfinned eel	*Anguilla dieffenbachii*	35.5
Common bully	*Gobiomorphus cotidianus*	31.2
Redfinned bully	*Gobiomorphus huttoni*	13.8
Inanga	*Galaxias maculatus*	9.5
Cran's bully	*Gobiomorphus basalis*	8.8
Torrentfish	*Cheimarrichthys fosteri*	4.6
Common smelt	*Retropinna retropinna*	3.4
Giant kokopu	*Galaxias argenteus*	2.2
Giant bully	*Gobiomorphus gobioides*	1.7
Koaro	*Galaxias brevipinnis*	1.4
Yelloweyed mullet	*Aldrichetta forsteri*	1.0
Grey mullet	*Mugil cephalus*	0.5
Dwarf inanga	*Galaxias gracilis*	0.3
INTRODUCED		
Mosquito fish	*Gambusia affinis*	7.5
Rudd	*Scardinius erythrophthalmus*	1.2
Goldfish	*Carassius auratus*	1.0
Koi carp	*Cyprinus carpio*	1.0
Tench	*Tinca tinca*	0.8
Perch	*Perca fluviatilis*	0.5
Brown trout	*Salmo trutta*	0.5
Rainbow trout	*Oncorhynchus mykiss*	0.2

3.0 PASSAGE REQUIREMENTS OF FISH

3.1 Migration and habitat requirements

Most of the indigenous fish species that occur in New Zealand's waterways have a juvenile migrant stage, therefore their adult populations are dependent on the success of the annual upstream migrations of juveniles. The migration times of some of the most important freshwater species found or expected in the Auckland Region are presented in Table 2. Critical factors considered to be important in the distribution and spawning success of the various species present in the region are given in Table 3.

3.2 Fish swimming ability

The ability of fish to migrate upstream is influenced by several factors including swimming ability, water temperature and behaviour (Boubée et al. 1999). The swimming ability of fish is defined as the maximum velocity it can swim against for a given period of time. Because indigenous New Zealand fish species migrate upstream at a small size, they have an even lower swimming ability than larger sized species considered weak swimmers overseas (Table 4). Therefore, New Zealand species are not able to negotiate velocities as high or distances as long as most Northern Hemisphere species.

In addition to swimming, several indigenous New Zealand fish species have the ability to climb moist surfaces (Table 5). This climbing ability varies between species (Table 6).

Table 2: Upstream and downstream migration times of some of the most important freshwater species found in the Auckland Region. ⇑, Upstream migration; ⇓, Downstream migration. L, Larvae; J, Juvenile or whitebait; A, Adult; S, Spawning adults.

Species	Life	Summer			Autumn			Winter			Spring		
	Stage	D	J	F	M	A	M	J	J	A	S	O	N
Eels	J	⇑	⇑	⇑	⇑								⇑
A. australis and *A. dieffenbachia*	A	⇓	⇓	⇓	⇓	⇓	⇓						
Grey mullet	J	⇑	⇑	⇑	⇓	⇓	⇓					⇑	⇑
Mugil cephalus	A	⇑	⇑	⇑	⇓	⇓	⇓					⇑	⇑
Trout	J	⇑			⇓	⇓	⇓					⇑	⇑
Salmo trutta and	A	⇑				⇓	⇓	⇓	⇓	⇓	⇓	⇑	⇑
Oncorhynchus mykiss	S					⇑	⇑	⇑	⇑	⇑	⇑		
Lamprey	J							⇓	⇓	⇓			
Geotria australis	A						⇑	⇑	⇑?	⇑?	⇑?		
Torrentfish	J	⇑	⇑	⇑									⇑
Cheimarrichthys fosteri	A	⇑				⇑	⇑	⇑	⇑	⇑	⇑		
	S	⇓				⇓	⇓	⇓					⇓
Smelt	L				⇓	⇓	⇓	⇓				⇓	⇓
Retropinna retropinna	J	⇑	⇑	⇑								⇑	⇑
(riverine stock)	A	⇑	⇑	⇑	⇓	⇓	⇓						⇑
Inanga	J	⇑	⇑							⇑	⇑	⇑	⇑
Galaxias maculatus	A	⇑	⇑							⇑	⇑	⇑	⇑
	S				⇓	⇓	⇓⇑	⇑	⇑				
Giant kokopu	L						⇓	⇓	⇓	⇓			
G. argenteus	J	⇑										⇑	⇑
	S[1]						⇓	⇓	⇓				
Banded kokopu and koaro	L						⇓	⇓	⇓				
G. fasciatus and *G.*	J									⇑	⇑	⇑	⇑
brevipinnis	S[1]					⇓?	⇓	⇓					
Common bully	L				⇓	⇓	⇓	⇓		⇓	⇓	⇓	⇓
Gobiomorphus cotidianus	J	⇑	⇑	⇑								⇑	⇑
Redfinned bully	L									⇓	⇓	⇓	⇓
G. huttoni	J	⇑	⇑	⇑?								⇑?	⇑
Shrimp	L			⇓	⇓						⇓	⇓	⇓
Paratya curvirostris	J		⇑	⇑	⇑	⇑			⇑				

[1] The migration of adult giant and banded kokopu is probably limited. Upstream movement after spawning or displacement by floods is possible.

Table 3: Critical habitat requirements for the life functioning and spawning of shrimps and freshwater fish species present or likely to be present in the Auckland Region.

Species	Larvae	Preferred adult habitat	Spawning
INDIGENOUS			
Shortfinned eel	at sea	Lowland waterways	at sea
Longfinned eel	at sea	Upper catchments	at sea
Grey mullet	at sea	Estuarine and lowland waterways ?	at sea ?
Yelloweyed mullet	at sea	Estuaries	at sea?
Lamprey	silt deposits	at sea	upper catchments
Torrentfish	sea or estuary?	estuary to upper catchments	estuary?
Smelt	sea or lake	lakes and low to midland waterways	lower reaches of flowing waterways ?
Inanga	at sea	lowland waterways	on spring tide in upper reaches of estuary
Dwarf inanga	lakes	lakes	lakes
Giant kokopu	sea or lake/pond	lake edges and slow flowing waters with good overhead cover	mid to low reaches of flowing waterways
Banded kokopu	sea or lake	small streams with good overhead cover	during freshes in adult habitat
Koaro	sea or lake/pond	bush clad streams with high water quality	during freshes in adult habitat
Common bully	Lowland waterways, lake/pond	lowland waterways, lake/pond	adult habitat
Redfinned bully	at sea	streams	streams
Cran's bully	streams	streams	streams
Giant bully	at sea	estuaries and lowland waterways	unknown
Shrimps	estuaries	estuaries and lowland waterways	adult habitat
INTRODUCED			
Rainbow and brown trout	streams	high quality water	clean gravel with high quality water
Mosquito fish	adult habitat	ponds, lakes and low to midland waterways	adult habitat (live bearer)
Rudd, goldfish, koi carp, tench and perch	adult habitat	ponds, lakes and low to midland waterways	adult habitat

Table 4: Swimming speeds, migration rates and velocity preferences of indigenous New Zealand freshwater fish species, including a comparison with some North American data for weak and strong swimmers. Sustained speed = the velocity that can be maintained for long timeframes; Steady speed = the velocity that can be maintained for minutes; Burst speed = the velocity that can be maintained for seconds. LCF = length to caudal fork.

Species	Speed (m s^{-1})	Comments	Source
New Zealand			
Inanga (whitebait)	0.01–0.18	Upstream migration gain in the Waikato River	Stancliff et al. 1988
Inanga (whitebait)	0.07–0.39	Catch release experiments in estuarine region	Boubée et al. 1992
Inanga (adult)	<0.15	Water velocity which fish select and can easily negotiate	Mitchell and Boubée 1995
	≈0.07	Preferred velocities	Mitchell and Boubée 1995
	0.30–0.34	Maximum water velocities in which the fish will swim freely	Mitchell and Boubée 1995
Banded kokopu (whitebait)	0.05	Upstream migration gain in the Waikato River	Stancliff et al. 1988
Elver (55–80 mm)	0.20–0.34	Sustained speed	Mitchell 1989
Grey mullet (85–96 mm LCF)	0.12–0.20	Sustained speed	Mitchell 1989
Mean NZ species [1] (excluding mullet) (mean 47–63 mm LCF)	0.20–0.32	Sustained speed	Mitchell 1989
Overseas			
Elvers (100 mm)	0.0–0.15	Sustained speed	Bell 1986
Arctic grayling (50–100 mm)	0.46–0.76	Steady speed	Bell 1986
Arctic grayling (adult)	0.81–2.1	Steady speed	Bell 1986
Grey mullet (13–69 mm)	0.14–0.46	Burst speed	Bell 1986
Brown trout	0.76–2.14 2.14–3.97	Steady speed Burst speed	Bell 1986

[1] From observations using juvenile shortfinned eels, common bullies, common smelt, inanga, and banded kokopu.

Table 5: Locomotory classification of some New Zealand freshwater fish species (modified from Mitchell and Boubée 1989).

Locomotory classification	Species
Anguilliforms: These fish are able to worm their way through interstices in stones or vegetation either in or out of the water. They are able to respire atmospheric oxygen if their skin remains damp.	Shortfinned and longfinned eels, and to some extent juvenile kokopu and koaro. Torrentfish may also fit into this category, but unlike eels they need to remain submerged at all times.
Climbers: These species climb the wetted margins of waterfalls, rapids and spillways. They adhere to the substrate using the surface tension and can have roughened “sucker like” pectoral and pelvic fins or even a sucking mouth (lamprey). The freshwater shrimp, a diadromous native crustacean, is an excellent climber.	Lamprey, elvers, juvenile kokopu and koaro, shrimp. Juvenile common and redfinned bullies to a limited extent.
Jumpers: These species are able to leap using the waves at waterfalls and rapids. As water velocity increases it becomes energy saving for these fish to jump over the obstacle.	Trout, salmon, and possibly (on a scale of 20–50 mm) smelt, inanga and kokopu spp.
Swimmers: Species that usually swim around obstacles. They rely on areas of low velocity to rest and reduce lactic acid build-up with intermittent “burst” type anaerobic activity to get past high velocity areas.	Inanga, smelt, grey mullet and juvenile bullies.

Table 6: Climbing ability (ranked from 1 = poor climber to 4 = good climber) of some common indigenous fish species found in the Auckland Region. J, Juveniles; A, Adults; S, Spawning adults.

Species	Life stage	1 (poor climbers)	2	3	4 (good climbers)
Shortfinned and Longfinned eels	J				✓
	A			✓	
	S[1]				
Torrentfish	J			✓	
	A		✓		
	S[1]		?		
Banded kokopu and koaro	J				✓
	A		?		
	S		?		
Giant kokopu and bully spp. (not giant)	J			✓	
	A		?		
	S		?		
Smelt and inanga (not dwarf)	J		✓		
	A		✓		
	S[1]		✓		
Mullet spp. (and giant bullies ?)	J	✓			
	A	✓			
	S[1]	✓			

[1] Species with some or all of the spawning occurring downstream, or at sea. Where climbing ability is shown it is for the returning adult.

3.3 What constitutes a barrier to fish passage?

3.3.1 Height

Any in-stream configuration, whether natural or artificial can become an insurmountable obstacle for fish if it causes a sudden change in the water surface or bed level. In the case of an artificial structure, this situation may occur at installation or develop as a result of subsequent erosion.

3.3.2. Water velocity and turbulence

Steepness, constricted flows, and low bed roughness may lead to water velocities that exceed the swimming capability of fish and so prevent upstream passage. In addition, uniform conditions of gradient, roughness, and depth can lead to an absence of low velocity zones where fish can rest and recover after swimming to exhaustion.

Until recently, the expectation has been that building additional roughness into a channel would improve fish passage. Thus, the use of corrugated pipe or the inclusion of baffles and weirs has often been recommended to improve fish passage through culverts. However, increased roughness can also result in levels of turbulence that can restrict the movements of small fish (Bates and Powers 1998).

3.3.3 Water depth

Insufficient water depth in channels and culverts often causes passage problems for the larger swimming species. Aprons at the outlets of culverts can present barriers during periods of low flows. In New Zealand, many upstream migrating fish species are small, can spend a considerable amount of time out of water, and have good climbing ability. Therefore, shallow depth is not necessarily a problem and could even be exploited as a means of excluding the larger introduced species.

3.3.4 Channel length

Channel length may be a problem for fish if water velocity restricts the distance they can travel at any one time to less than the full channel length. Even if the fish can maintain a stationary position between periods of forward movement, the high-energy cost involved may mean that they become exhausted before they reach the end.

3.3.5 Light

The effect of light, or the lack of it, on fish migration remains an area of debate both here in New Zealand and overseas. Darkness is not a barrier for elvers and there is evidence that banded kokopu can migrate through long dark culverts. Information on other species is lacking, but observations indicate that many indigenous fish only require very low light levels in order to migrate. Fish release trials undertaken in Auckland culverts showed that fish will pass through when light levels are as low as 0.4% of natural light levels.

3.3.6 Climbing medium

In order to surmount obstacles, climbing fish species such as elvers and koaro require a continuous smooth wetted margin. A small break in this wetted margin, water turbulence and/or wave action can block the upstream passage of the most determined migrators.

4.0 WHEN SHOULD FISH PASSAGE BE CONSIDERED

When considering the need to facilitate fish passage, it is essential that the following points are considered (see also Figure 2):

- **Species present and distribution within the catchment.** The distribution of fish will indicate whether migrants pass through a potential barrier site to access waters higher in the catchment. Knowing which species are present (and thus their swimming abilities and behaviours) enables potential passage problems to be identified, and the design to be adjusted accordingly. Furthermore, the barrier may have allowed a desirable species to develop and the population could be compromised if passage for other species is eased. The need to contain a noxious species may also have to be considered.

- **The size and type of habitat available up stream**. If the habitat is not of the correct type or extensive enough to support a population of a particular species it may not be necessary to provide passage. Furthermore, if contaminated sites exist upstream, allowing passage may have undesirable consequences.

- **The presence of other migration barriers both upstream and downstream of the culvert**. This will determine whether fish passage is an issue (it may be pointless to ensure passage at a structure if there are barriers just above or below which cannot be overcome). These barriers may be man-made (such as dams and other culverts) or natural (like waterfalls and rapids). If an artificial downstream barrier exists opportunities for fish passage should not be foreclosed. The option of restoring passage over that barrier needs to be assessed in terms of feasibility, the likely timeline and responsibility for the restoration of passage.

- **The timing of fish migrations, duration and their flow requirements**. The timing of migrations can be used to set the flows at which the design will need to provide passage, and help to schedule construction to minimise disruption to fish migration. The timing of migration may vary slightly between years and location.

- **Altitude and distance from the sea** The few diadromous fish species which are found at high elevations (> 200 m) have good climbing abilities and can negotiate sections of river that are impassable to lowland species. Fish passage requirements at such sites need not be as stringent as at lower elevations. Determining which species, if any, are present at what densities is therefore essential.

ASSESSMENT OF AN IN-STREAM STRUCTURE

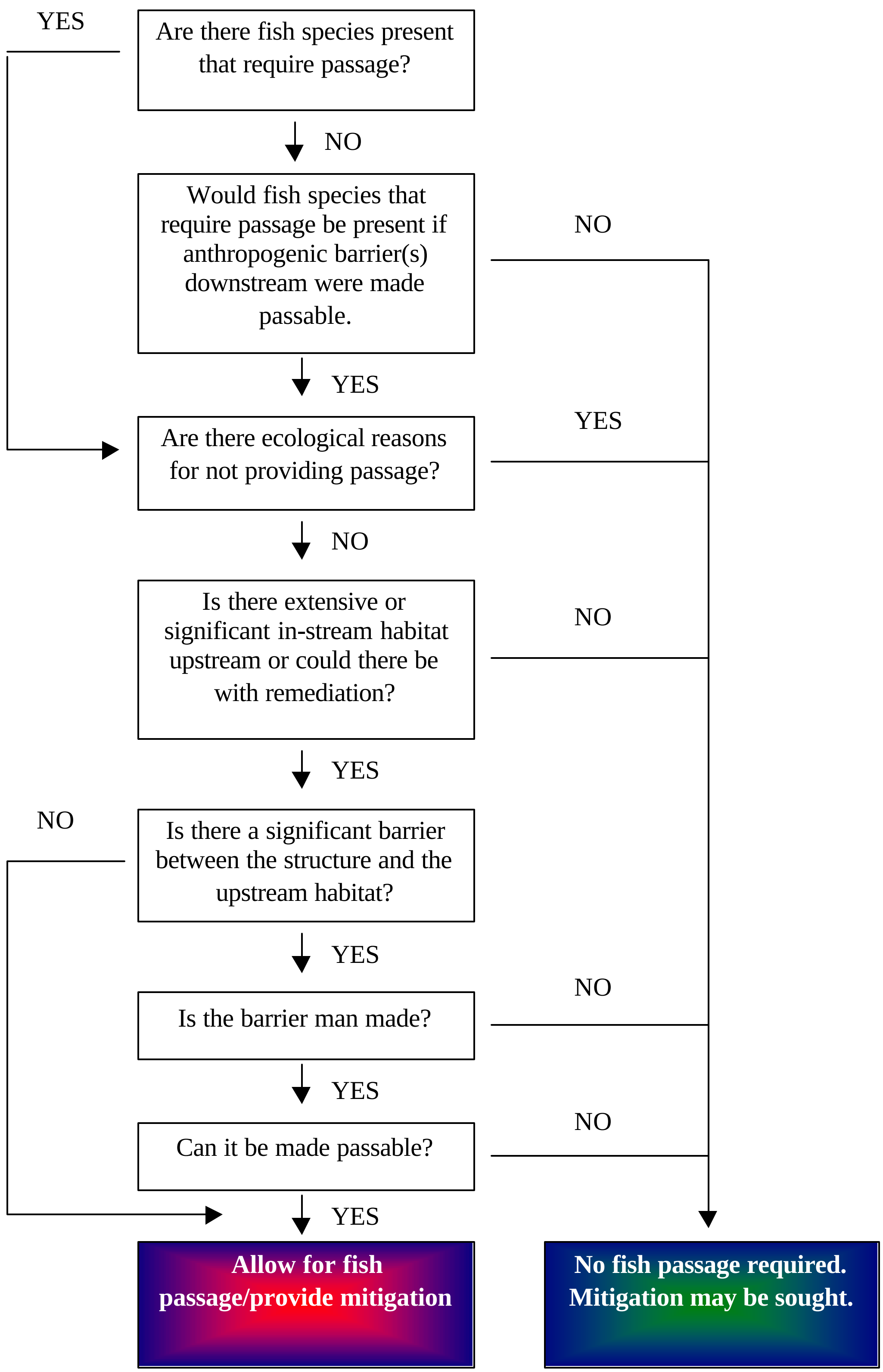


Figure 2: Flow chart to aid in the assessment of potential in-stream fish barriers.

5.0 BARRIERS TO FISH PASSAGE IN THE AUCKLAND REGION

Several types of barriers were identified in a survey of key catchments within the Auckland Region (Evans and Glover 1999). Some were natural features such as waterfalls, rapids, chutes and debris jams (Plates 1 and 2).

In addition to these natural access problems, artificial barriers created by urban development have consistently ignored the needs for indigenous fish passage to and from the sea. The most common of these artificial barriers in the Auckland Region are the badly positioned or undersized culverts (Plates 3 and 4). Other types of barriers include fords (Plate 5), dams and diversion structures (Plates 6 and 7), weirs (including flow measuring weirs, Plate 8), channelisation (Plate 9), bed erosion control (Plate 10), and streambed modifications (Plate 11). In many cases, water flowing over or through these structures was found to be too swift (Plate 12) or too shallow (Plate 13) for fish to pass through with ease. Means of preventing these problems at construction, and retrofitting options where the structure already exists, are shown in Plates 3 to13.

The flashy nature of Auckland streams which, combined with prolonged periods of very low flows, can also severely limit fish passage. The high flows not only require the installation of very large in-stream structures, but also result in a very high incidence of bank and streambed erosion. During low flows, although indigenous fish are well adapted to survive in shaded remnant pools, upstream passage of new recruits is often limited by water depth.

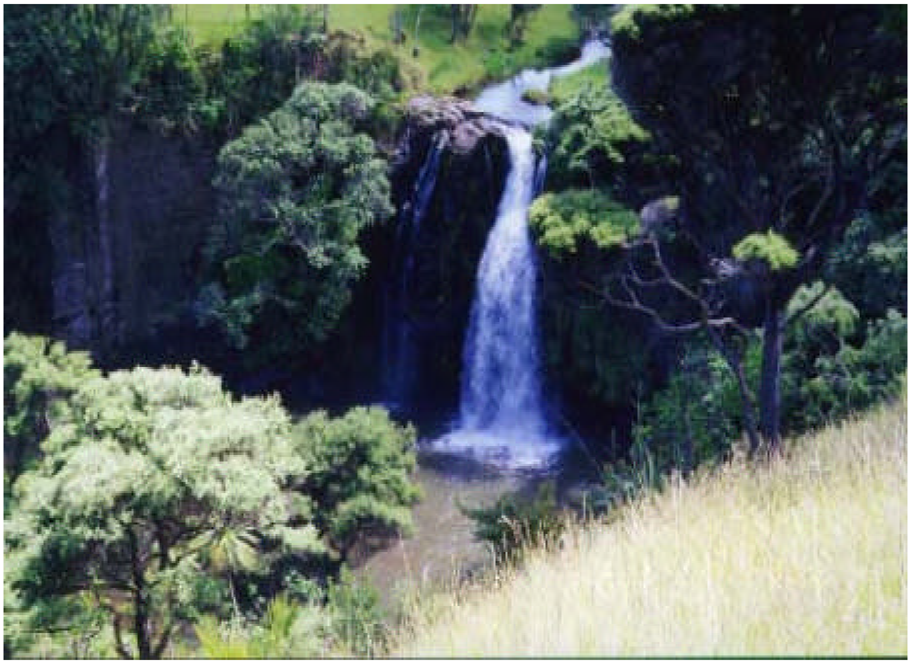


Plate 1: Waterfall on Okiritoto Stream. Most fish species, except for elvers and climbing galaxiids (i.e. koaro and banded kokopu), would find such natural structures impassable. Only climbing species, or species able to form landlocked populations, need to be considered above such natural structures.

Plate 2: Rapids on Okiritoto Stream. Most fish species, except for poor climbers like mullet, smelt and inanga, would easily negotiate such features.

EXISTING PROBLEM

Climbing fish species are unable to reach the culvert at low flows, and barrel velocities are too great at medium and high flows.

SOLUTIONS AT CONSTRUCTION

- Use a large culvert with the invert (i.e. the culvert floor) positioned below the streambed.
- Construct notched water/bed level control device at outlet.
- Armour streambed.
- Armour stream banks.

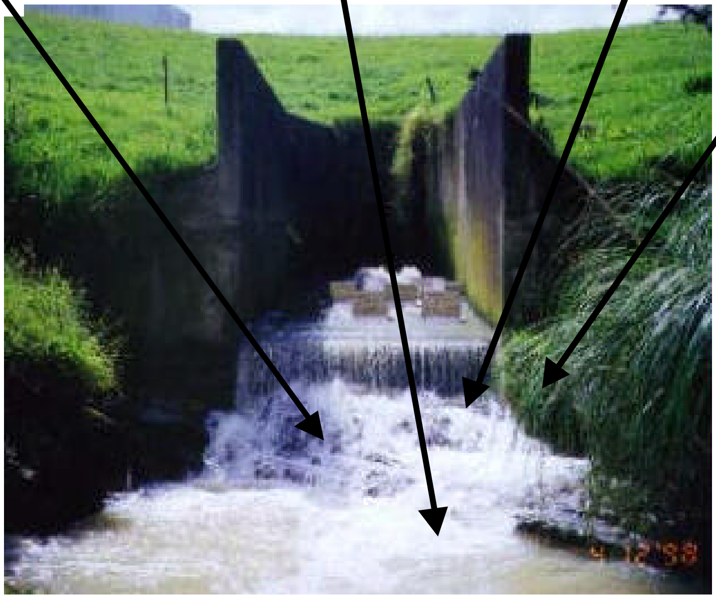
RETROFITTING OPTIONS

- Build notched weir(s) downstream of the outlet to flood the toe of the culvert (also see Fig. 3, Page 30).
- Armour stream banks with rocks and mortar to create a rounded headwall.
- Insert baffles or spoilers on culvert invert to reduce water velocities at low and medium flows.

Plate 3: Small culvert with overhanging outlet on Puhinui Stream.

EXISTING PROBLEM

High water velocities, turbulent flows at outlet, vertical drop at end of outlet apron, and no wetted margins for climbing species.



SOLUTIONS AT CONSTRUCTION

- Use a larger culvert.
- Set culvert invert below streambed.
- Armour stream banks with riprap.
- Armour streambed.
- Construct a dished apron to accommodate low flows.

RETROFITTING OPTIONS

Preferred option:

- Fill streambed with rocks and mortar to remove vertical drop.
- Construct flow control weir(s) downstream of outlet to flood the toe of the culvert and create resting pools.

Climbing species option:

- Install climbing media along culvert wall (e.g. brush material).
- Install access ramp.

Plate 4: Culvert on Oteha Stream.

EXISTING PROBLEM

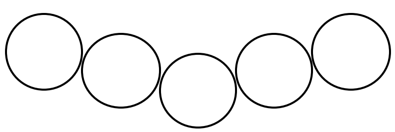
High barrel velocities restrict upstream fish passage to low flow periods and to anguilliform locomotors and climbers only. Some passage possible during floods when the ford is overtopped.

SOLUTION AT CONSTRUCTION

Option 1:
- Use bridge (pictured above ford).

Option 2:
- Use large arch shaped culvert with the invert positioned below the streambed.

Option 3:
- Construct multi-barrel system of culverts, with the culverts closest to stream banks sitting higher than the central culvert(s) (see below).



High water velocities

Plate 5: Ford on Oratia Stream.

RETROFITTING OPTIONS

- Remove structure.
- Construct flow control weir(s) to increase the depth of water throug the ford.
- Remove a section of the ford and bridge over the gap (cattle stop concept).

Existing problem

Fish passage limited to climbing species only. Upstream and downstream passage prevented by permeable rock bed below dam.

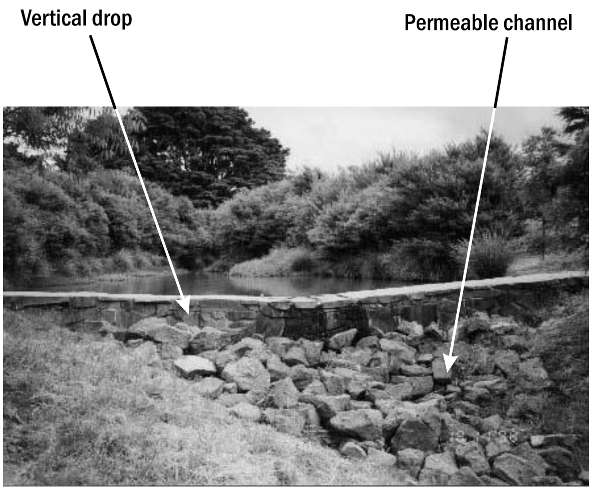


Plate 6: Low dam on Puhinui Stream.

Solution at construction

- Construct a sloping dam face that incorporates a low flow channel or;
- construct a bypass channel along one of the banks or;
- construct a fishway.

Retrofitting options

- Create an artificial channel on dam face by filling the dam face with smaller rocks grouted into place to prevent water seepage or;
- construct a bypass channel along one of the banks or;
- construct a fishway.

Existing problem

Fish passage limited to climbing species only.

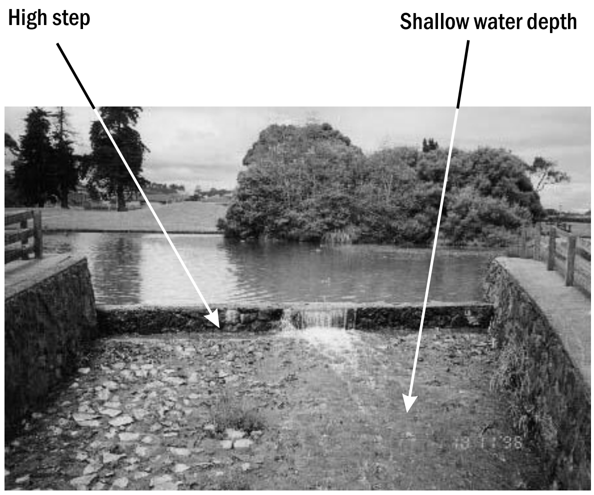


Plate 7: Dam spillway on Puhinui Stream.

Solutions at construction

- Construct the weir crest on a slope (or with a notch). Create a pool and weir channel on the spillway. Ensure there are no steps or velocity barriers anywhere between the toe of the spillway and the head pond.
- Alternatively, construct a bypass channel along one bank.

Retrofitting options

Option 1:

- Build a fish pass on the spillway.

Option 2:

- Notch the weir and form a pool and weir channel in a zigzag pattern down the spillway face.

Option 3:

- Construct a natural channel on one side of the spillway. (Ensure that the channel entry is at the base of spillway.)

Existing problem

Fish passage limited to climbing species only.

Plate 8: Flow measuring weir on Meola Creek.

Solutions at construction

- Build a natural rock weir and calibrate.

Retrofitting options

Option 1:

- Remove concrete structure and construct a stable calibrated reach with rocks and mortar.

Option 2:

- Fill downstream end of wall with rock and mortar to create a climbing surface - recalibrate weir.
- If swimming species require passage, construct notched rock weirs downstream to flood the existing weir at low and medium flows - recalibrate weir.

Existing problem

Fish passage problems include high water velocities at medium and high flows, no in-stream features where fish can rest, feed, or take refuge. Lack of shading leads to increased water temperature.

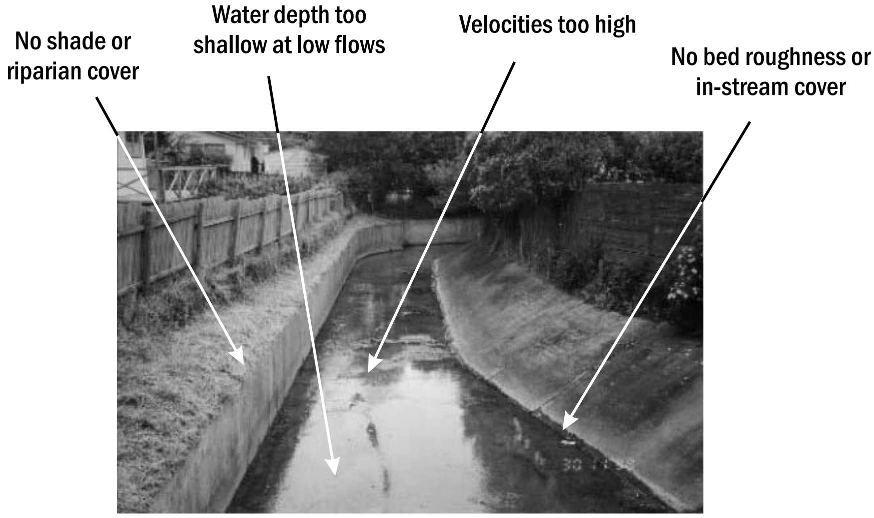


Plate 9: Channelised section on Awaruku Stream.

Solutions at construction

- Use rock and mortar (at least on one bank) to create a "natural" stream bed.
- Use large rocks in channel to create resting areas and reduce water velocities at medium to high flows.
- Plant vegetation along bank to provide shade and cover.

Retrofitting options

- Plant shade species along channel banks.
- Insert large rocks in the channel to create diversity.
- Cement rocks along one side of the channel to help reduce velocities and provide resting areas for fish.
- Remove sections of the smooth concrete channel and rebuilt using rocks and grout so as to create pools and backwaters.

Existing problem

The upstream and downstream passage of fish is not possible except during high flows when the weir is overtopped.

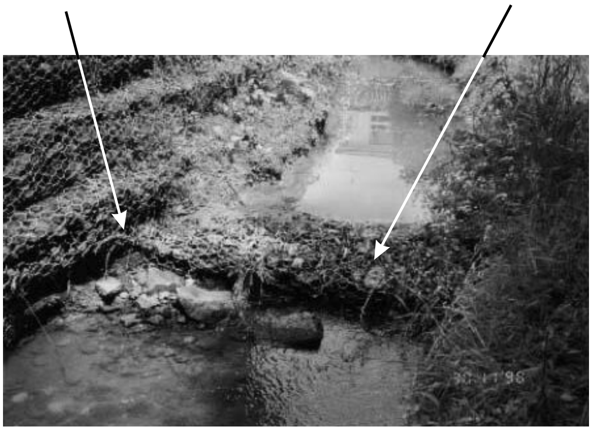


Plate 10: Water permeable erosion control weir on Awaruku Stream.

Solutions at construction

- Use rocks to create a notched weir.
- Plant shade species.
- Use large rocks to stabilise the stream banks.

Retrofitting options

Option 1:

- Remove gabion basket and replace with one or more notched large rock weirs.

Option 2:

- Create notch in existing gabion basket and grout gabion basket.

Option 3:

- Add one or more notched rock weirs downstream to flood existing weir.

Existing problem

Passage possible for climbing species only (Note also the permeable erosion control mattress and steep drop at top of ramp).

Plate 11: Steep bedslope modification at entry of culvert on an unnamed tributary of Weiti Stream.

Solutions at construction

- Regrade upstream channel to even out slope. Insert notched rock weirs if required.
- Dish inlet apron and use rocks to produce a low velocity zone along the margins at all flows.
- Use embedded rocks on channel floor and banks to prevent erosion. Do not create steps or velocity barriers in the channel.

Retrofitting options

Option 1:

- Remove ramp if passage for swimming species is required and regrade upstream reach.

Option 2:

- If only climbing species are present reshape apron (dish and roughen surface) to allow passage at medium flows.
- Grout channel floor.

Existing problem

Passage restricted for weak swimmers. No substrate available for anguilliform locomotion.

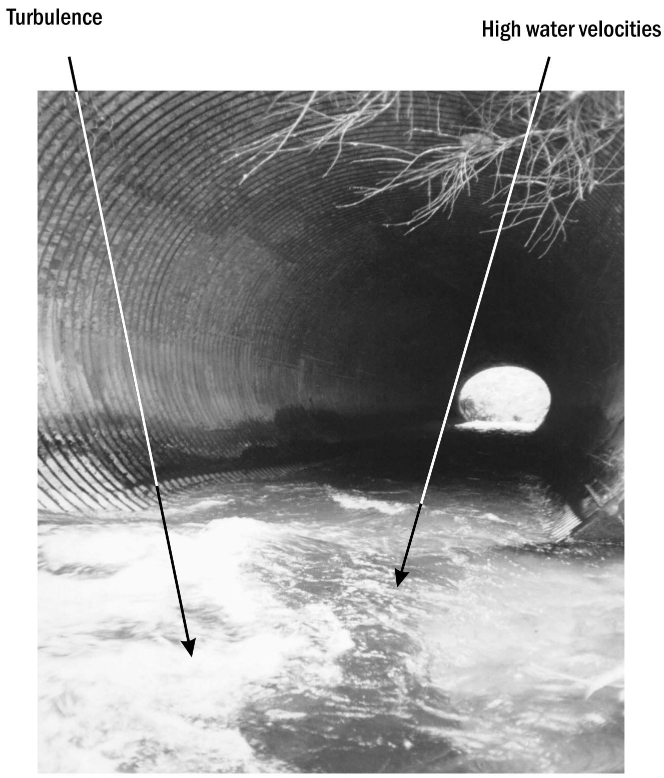


Plate 12: Fast turbulent flows through culvert.

Solutions at construction

- Install the culvert with the invert positioned below the streambed.
- If required, insert rocks or baffles on the floor of the culvert.
- Build notched weir(s) at outlet to flood the toe of the culvert.
- Create bevelled headwall at inlet and outlet.

Retrofitting options

- Build notched weir(s) at outlet to increase water depth in culvert.
- Insert baffles or spoilers on floor of culvert to reduce water velocities.
- Build rounded rock headwall to help reduce turbulence at inlet and outlet.

Existing problem

Passage limited to climbing species only.

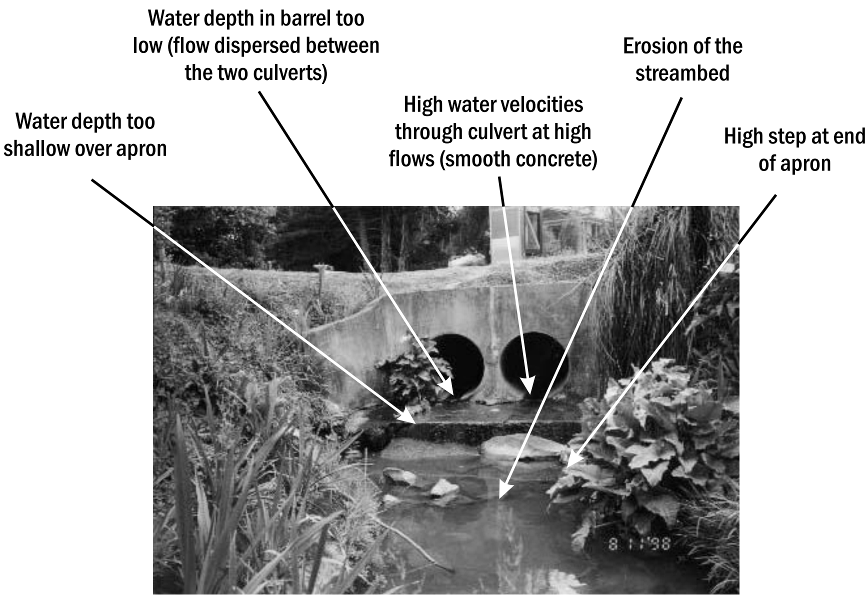


Plate 13: Water level too low in culvert and over downstream apron.

Solutions at construction

- Armour stream banks
- Armour streambed

Option 1:

- Build a single large culvert with the invert positioned below the streambed.

Option 2:

- Place one barrel lower than the other to cater for passage during low flow conditions.
- Include rocks on barrel floor or insert baffles to reduce water velocities through the culvert.

Retrofitting options

- Insert spoilers or baffles to reduce water velocities through the culvert barrel.
- Partially block off one of the culverts at the inlet to concentrate water through one culvert during low flows.
- Build notched weir(s) downstream of apron to flood the toe of the culvert.
- Dish apron (or flood).

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.

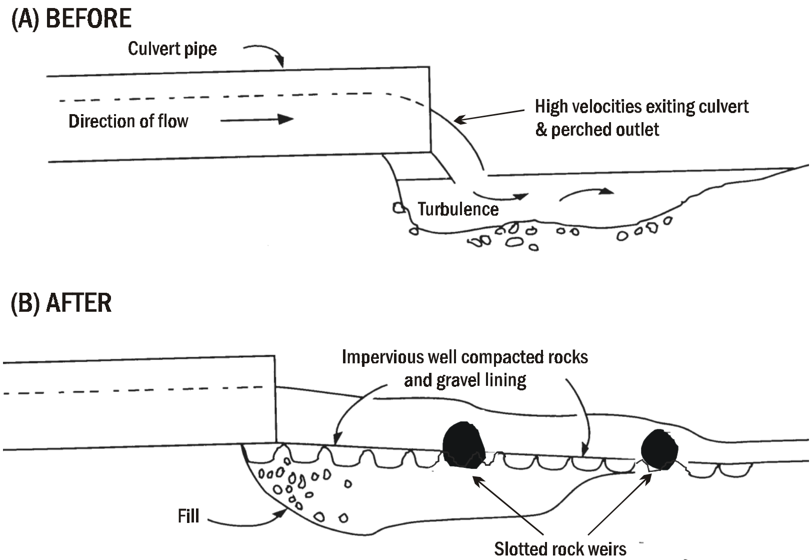


Figure 3: A retrofitting option for perched culverts using rock weirs and fill (modified from Clay 1995).

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.

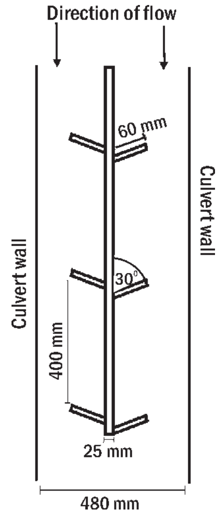


Figure 4: Baffle design that allows passage of NZ species. The height of the baffle in this example was 60 mm (from Boubée et al. 1999).

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.

No-slope Design (Stream slope)	Conditions met?
Culvert installed at **same slope** and aligned with natural stream channel.	☐
Culvert width equal to or greater than **average streambed width.**	☐
Culvert **invert countersunk** (minimum 20% of culvert diameter).	☐

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

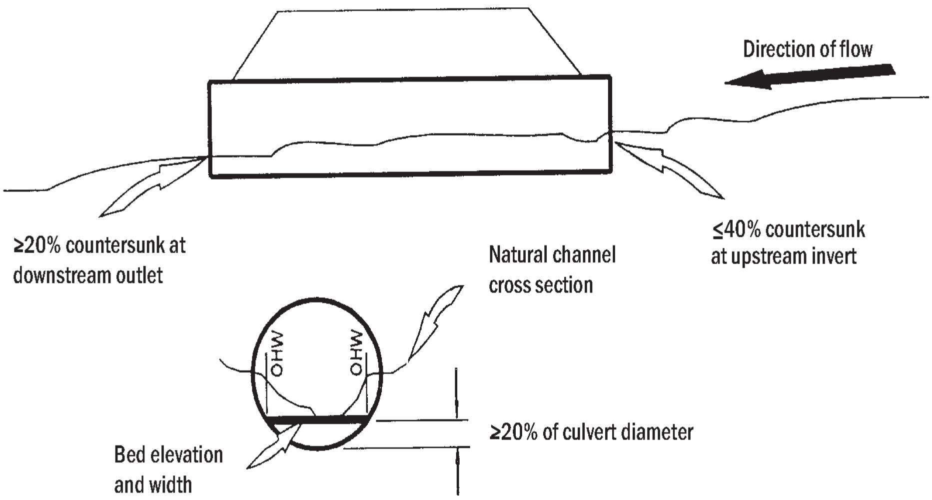


Figure 8: Stream Simulation design assessment diagram for culverts. All conditions need to be met before the design can be considered acceptable.

Stream simulation design	Conditions met?
Culvert width equal to or greater than **average streambed width.**	☐
Culvert **invert countersunk.**	☐
(1) Culvert installed at **same slope** and **aligned** to stream channel (preferred situation) or (2), / (2) Culvert installed at **same alignment** and a **steeper slope** than natural stream channel.	☐
Bed retention devices installed on culvert floor, or shown to be unnecessary.	☐
Water/bed level control devices at inlet/outlet installed or shown to be unnecessary (no risk of erosion).	☐
Stream banks and streambed at inlet/outlet **armoured with riprap** or shown to be unnecessary.	☐
Long term monitoring of channel bed stability. Maintenance programme in place.	☐

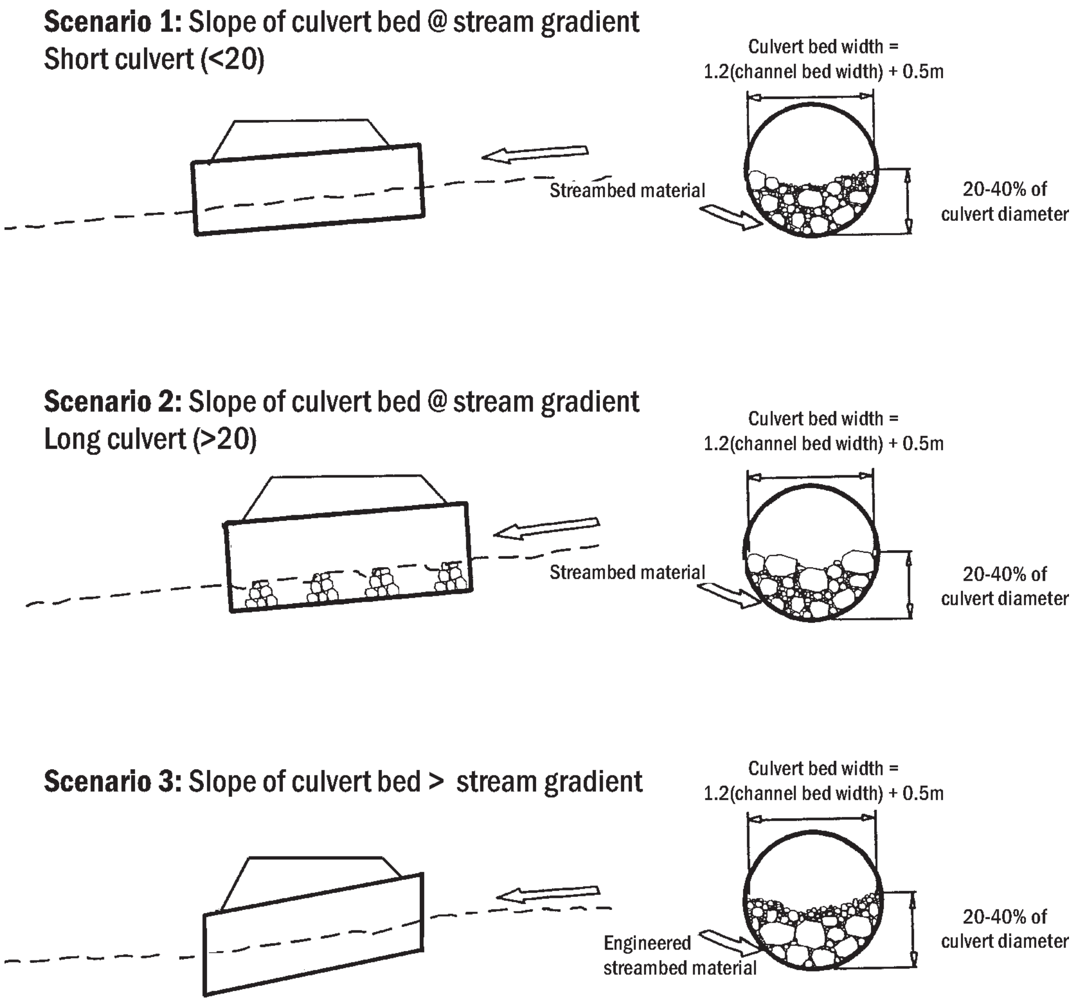


Figure 9: Stream simulation culvert design scenarios (modified from Bates 1999). Care needs to be taken when inserting rubble onto the floor of the culvert as at low flows all the water can disappear into the substrate. In the above diagram we stipulate that 20-40% of the culvert diameter should be filled 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.

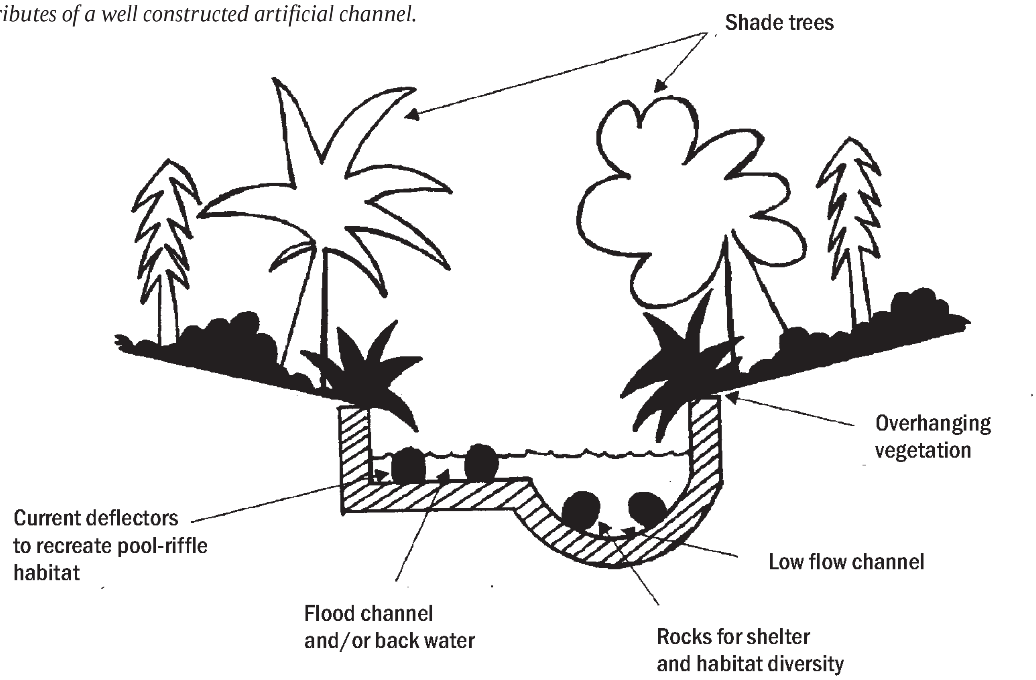
6.2 Low weirs and water/bed level control devices

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).

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.

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).

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)

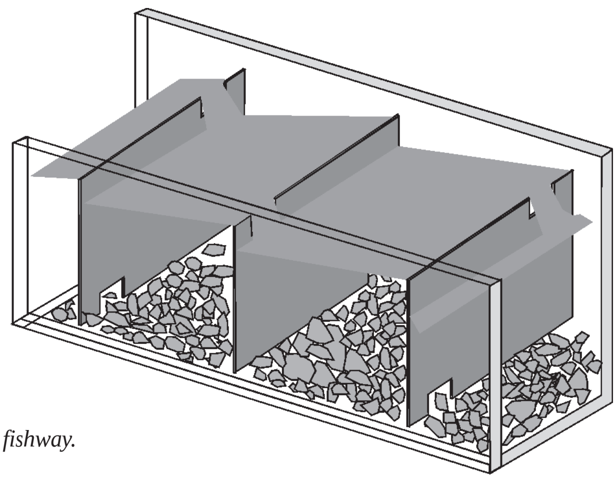


Figure 13: Diagram of weir (pool) type fishway.

Vertical slot fishways

The basic design of a vertical slot fishway is a rectangular channel partitioned by baffles into resting pools. When the water is flowing the fish swim from pool to pool through vertical slots that are orientated vertically. The advantage of this design is that passage is possible at a variety of water levels (Plate 21, Fig. 14). Passage of small, bottom dwelling species can be achieved by lining the floor of the channel with rocks. For surface orientated weak swimmers the velocity between the slots can be adjusted and/or baffles installed along the wall of the fishway at the appropriate level.

Plate 21: Vertical slot fishway retrofitted to a small power plant.

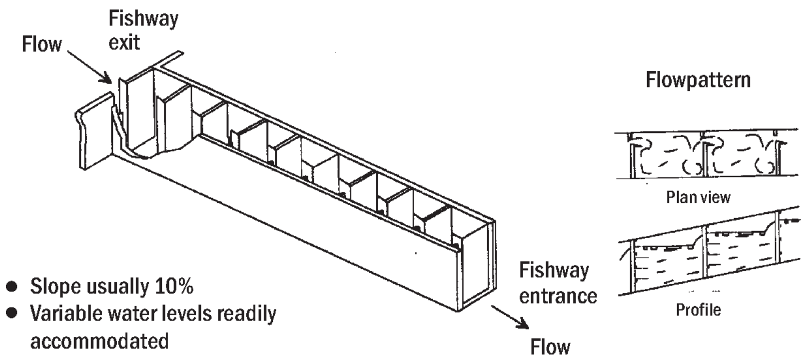


Figure 14: Characteristics of a vertical slot fishway (from Office of Technology Assessment 1995).

Plate 22: *Denil fishway.*

Denil fishways

The Denil fishway is essentially an artificially roughened channel. The basic design of a Denil fishway is a rectangular chute with baffles pointing upstream extending from the sides and bottom. (Plate 22, Fig. 15). The design can be adjusted to allow passage of weak swimmers.

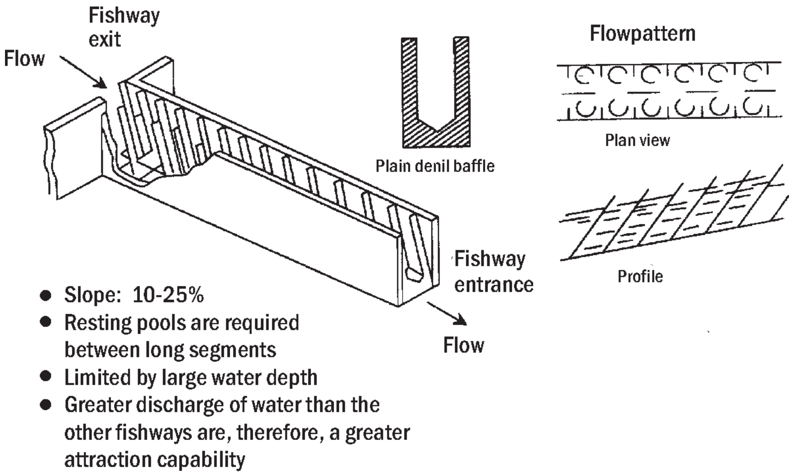


Figure 15: Characteristics of a Denil fishway (from Office of Technology Assessment 1995).

Eel ladders

Eel ladders are rectangular channels lined with gravel or projections through which fish weave their way upstream (Plate 23, Fig. 16). The projections can be nylon bristles or pins mounted onto a base vertically, and spaced at a distance that is appropriate for the target species. Different spacing regimes within the same channel may be used if required. The channel can be made of wood, plastic, or metal, and should preferably be set at an incline to allow for changes in water depths. Water for the pass can enter directly into the pass at the exit or be pumped into it. It is essential to include an attraction flow at the bottom of the pass. Trials undertaken in New Zealand have shown that such passes are effective for climbing galaxiids such as banded kokopu. When positioned at a low slope eel ladders can allow the passage of bullies over short distances.

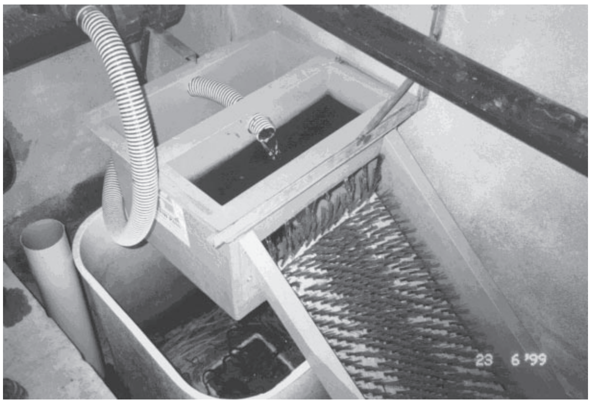


Plate 23: Eel ladder and trap.

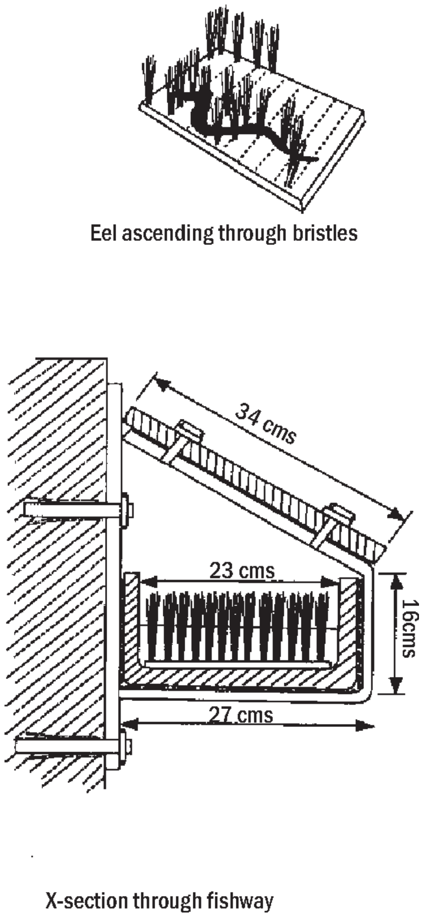


Figure 16: The basic principle of the eel ladder (taken from Clay 1995).

2) Nature-like fishways

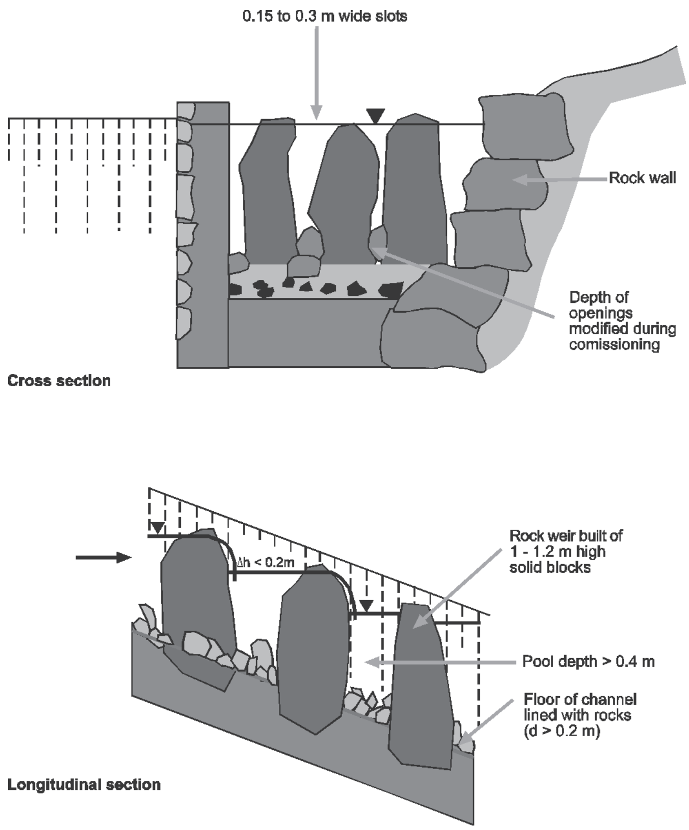
There are three basic designs for nature-like fishways:

- rock-cascade fishways (Fig 17).
- ramp type fishways (Plate 24).
- nature-like bypass channels (Fig 18 and Plate 25).

Rock-cascade fishways

The rock-cascade fishway combines elements of fish ramps and pool-type fishways (Fig. 17). The construction is similar to pool-type fishways, but the baffles are made of boulders and the flow passes through vertical slots between the boulders. The main advantage of this type of pass is that it allows for both the upstream and downstream passage of a variety of species, especially those using the anguilliform type of locomotion. Generally these types of fishways are much cheaper to build and maintain than traditional fish passes.

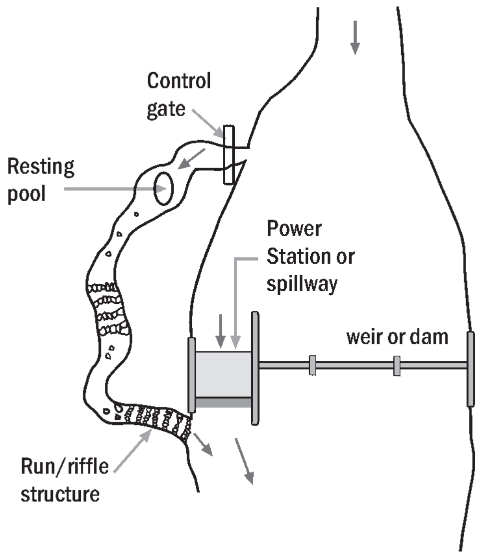
Figure 17: Principle of the rock-cascade fishway.



Ramp type fishways

These fishways consist of boulder ramps that either cover the whole width or a section of the barrier (Plate 24). The main advantage of this type of fishway is that it blends into the surrounding landscape. This type of fishway is ideal where the catchment is prone to flood and erosion. The construction materials (rocks) should be readily available (Harris et al. 1998). Where the catchment is subjected to periods of low flows, the rocks must be grouted to ensure that water is flowing over (and not through) the structure at all times. Low flow channel(s) must be incorporated into the ramp design.

Plate 24: Rock ramp type fishway over a spillway section of an irrigation dam. Note the low flow channel.



Nature-like bypass channels

Bypass channels offer an alternative route around a weir with a nature-like stream (Fig. 18 and Plate 25). This type of fishway has a range of applications and is suitable for all barriers if there is sufficient space. Nature-like bypass channels are particularly useful for upgrading existing installations. These types of fishways are considerably cheaper to construct than traditional fish passes. They are negotiable by most fish species and blend into the surrounding landscape. Care must be taken to ensure that the velocity at the channel inlet and outlet can be negotiated by all species. This is particularly important where flow control devices (e.g. gates) are installed.

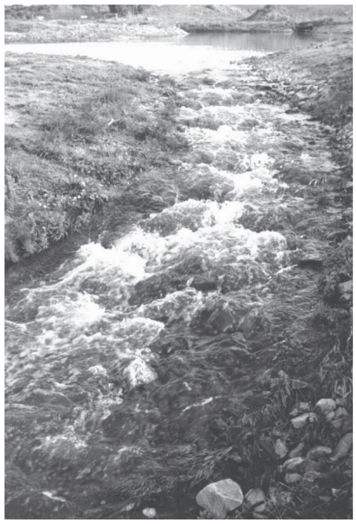


Plate 25: Upper section of a nature-like bypass channel constructed to allow passage of indigenous fish species over a weir. Note the low velocities along the margins.

Figure 18: Principle of the nature-like bypass channel.

3) Fish lifts and fish locks

Experience both here and overseas has shown that fish lift and fish locks are the most effective type of fish passes for high dams. Catch and transfer operations that are successfully operating throughout New Zealand are based on this system. The concept is to attract and trap fish into an enclosure that either automatically transfers the catch upstream, or transfers it to a holding facility for manual transfer upstream. The later system is particularly useful where there are other barriers upstream. In its simplest form, the trap and transfer system consists of a trap (at most a ramp and holding bin) and a bucket for upstream transfer.

Fish lifts

Fish lifts can be defined as any mechanical means of transporting fish upstream over a dam (Plate 26). Fish pumps may also be included in this category.

Fish locks

A fish lock is a device that raises fish over dams by filling a chamber containing the fish with water until the water surface in the lock reaches or comes close enough to the reservoir level to let the fish swim into the reservoir above the dam (Fig. 19). Fish locks have a range of applications including situations where passage is required over a high dam, and where space and water are limited. The disadvantages of this method include high construction costs and ongoing operational and maintenance costs. The advantages include low water consumption. Fish locks are suitable for salmonids and weak swimming species, and less suitable for bottom-living and small fish.

Plate 26: Elver fish lift on the Arguenon Dam, France.

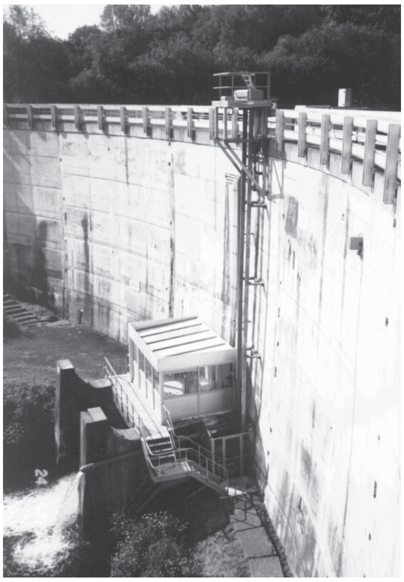
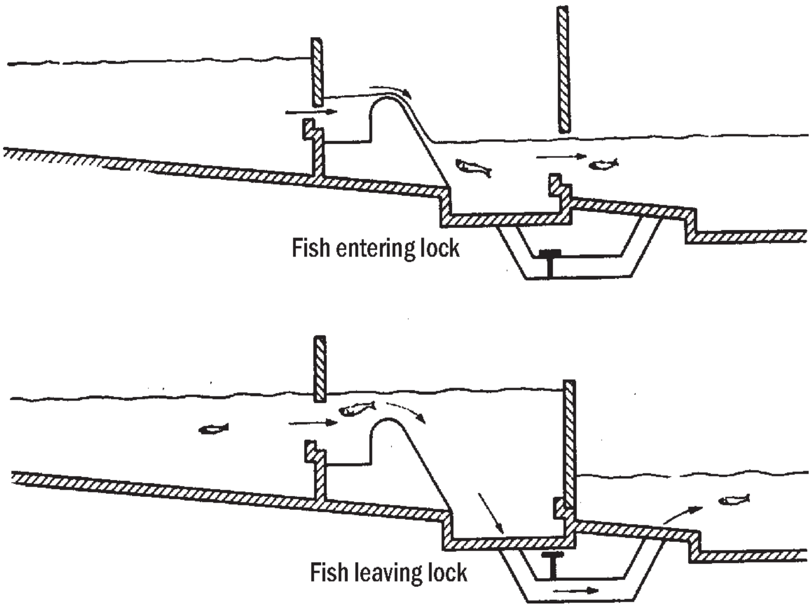


Figure 19: Schematic drawing illustrating the basic operation of a fish lock (taken from Clay 1995).



7.0 References

Bates, K.M. (1992). *Fishway Design Guidelines for Pacific Salmon.* Working Paper 1.6, 1/97. Washington Department of Fish and Wildlife, Olympia.

Bates, K.; Powers, P. (1998). *Upstream passage of juvenile coho salmon through roughened culverts.* In M. Jungwirth, S. Schmutz, and S. Weiss (eds). Fish Migration and Fish Bypass. Fishing News Books. 438 p.

Bates, K. (1999). *Fish Passage Design at Road Culverts. A design manual for fish passage at road crossings.* Washington Department of Fish and Wildlife. Olympia. http://www.wa.govt/wdfw.

Bell, M.C. (1986). *Fisheries Handbook of Engineering Requirements and Biological Criteria.* United States Army Corps of Engineers, Fish Passage Development and Evaluation Program, Portland. 290 p.

Bender, M.; Katopodis, C.; Simonovic, S.P. (1992). *A prototype expert system for fishway design.* Environmental Monitoring and Assessment 23: 115-127.

Boubée, J.A.T.; West, D.W.; Mora, A.L. (1992). *Awakino River Whitebait Fishery.* New Zealand Freshwater Fisheries Miscellaneous Report No. 129. MAF Fisheries, Christchurch.

Boubée, J.A.T.; Jowett, I.; Nicols, S.; Williams, E. (1999). *Fish Passage at Culverts: A Review, with Possible Solutions for New Zealand Indigenous Species.* Joint NIWA/DOC publication, 118 p.

Clay, C.H. (1995). *Design of Fishways and other Fish Facilities.* Second Edition. CRC Press, Inc., Boca Raton. 248 p.

Evans, B.; Glover, D. (1999). *Barriers to fish passage in the Auckland Region; Identification of barriers and monitoring the effect on native fish migration.* Internal Report, Auckland Regional Council.

Harris, J.H.; Thorncraft, G.; Wem, P. (1998). *Evaluation of rock-ramp fishways in Australia.* In M. Jungwirth, S. Schmutz, and S. Weiss (eds). Fish Migration and Fish Bypass. Fishing News Books. 438 p.

Hauer, F.R.; Lamberti, G.A. (1996). *Methods in Stream Ecology.* Academic Press, San Diego, California. 674 p.

Jowett, I.; Richardson, J. (1995). *Habitat preferences of common, riverine New Zealand native fishes and implications for flow management.* New Zealand Journal of Marine and Freshwater Research 29: 13-23.

Jungwirth, M.; Schmutz, S. (1996). *International conference on Fish migration and fish bypass-channels.* 24-16 September 1996, Vienna Austria. Published by the Department of Hydrobiology, Fisheries and Aquaculture, University of Agricultural Sciences, Vienna .

Mitchell, C.P. (1989). *Swimming performances of some native freshwater fishes.* New Zealand Journal of Marine and Freshwater Research 23: 181-187.

Mitchell, C.P.; Boubée, J.A.T. (1989). *Investigations into Fish Pass Design.* Stage I. New Zealand Freshwater Fisheries Miscellaneous Report No. 50. MAF Fisheries, Rotorua. 21 p.

Mitchell, C.P.; Boubée, J.A.T. (1995). *Evaluations of Materials to Allow Fish Passage Past Huntly Power Station.* Report to ECNZ by Mitchell and Associates. 10 p.

Newbury, R.W. (1996). *Dynamics of flow.* Pp 75-92. In F.R. Hauer and G.A. Lamberti (eds). Methods in Stream Ecology, Academic Press, San Diego, California.

Office of Technology and Assessment. (1995). F*ish Passage Technologies: Protection at Hydropower Facilities.* OTA-ENV-641. Government Printing Office, Washington, DC. 167 p.

Stancliff, A.G.; Boubée, J.A.T.; Palmer, D.; Mitchell, C.P. (1988). *The upstream migration of whitebait species in the lower Waikato River.* New Zealand Freshwater Fisheries Report No. 96. Ministry of Agriculture and Fisheries. 44 p.

Swales, S. (1989). *The use of instream habitat improvement methodology in mitigating the adverse effects of river regulation on fisheries.* Pp. 185-208. In: J. Gore and G. Petts (eds.). Alternatives in Regulated River Management. C.R.C. Press, Boca Raton, FL.