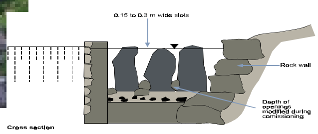
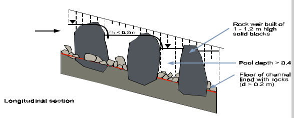
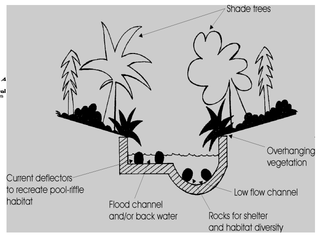
# fish passage guidelines

# 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.

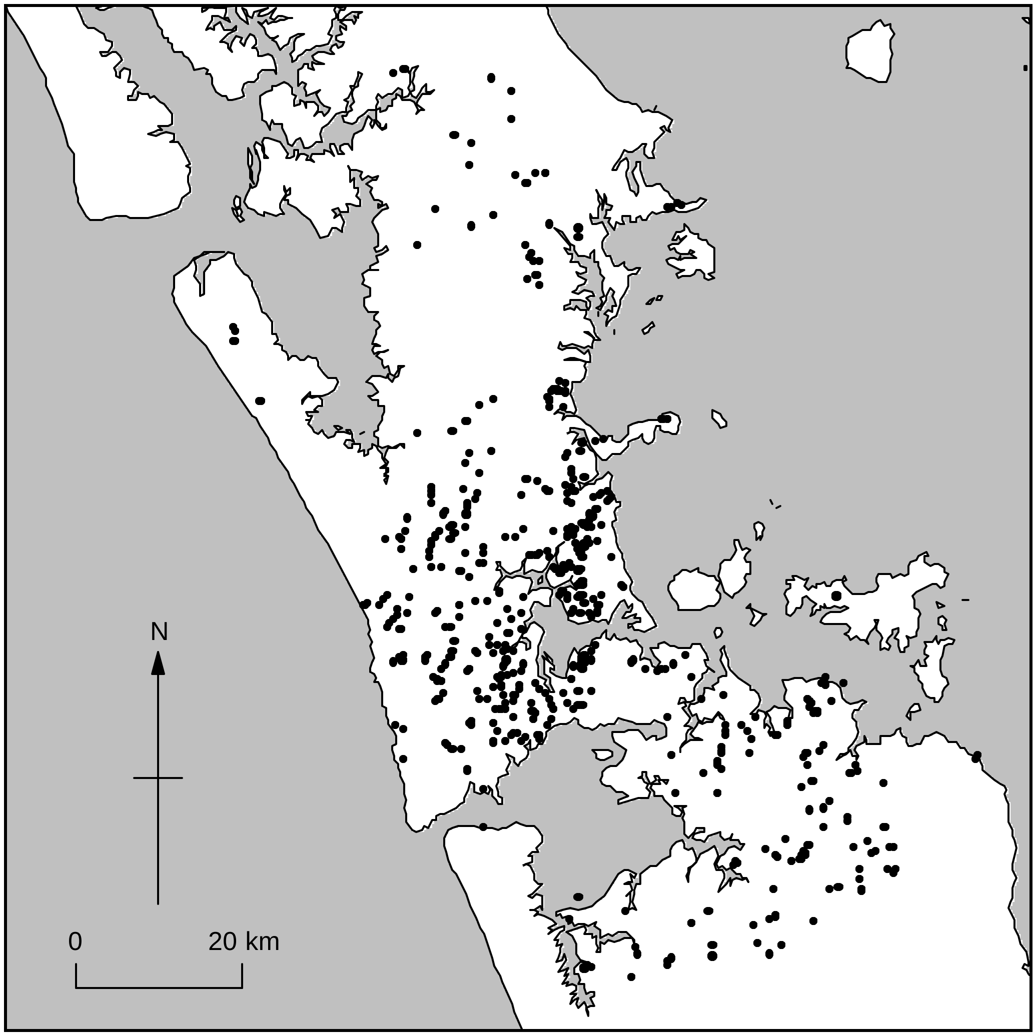



**Figure 1:** Location of sites within the Auckland Region where freshwater fish information is available on the New Zealand freshwater fish database.

**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<br>2.14–3.97 | Steady speed<br>Burst speed | <br>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

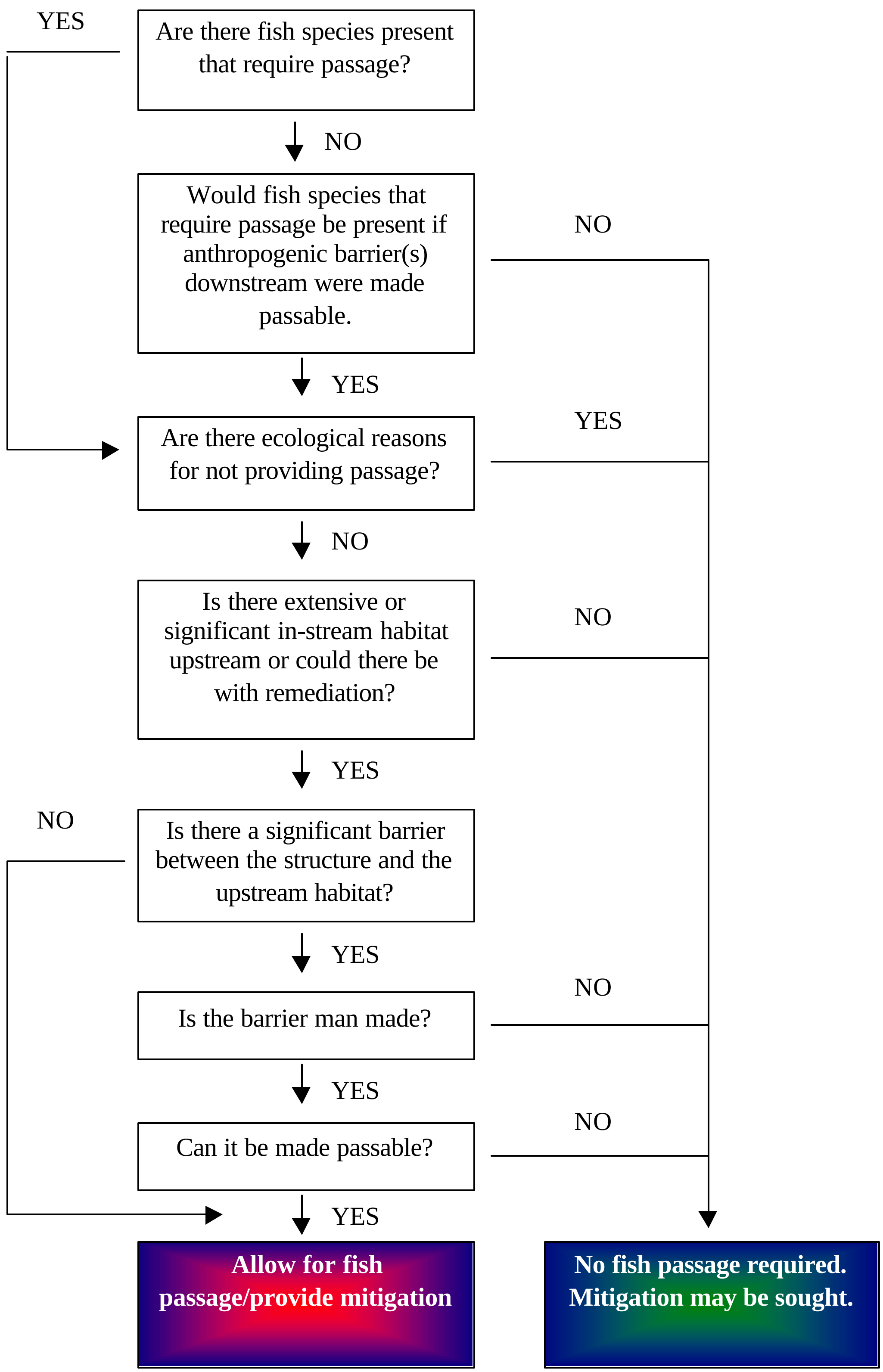



**Figure 2:** Flow chart to aid in the assessment of potential in-stream fish barriers.

## 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.

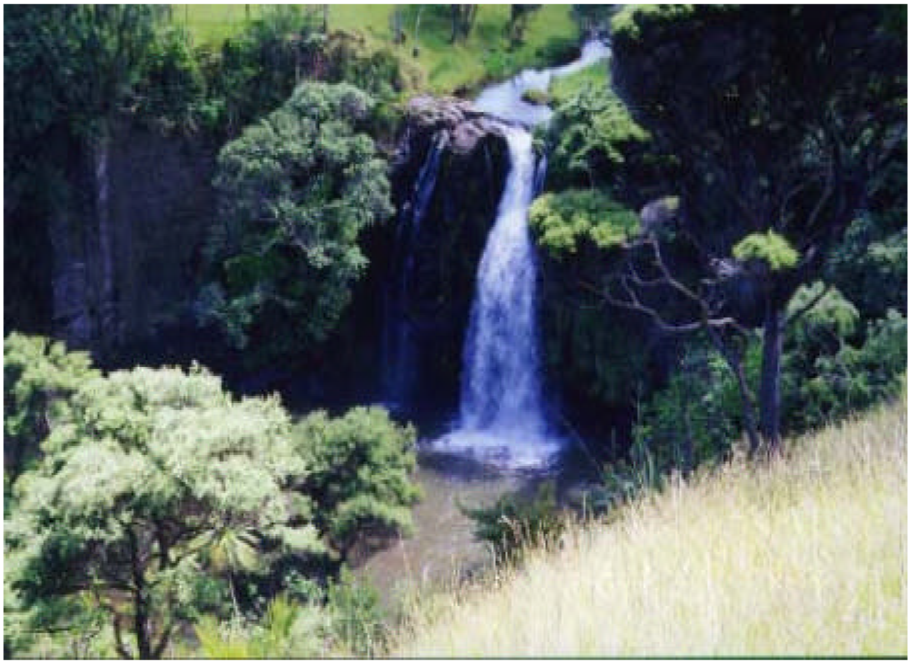


**Plate 1:** Waterfall on Okiritoto Stream. Most fish species, except for elvers and climbing galaxiids (i.e. koaro and banded kokopu), would find such natural structures impassable. Only climbing species, or species able to form landlocked populations, need to be considered above such natural structures.

**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.

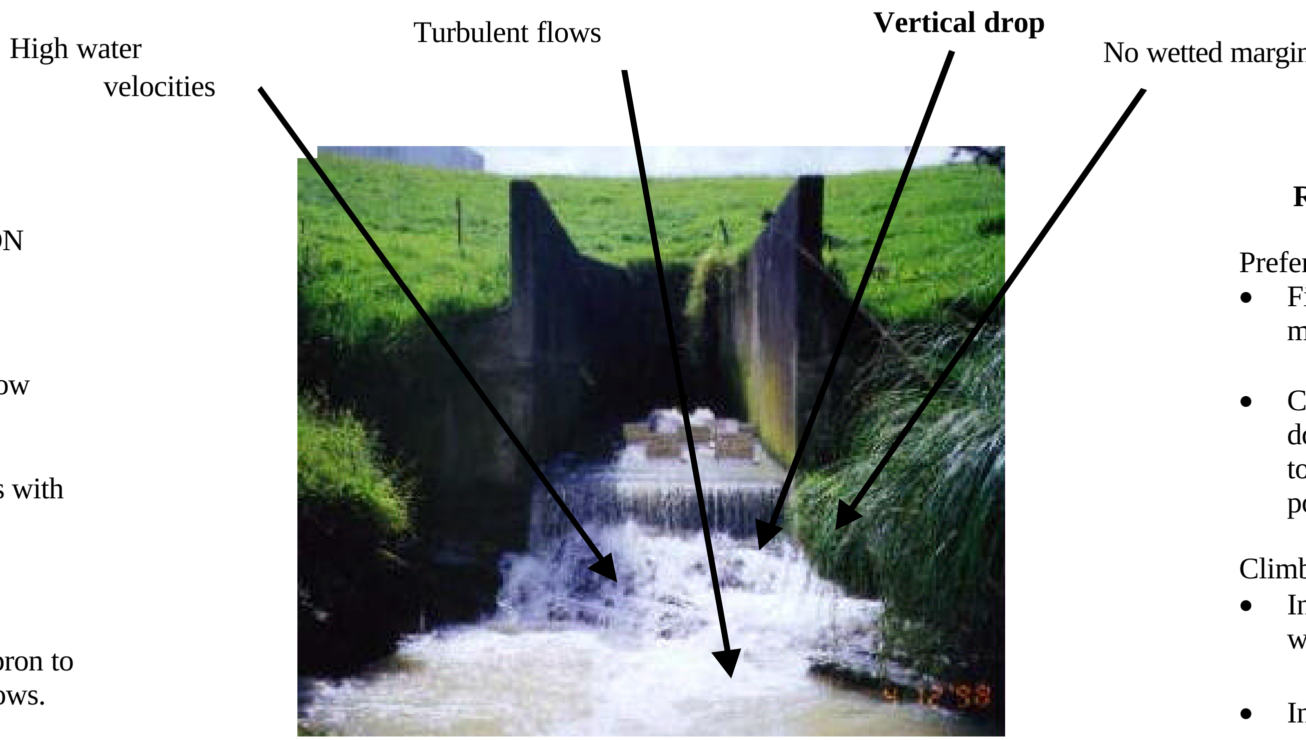
**Plate 3:** Small culvert with overhanging outlet on Puhinui Stream.

**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:

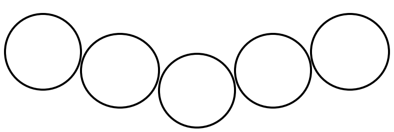
- Use bridge (pictured above ford).

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).




**RETROFITTING OPTIONS**

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

**Plate 5:** Ford on Oratia Stream.