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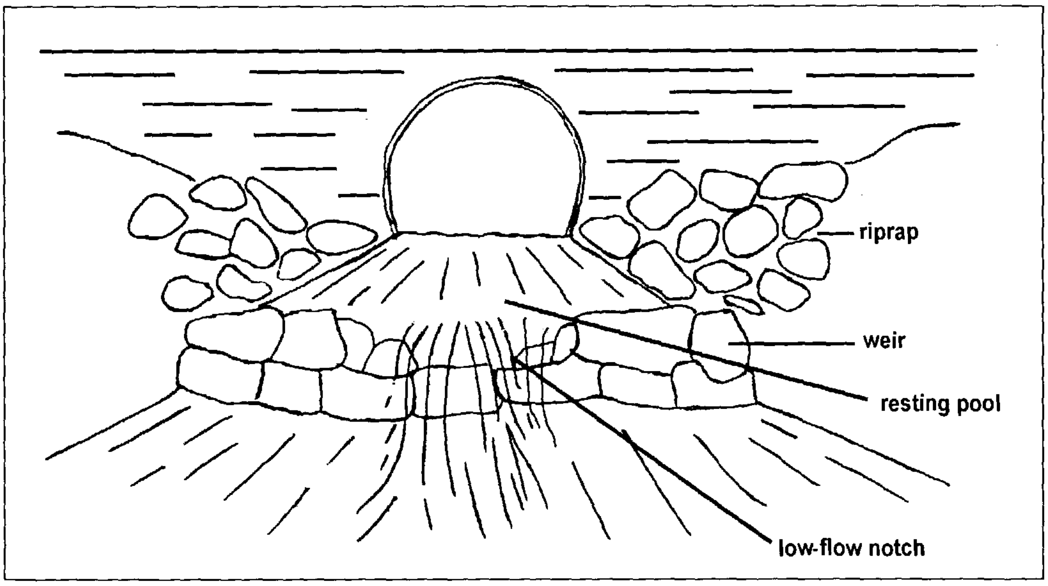

Figure 25. Resting pool concept at a culvert outlet. Note low-flow notch and the use of riprap for bank protection.

Where stream erosion is a problem, the banks must be protected (Plate 5). However, riprap near the inlet should be firmly anchored to prevent it being knocked loose and accumulating in the inlet or barrel, thus increasing velocities and impairing the culvert's design capacity.

Table 4. *Size of bed material mobilised by differing water velocities (from Evans and Johnston 1974).*

Material		Diameter (mm)	Mean velocity (m s^{-1})
Silt		0.005	0.12
Sand	Fine	0.05	0.2
	Medium	0.25	0.3
	Coarse	1	0.55
Gravel	Fine	2.5	0.65
	Medium	5	0.8
	Coarse	10	1
Pebbles	Fine	15	1.2
	Medium	25	1.4
	Coarse	40	1.8
Rubble	Small	75	2.4
	Medium	100	2.7
	Large	150	3.3
Boulders		200	3.9

The minimum water depth to be provided in the culvert by the outlet pool is recommended by Dane (1978a and 1978b) as 0.23 m above the bottom or the lowest point of fish passage structures (e.g. baffles). Other recommendations are specific to particular species. In more general terms, and more applicable to New Zealand, Dane (1978a) also refers to a depth that submerges the largest fish that will use the culvert. Most of New Zealand's indigenous freshwater fish species are small, can spend some time out of water, and have good climbing abilities. Therefore water depth and weir slope could be manipulated to exclude larger species such as trout. However, passage of these larger species could still occur at higher discharges.

10 ASSESSING AND INSTALLING FISH-FRIENDLY CULVERTS

This section provides guidance for the construction and retrofitting of culverts that will not block the migration of freshwater indigenous fish species. Although primarily aimed at road crossing culverts, some of the solutions proposed are applicable to the numerous low head weirs and artificial channels that can also impede fish passage. As additional information is gathered, concepts and guidelines developed here will need to be incorporated into any future review and update.

10.1 Choice and positioning of structure

All stream crossings have the potential to affect the aquatic habitat and its biota. It is therefore essential that that the number of new stream crossings is minimised through proper planning. When a stream crossing is shown to be essential, bridges are usually the best option for ensuring fish passage. However, the proper choice of culvert and correct installation will reduce the impact on the habitat and ensure fish passage. To minimise the length (cost) of a culvert, it often desirable 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 up stream and down stream end of the culvert and the important loss of energy dissipation capacity caused by the shortening of the channel. Therefore, where ever possible, culverts should be wider than the stream channel, be on the same slope, have a buried invert, be installed in a straight line, and have contoured inlets and outlets (also see Section 13). To assist in the evaluation of culverts a checklist of factors that need to be considered when assessing fish passage is provided in Appendix D.

10.2 Fish-friendly culvert designs

Fish passage may be provided through a combination of culvert slope, elevation, roughness, and allowing or modifying the up stream channel so that it re-grades to a steeper gradient. Four options are proposed to achieved fish passage at new culverts:

- stream slope option;
- hydraulic design option;
- stream simulation option;
- climbing species option.

The **stream slope option** requires little if any calculation but may require the installation of a very conservative structure. In practice the stream slope option will be limited to short culverts in low-gradient streams. Conversely, the **hydraulic design option** is based on the velocity and depth requirements of a target fish species.

Although requiring more complex calculations, it usually allows the installation of a smaller culvert compared to the stream slope option. Computer programmes such as the “*Culvert*” software described in Appendix F have simplified procedures for implementing the hydraulic design option. The third option, the **stream simulation option**, mimics the natural channel inside the culvert and therefore provides passage of fish naturally migrating through the reach. Finally the **climbing species option** uses the ability of many native freshwater fish species (e.g. elvers and koaro) to progress up stream on a wetted margin. In term of design, the climbing species option is the least restrictive, but is only useful in high-gradient streams where fish diversity is already limited.

10.3 Stream slope design option

Fish passage can be expected if the culvert is sufficiently large and installed below the natural streambed so that natural bedload movement forms a stable bed inside the culvert (Plate 11).

Plate 11. *Fish-friendly culvert illustrating the “stream slope design option*

The stream slope option can be defined as:

- width equal to or greater than the average streambed width at the elevation the culvert intersects the streambed (Plate 11);
- gradient equivalent to or flatter than the existing stream;
- culvert invert well below the current streambed (minimum of 20% of culvert diameter at downstream end);

- culvert aligned to channel.

Limitations

The length of the culvert is limited by the need to restrict the difference in bed level between the upstream and downstream ends of the culvert, to less than 20% of culvert diameter (e.g. for a 1.5 m culvert the rise can only be 0.3 m).

Minimum information required

- Map reference;
- catchment name;
- channel name (if known);
- average channel width (average of at least 3 measurements both up stream and down stream of the culvert);
- channel slope;
- type of bed material present;
- culvert orientation;
- diameter and length of culvert;
- channel bed elevation at up stream and down stream end of culvert.

10.4 Hydraulic design option

The culvert design is based on the swimming ability of a target fish species. Ensuring that coarse bed material is retained on the floor of the culvert, or installing baffles/spoilers that increase energy dissipation and create resting areas for fish, allows smaller and steeper culverts to be installed without compromising fish passage.

The hydraulic design option is defined as:

- *Either:* the culvert design allows passage of the target fish without the need for resting areas or baffles/spoilers; *Or:* the culvert design allows passage of the target fish once resting areas, additional bed roughness, and or baffles/spoilers are installed;
- the channel remains untouched up stream and down stream of the culvert;
- armouring of the bed is required up stream and down stream of the culvert to control erosion;
- the invert is set below the streambed level at the downstream end of the culvert;

- one or more weirs may need to be installed to induce backwatering of the toe of the culvert;
- monitoring and maintenance plan are drawn.

Limitations

This option requires extensive on-site survey information and barrel velocity, and depth calculations using a software programme such as "*Culvert*". There are significant errors associated with the estimation, making conservative assumptions essential. One of the biggest hurdles is that there is little information on the energy dissipation ability of natural materials or spoilers/weirs that may be inserted in the culvert to facilitate passage. The ability of these structures to form resting areas for fish is also not fully tested. Until more *in situ* measurements can be made, monitoring will be essential to show that the chosen design allows fish passage.

Minimum information required

- Map reference;
- catchment name;
- channel name (if known);
- average channel width (average of at least 3 measurements both up stream and downstream of the culvert);
- channel slope, both up stream and down stream of the culvert,
- average as well as minimum channel flow during the upstream migration period (September to February);
- type of bed material present;
- culvert orientation;
- diameter and length of culvert;
- design fish name (usually the weakest of the species/size of fish present);
- channel bed elevation at up stream and down stream end of culvert;
- simulation calculations and results;
- culvert design and monitoring plan.

10.5 Stream simulation option

This design aims to re-create a meandering stream and/or a pool riffle sequence within the culvert so that it can essentially function as a natural channel. This design is suitable for steep channels and long culverts.

The stream simulation option is defined as:

- allowing passage of all target species;
- culvert slope close to that of a natural channel;
- culvert width as per natural channel, plus 0.5 m as a minimum;
- native bed material inserted and possibly artificially maintained within the culvert;
- channel bed at up stream and down stream end of culvert protected against erosion and/or aggradation/degradation.

Limitations

A very large culvert is required. This option presents some risks of poor performance, as design and construction expertise is limited. Monitoring may be required.

Minimum information required

- Map reference;
- catchment name;
- channel name (if known);
- full description of existing channel;
- full description of channel on which the re-created channel will be designed (preferably a section of stream above or below the chosen site). Proof of fish passage at that site;
- description of bed material to be used and source;
- description on how this material will be retained in the culvert;
- culvert orientation;
- diameter and length of culvert;
- fish species the culvert is designed to cater for (usually the weakest of the species/size of fish present);
- channel bed elevation at up stream and down stream end of culvert;
- full culvert design and monitoring plan;
- description of inspection and maintenance schedule.

10.6 Climbing species option

Many New Zealand indigenous fish species are good climbers (Plate 12) and can surmount barriers such as waterfalls by using the wetted margin. This design option utilises this climbing ability.

Plate 12. *Koaro making the use of the wetted margin of a culvert for resting and upstream passage (photo C. Mitchell).*

The climbing species option is defined as:

- culvert designed primarily on flood capacity requirements;
- streambed up stream and down stream of culvert is well armoured to prevent erosion resulting in an overhung culvert;
- smooth rounded transition between river bank and barrel, entrance and outlet to ensure continuous wetted margin at low and average flows;
- no break or sharp angles within culvert barrel;
- smooth-walled (at least in lower half of culvert).
- culvert never more than 45% and preferably less than 30% full at average flows.

Limitations

Until more information is obtained on the climbing ability of species like bullies and lamprey, the design is limited to elvers and juveniles of koaro, banded, short-jawed and giant kokopu.

Minimum information required

- Map reference;
- catchment name;

- channel name (if known);
- species composition;
- average flow and estimated water depth in culvert at average flow;
- description of armouring to be made;
- description of inlet and outlet structure and barrel wall;
- inspection and maintenance schedule;
- mitigation action to be taken where non-climbing species are present.

10.7 Control of channel slope and retrofits

In order to install a culvert with no slope, or to ensure back watering of the downstream end of a culvert, it may be necessary to install one or more weirs either up stream or down stream of the culverts. These weirs may also be constructed where small barriers such as overhanging culverts or vertical structures exist.

The simplest and most effective means of constructing these weirs is to bury large rocks on the streambed and river bank. Careful attention must be paid to how the boulders fit together so they can form a stable structure. Ideally each boulder should bear against the downstream neighbour, so the thrust of the flow and bedload is transferred through the weir to the bank (Plate 9). In most situations however downstream protection can simply be achieved by manipulating rubble with a digger until a meandering pattern of pools and runs is created. Hardwood logs, where available, may also be angled across the stream to create the same effect.

Where erosion is likely to be high, concrete may be used to fill interstices. Cables and anchors may be required to stop larger rocks from moving during floods. Gabion mattresses may be used but can cause problems at low flows, when the water disappears between the fill, trapping any fish that may be trying to migrate down stream with the current.

Where a downstream control is not possible, it may be necessary to re-grade the channel up stream using weirs to control erosion and maintain the channel shape. Where blasting is required, consideration for the instream community must be made so as to minimise potential losses and disturbance.

Such channel manipulations will result in a large amount of silt movement which will affect downstream communities. It is therefore essential that any channel work be undertaken when biological activity (including spawning and migration) is reduced and the chance of flushing the disturbed material is maximised.

11 MONITORING

Once a culvert has been installed or retrofitted, monitoring should be undertaken to ensure that the design is functioning as required. This may be carried out in a number of ways:

- through catch and release experiments, whereby marked individuals of the design fish are released below the culvert and trapping conducted above it, to determine if successful passage occurs (see Stancliff et al. 1988 for methods);
- fish surveys of the upper catchment or netting/trapping above the culvert during migration periods;
- fish sampling and/or observations to detect fish unable to migrate;
- monitoring critical populations over several seasons to detect changes.

The extent to which the culvert has been successful in passing fish should be monitored so that further modifications can be undertaken if necessary.

12 CONCLUSIONS

General features of culvert design and installation from North America may be applied in New Zealand (see Interim Recommendations, Section 13). However, more specific features concerned with the successful passage of fish, such as water depth and velocity limits, aprons, culvert material, pool depths, and baffle design, may not be directly applicable, because of the different swimming abilities and behaviours of our indigenous species.

Many indigenous fishes have good climbing abilities (e.g. elvers, koaro, banded kokopu and to some extent bullies) or can make use of velocities near the streambed and interstices between substrate particles to progress up stream (e.g. bullies and torrent fish). Therefore, it may not always be necessary to provide the low velocity zones required by salmonids or weak swimming fish. Ensuring the availability of an unbroken moist surface, with no overhanging outlet, may be all that is required where only the most adept climbing species need to be catered for. Additionally, “minimum” criteria may be used to exclude introduced species such as trout. However, control of velocity and some limit on water depth may be necessary for passing species which rely solely on swimming.

13 INTERIM RECOMMENDATIONS

13.1 Pre-culvert considerations

Before making fish passage requirement mandatory at a site, it is important to consider factors such as the presence of other barriers, species distribution, as well as size and type of habitat available. The flow diagram in Appendix E outlines the steps that should be taken when determining fish passage requirements at a potential barrier.

13.2 General culvert design

Whenever possible, and where fish passage is necessary, the following initiatives should be implemented:

- The culvert should be positioned so that its **gradient** and **alignment** are the same as the stream;
- the culvert should be installed in a straight line;
- culvert **width** should be equal to or greater than the average streambed width at the elevation 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);
- **weirs** should be notched and impermeable so that a pathway over the weir is present at all flows;
- 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. 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 or constructed weir could itself prevent passage;
- **armouring** of the banks with riprap at the outlet and inlet may be required to prevent erosion;
- the **average barrel velocity** should ideally be **below 0.3 m s^{-1}**; 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};
- where average barrel velocities are greater than 0.3 m s^{-1}, smooth culverts provide a more **suitable surface for climbing** indigenous New Zealand species than ribbed ones (note, however, that ribbed culverts of the Polyflo type are useful for reducing barrel velocities at low flows);

- **spoiler baffles** are useful for reducing barrel velocities and providing resting areas. 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;
- **baffles** are useful to ease passage of salmonids but to ensure an uninterrupted pathway for 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 (for large or box culverts) 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 upstream migration period;
- a monitoring and maintenance programme should be implemented.

13.3 Further information required

The following information is required to formulate stringent passage criteria for culverts in New Zealand:

- Determine which indigenous species with climbing abilities are able to negotiate culverts with ease, and, if so, under what conditions (culvert type, culvert length, retrofits etc.) and what zone is used most effectively;
- determine the migration path and velocity zones that swimming indigenous fish species use to negotiate culverts of varying designs;
- laboratory observations indicate that New Zealand's small indigenous fish species can become trapped by turbulence and back eddies. This may be particularly important in ribbed culverts. Field studies are required to quantify this problem and determine which species and sizes of fish are affected by turbulence and back eddies;
- in culverts installed to the design parameters described in Section 13.2, determine if existing low-velocity zones are sufficient to allow passage of swimming species and, if not, whether baffles or other barrel retrofits will assist the passage of climbing species. The installation, field testing and monitoring of these structures is required;

- determine the effect of light on the migration of indigenous fish through culverts;
- determine the passage requirements of post-juvenile and adult indigenous fish species (velocities, timing etc.) and compare with those of juveniles;
- currently there is inadequate information on culvert channel roughness (Manning’s N) and how this may change with flow. In particular, the effect of inserting baffles and weirs needs to be quantified;
- investigate the cost and reliability of design and retrofitting options;
- continue to refine fish friendly culvert designs as well as assessment and monitoring techniques.

13.4 Reporting

The most effective means of advancing on current knowledge and techniques is to ensure that successes and failures are reported. All users are encouraged to submit comments to the authors for incorporation into any future review and updates.

14 ACKNOWLEDGEMENTS

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GLOSSARY

anadromous: Fish that migrate from the ocean to fresh water to spawn, with the young undergoing some development there before returning to the sea to mature (e.g. Atlantic salmon, lamprey).

apron: Protective slope downstream of a culvert to shield the streambed from the energy of exiting water.

baffles: Concrete, wooden or steel blocks built or bolted onto the culvert floor to increase bed roughness and reduce water velocities.

bed: The stream bottom.

bed armouring: Placement of rocks or similar objects, including artificial material, on the bed to protect it from erosion.

bed load: Sediment, rocks and stones etc. which are moved along the bed by the force of the flow, rather than being carried in suspension.

boundary layer: A layer of slower moving water surrounding objects, such as the substrate, which increases in thickness with the roughness of the object.

burst swimming speed: A fish's swimming speed which is maintained only for a matter of seconds. Often used for feeding or to escape predation. Also known as darting speed.

catadromous: Fish that migrate from fresh water to the ocean to spawn, with the young undergoing some development there before returning to fresh water to mature (e.g. freshwater eels).

climbing species: Fish which climb moist surfaces and wetted margins. They adhere to the substrate by surface tension and can have roughened "sucker-like" pectoral and pelvic fins, or even a sucking mouth.

cruising swimming speed: A fish's swimming speed which is maintained for long periods. Mostly used in normal functions. Also referred to by some authors as sustained speed.

depressed invert: An invert which is buried below the natural streambed surface so that the bottom of the culvert is filled with bed material. May occur naturally or be created deliberately (artificially depressed invert).

design fish: The target size and/or species of fish which the culvert should be designed to pass.

diadromous: Fish that migrate between fresh water and the sea—in either direction—often for reproductive purposes (e.g. smelt).

elevated outlet: An outlet which is positioned above the stream surface so that there is a drop from the culvert down to the stream.

endemic: Species which are found only in one country or area.

fill: The material surrounding a culvert.

gradient: rate of change in height with distance. Also referred to as the slope.

headwall: An exterior wall surrounding the culvert inlet.

headwater: The water just up stream of a culvert.

high fill: A situation where the amount and weight of material on top of a culvert is very large, placing a high loading pressure on both the pipe and the bed material.

indigenous: native, although not necessarily restricted, to an area.

introduced: Species released by humans, either deliberately or accidentally, in a country or area where they did not previously occur.

invert: The lowest part of a culvert's internal cross-section (i.e. the floor).

jumping species: Fish which are able to leap using standing waves generated at waterfalls and rapids. As water velocity increases, it becomes energy-saving for these fish to attempt to jump over obstacles.

obligately diadromous: Fish species which must migrate between fresh water and the sea to complete their life cycle.

perched outlet: The development of an elevated outlet by erosion of the stream channel below it.

rebar: Steel reinforcing rods.

red muscle: Muscles which contract slowly and are used for slow, sustained activity, so do not deplete oxygen or fatigue easily. Also known as slow-twitch muscle fibres.

resting areas: Zones of low-velocity water where fish are able to rest and recover from their previous activity before continuing up stream.

retrofitting: The addition of structures to correct problems discovered after the culvert has been installed and found to be functioning incorrectly.

riffle-pool sequence: Alternating stretches of flowing and still (pooled) water.

riprap: Rocks or boulders used to cover areas of the stream bank or channel to protect it from erosion.

seed boulders: Boulders placed in a culvert or channel to initiate the entrapment of further debris.

sustained swimming speed: A fish's swimming speed which can be maintained for long periods. Also referred to by some authors as cruising and prolonged speed.

swimming species: Fish which usually swim around obstacles and 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.

tailwater: The water just downstream of a culvert.

tailwater control device: Structures placed below the culvert, generally to increase the tailwater elevation.

weir: A small dam of rock, logs or concrete used to control the water depth and flow in streams.

wetted margin: The part of the channel wall just above the water surface which is wet by splashes from the flow, and which is used by climbing fish species.

white muscle: Muscles which contract quickly and are used for bursts of activity, thus depleting oxygen and fatiguing rapidly. Also known as fast-twitch muscle fibres.

APPENDIX A

Freshwater Fisheries Regulations 1983

Part VI

Fish passage

41. **Scope**—(1) This part of these regulations shall apply to every dam or diversion structure in any natural river, stream, or water.

(2) For the purposes of these regulations "dam or diversion structure" shall not include—

(a) Any net, trap, or structure erected and used solely for the purpose of taking or holding fish in accordance with the provisions of the Act, or of these regulations:

(b) Any dam constructed on dry or swampy land or ephemeral water courses for the express purpose of watering domestic stock or providing habitat for water birds:

(c) Any water diversion not being incorporated into or with a dam, that is solely and reasonably required for domestic needs or for the purposes or watering domestic stock and that empties, without dead ends, into any viable fish habitat:

(d) Any structure authorised by a Regional Water Board not requiring a water right that in no way impedes the passage of fish.

(3) For the purposes of this Part of these regulations, the term "occupier" includes the owner of any land when there is no apparent occupier; and also includes any person doing any work by contract for the occupier.

42. **Culverts and fords**—(1) Notwithstanding regulation 41(2)(d) of these regulations, no person shall construct any culvert or ford in any natural river, stream, or water in such a way that the passage of fish would be impeded, without the written approval of the Director-General incorporating such conditions as the Director-General thinks appropriate.

(2) The occupier of any land shall maintain any culvert of ford in any natural river, stream, or water (including the bed of any such natural river, stream, or water in the vicinity of the culvert or ford) in such a way as to allow the free passage of fish:

Provided that this requirement shall cease if the culvert or ford is completely removed or a written exemption has been given by the Director-General.

43. Dams and diversion structures—(1) The Director-General may require that any dam or diversion structure proposed to be built include a fish facility:

Provided that this requirement shall not apply to any dam or diversion structure subject to a water right issued under the provisions of the Water and Soil Conservation Act 1967 prior to the 1st day of January 1984.

(2) Any person proposing to build such a dam or diversion structure shall notify the Director-General and forward a submission seeking the Director-General's approval or dispensation from the requirements of these regulations, shall supply to the Director-General such information as is reasonably required by the Director-General to assist him in deciding his requirements (including plans and specifications of the proposed structure and any proposed fish facility).

(3) Should the Director-General consider that the information supplied is inadequate, he shall, within 28 days, advise the applicant as to what further information is required.

44. Requirement for a fish facility—(1) If, in the opinion of the Director-General, a fish facility is required or dispensation from such a requirement is acceptable, the Director-General shall as soon as practical but in no case longer than 6 months if a fish facility is required from the date of receiving all information required, or 3 months where a fish facility is not required from the date of receiving all information required, forward his written requirement or dispensation to whomsoever made the submission.

(2) Where in the opinion of the Director-General a fish facility is required he shall specify what is required to enable fish to pass or stop the passage of fish, and while not limiting this general requirement may specify—

(a) The type, general dimensions, and general design of any fish pass to be utilised:

(b) The type, general dimensions, general design, and placement of any fish screen utilised.

(3) Subject to the Water and Soil Conservation Act 1967 and any determination under that Act, the Director-General may specify—

(a) The type and placement of any water intake to be utilised where fish screens are not required:

(b) The flow of water through any fish pass and the periods of the day and year when the pass must be operational:

(c) The volume, velocity, and placement of additional water to attract migrating fish to any fish pass:

(d) The type and scope of any remedial works in connection with any fish screen or fish pass to enable fish to approach the structure or to be returned to the normal course of the water channel:

(e) The volume or relative proportion of water that shall remain downstream of any dam or diversion structure and the period of day or year that such water flows shall be provided.

(4) Every approval given by the Director-General shall expire 3 years from the date of issue if the construction of the dam or diversion structure is not completed, or such longer time as he may allow.

(5) The manager of every dam or diversion structure in connection with which a fish facility is provided shall at all times keep such fish facility in good and satisfactory repair and order, so that fish may freely pass and return at all times or are prevented from passing as specified under these regulations.

45. **Adequate water**—The manager of every dam or diversion structure in connection with which a fish facility is provided shall, subject to the Water and Soil Conservation Act 1967 and any relevant determination under that Act, maintain a flow of water through or past such fish facility sufficient in quantity to allow the facility to function as specified at all times or periods specified; but no person shall be liable for a breach of this regulation due to drought, flood, or other sources beyond his control if the default is made good as soon as reasonably possible.

46. **Required maintenance or repair**—The Director-General may serve notice in writing to the manager of any fish facility notifying him of any defects or want of repair in such fish facility and requiring him within a reasonable time to be therein prescribed to remove any defect or make such repairs as may be required:

Provided that nothing in this regulation shall affect the liability of a manager under regulation 44 of these regulations.

47. **Damage**—No person shall wilfully injure or damage any fish facility.

48. **Alterations**—No person shall, without the written consent of the Director-General, make a structural alteration in any fish facility.

49. **Inspection of fish facilities**—Any Officer may at all reasonable times enter upon any fish facility and upon any remedial works or upon the land bordering such fish facility or remedial works for the purpose of their inspection.

50. **Protection of fish**—No person, other than an Officer acting in his official capacity, shall take or attempt to take any fish on its passage through a fish facility, or place any obstruction therein or within a radius of 50 m of any point of a fish facility, or shall within a radius of 50 m of any point of a fish facility use any contrivance whereby fish may be impeded in any way in freely entering or passing through or passing by a fish facility except as may be provided by the Director-General in writing to the manager of the fish facility.

In the interpretation of the Freshwater Fisheries Regulations 1983, unless otherwise stated:

Act means the Conservation Act (as amended by the Conservation Law Reform Act 1990).

Dam means any structure designed to confine, direct, or control water, whether permanent or temporary; and includes weirs.

Director-General is the Director-General of Conservation.

Diversion structure means any structure designed to divert or abstract natural water from its natural channel or bed whether permanent or temporary.

Fish facility means any structure or device, including any fish pass or fish screen inserted in or by any water course or lake, to stop, permit, or control the passage of fish through, around, or past any dam or other structure impeding the natural movement of fish up stream or down stream.

Fish pass means any structure providing passage through or over any barrier to their passage.

Fish screen means any device whether moving or stationary designed to impede or stop the passage of fish.

Officer means a warranted officer as provided for under the Conservation Act 1987

APPENDIX B

Annotated bibliography, * *bibliographies taken directly from Baker and Votapka (1990).*

Austroads. 1994. *Culverts. Waterway Design. A Guide to the Hydraulic Design of Bridges, Culverts and Floodways.* Austroads, Sydney. pp. 85–121.

A chapter from a book by Australian road and traffic authorities containing national standards for the design of roading structures associated with waterways. The chapter provides guidelines on culvert location, alignment, gradient, siltation, safety, inlet design, end treatment, scour, debris control, design procedures, and calculation of hydraulic parameters. Charts and tables are included to assist with the latter, and diagrams used to illustrate other points.

Baker, C.O. and Votapka, F.E. 1990. *Fish Passage Through Culverts.* Report No. FHWA-FL-90-006. United States Department of Agriculture Forest Service and United States Department of Transportation Federal Highway Administration, San Dimas, CA. 67 p.

This report is aimed at biologists and engineers designing road drainage structures to ease fish passage, and is divided into sections on biology, engineering and hydraulics. Important attributes of fish and habitats which should be considered are outlined, and the problems and benefits of the varying culvert types are discussed, with guidelines given for site selection and culvert installation. Factors determining the hydraulic capacity of culverts are outlined, with diagrams showing culvert capacity in differing conditions. Guidelines for the use of baffles; and anticipation, prevention and correction of outfall perching are also included. This report contains tables and diagrams illustrating the swimming performance of migratory North American freshwater fish species, spawning times, culvert entrance designs and positions, and baffle designs.

Bates, K. M. 1992. *Fishway Design Guidelines for Pacific Salmon*. Washington Department of Fish and Wildlife, Olympia.

A working paper based on studies by a range of investigators and the field experience of the author. It covers many aspects of fish passes such as pre-design data, entrance and exit design, water supply and flow, fish ladders and tributary fishways. Although aimed at Pacific salmon and steelhead—but applicable to other salmonid species—the paper is of interest to those considering indigenous New Zealand species.

It includes a useful section on culverts which contains general design features such as shape, installation, channel stability, flow conditions, bed construction and scour pools. The use of baffles is well covered and includes features of design not mentioned in other works. The paper also includes a section on the upstream passage of juveniles. While again referring to salmon and steelhead trout, its examination of boundary layers and the effect of turbulence is highly relevant for New Zealand's indigenous species.

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

Work in progress.

This manual describes the processes involved in the design of permanent new, retrofit, or replacement road crossing culverts that will not block the migration of salmonids. Intended for use by designers of culverts including private landowners and engineers.

Behlke, C.E. 1987. Hydraulic relationships between swimming fish and water flowing in culverts. *Proceedings of Second International Cold Regions Environmental Engineering Conference*. Edmonton, Alberta.

This paper describes, and provides equations for calculating, the forces acting on fish (buoyant forces, weight, pressure gradients, and profile drag); and the power and energy required to move against them. Although referring to entry, and passage through culverts, the concepts can be applied to any fish passage.

Behlke, C.E. 1991. Power and energy implications of passage structures for fish. *American Fisheries Society Symposium* 10: 289–298.

This paper contains very similar information to Behlke (1987), but is applied to a range of passage features including lakes; steep chutes; and the inlet, outlet and barrel of culverts.

Behlke, C. E. and Braley, W. A. 1993. *Fishpass. Alaska Fish Passage Program For Culvert Analysis. Version 1.0, January 1991 – Software Documentation.*

Documentation for a software package that determines whether culvert designs allow passage of weak swimming fish. Also provides the means of adjusting the designs to allow passage. The theory behind the package is described in Behlke et al. (1991).

Behlke, C.E., Kane, D.L., McLean, R.F. and Travis, M.D. 1991. *Fundamentals of Culvert Design for Passage of Weak-Swimming Fish.* Report No. FHWA-AK-RD-90-10. State of Alaska Department of Transportation and Public Facilities in co-operation with U.S. Department of Transportation Federal Highway Administration, Fairbanks. 159 p.

This report discusses the swimming capabilities of fish and provides equations to calculate swimming performance and requirements. It also reviews the hydraulic conditions encountered in culverts, and provides equations to determine design structures and features to match the swimming performance of fish. Steps and calculations for the design of new, and modification of existing, culverts are also provided.

Behlke, C.E., Kane, D.L., McLean, R.F. and Travis, M.D. 1993. Economic Culvert Design Using Fish Swimming Energy and Power Capabilities. Bioengineering Section of the American Fisheries Society, Portland, Oregon. *Fish Passage Policy and Technology. Proceedings of a Symposium*. pp. 95–99.

This paper summarises information of Behlke et al. (1991) on the use of culvert hydraulics and fish swimming ability to design culverts that allow fish passage. Includes equations for calculation of swimming power, the forces acting on fish within culverts, and the energy required to negotiate the culvert.

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.

*A wide range of information on fisheries and engineering problems is included. Areas applicable to fish passage are discussed in several chapters, including passage around dams, fishways and other conduits, swimming speeds, and velocity barriers. Chapter 31 deals specifically with culverts and briefly discusses some of the hydraulic characteristics. Some general guidelines for culvert installation are provided: culverts should be installed close to zero gradient; average velocities with a slope of 0.5 percent are 4.8 to 2.6 ft, which will allow fish to pass; culvert floor roughness should approximate natural streambed; and a minimum swimming depth of 12 in. should be allowed. Darkness in a culvert is not considered a block to fish passage.

Boubée, J.A.T. 1995. *Gravel-lined up stream fish passes. Construction guide.* A report for the Department of Conservation. National Institute of Water and Atmospheric Research, Hamilton. 18 p.

This report gives construction guidelines for gravel-lined fish passes – one of three types of pass considered most suitable, by the author, for New Zealand species. The species which could use the pass, and their migration timing, are detailed. Factors influencing the decision to install a pass, the type of pass used and the site chosen are outlined, as are statutory and consultation requirements. Necessary maintenance activities are listed.

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

The results of a catch and release experiment with stained whitebait in the Awakino River. Catch rates and distribution of catches were determined, and related to tidal and moon cycles, weather, and the number of whitebaiters. Migration rate of whitebait was determined.

Brett, J.R. and Glass, N.R. 1973. Metabolic rates and critical swimming speeds of sockeye salmon (*Oncorhynchus nerka*) in relation to size and temperature. *Journal of the Fisheries Research Board of Canada 30*: 379–387.

Determined that an increase of 5°C in water temperature increased the maximum sustained swimming speed of sockeye salmon by about 20%.

Clancy, C.G. and Reichmuth, D.R. 1990. A detachable fishway for steep culverts. *North American Journal of Fisheries Management* 10: 244–246.

A description of the design, installation and effect of a fishway placed in an existing culvert blocking up stream migration of fish. Its effectiveness is compared to a neighbouring culvert which was not fitted with a fishway.

Clay, C.H. 1995. Fish passage through road culverts. In *Design of Fishways and Other Fish Facilities.* Lewis Publishers, Boca Raton. 248 p.

This chapter outlines some of the biological and engineering factors which must be considered in culvert design. Design features facilitating fish passage through both new and existing culverts are discussed, including materials; the use, and types, of baffles; multiple barrels; and erosion protection. Key recommendations from published literature are summarised.

Cocks, J. 1993. A Fishway on the Nokomai. *New Zealand Engineering* 48: 18–20.

An article briefly describing the design of a natural pool and weir fishway in a stream channel, and the theory behind it. Includes physical site characteristics and design features incorporated to accommodate fish passage that may be relevant to the construction of downstream weir structures built to remedy or prevent perching of culvert outlets.

Dane, B.G. 1978a. *A Review and Resolution of Fish Passage Problems at Culvert Sites in British Columbia.* Fisheries and Marine Service Technical Report No. 810. Department of Fisheries and Environment, Vancouver. 126 p.

*This report includes guidelines for culvert design and installation, and describes salmonid passage requirements and hydraulic parameters. Five types of culverts are described. Their characteristics are compared with photos and sketches. The author describes type, cause, and effect of obstructions in the spawning/rearing area, as well as effects of habitat and hydraulic instability. Recommendations are made for the installation of culverts to avoid conflict with fish use in the stream during construction.

Dane, B.G. 1978b. *Culvert Guidelines: Recommendations for the Design and Installation of Culverts in British Columbia to Avoid Conflict with Anadromous Fish.* Fisheries and Marine Service Technical Report No. 811. Department of Fisheries and Environment, Vancouver. 55 p.

A summary report of the publication by Dane (1978a).

Evans, W.A. and Johnston, F.B. 1974. *Fish Migration and Fish Passage. A Practical Guide to Solving Fish Passage Problems.* United States Department of Agriculture Forest Service, Washington, DC. 43 p.

*This guide discusses the swimming ability of fish species in up stream and down stream migrations. Barriers include natural bed rock, debris jams, thermal barriers, short- and long-term dams, culverts, fords, and bridges. Included is a procedure for designing new installations of stream-crossing structures which includes checking into migration periods, stream flow, and site data. Inspection of and correcting existing culverts are discussed with an inventory and evaluation method used in USDA Forest Service Region 5 to identify fish passage problems. A case history from USDA Forest Service Region 6 of a fish passage problem with a successful solution is presented in detail. Graphs for water velocity and depth in circular, box, and arch culverts are in the Appendix. These graphs are for approximation only but are accurate enough for fish migration problems. The graphs are not intended for determining size and slope of culverts. Hydraulic data for bottomless arches and bridges are not provided in this guide.

Overall, this is a good practical guide with adequate technical data to provide engineers and biologists information to aid in checking existing and designing new stream crossing structures.

Good, W.R. 1990. A fyke net for rescue of fish stranded in culverts. *North American Journal of Fisheries Management* 10: 115–117.

A description of a fyke net designed for use in shallow water, and its effectiveness in capturing fish stranded in the culverts of irrigation systems when discharge is reduced or stopped. Of potential use for monitoring culverts.

Henderson, F.M. 1966. *Open Channel Flow.* Macmillan Series in Civil Engineering. Macmillan Publishing Co. Inc., New York. 522 p.

This book is aimed mainly at students of civil engineering but may also be of interest to practising engineers. It covers the fundamentals of open channel flow and their practical application. Areas covered include flow resistance, longitudinal changes in depth under non-uniform flow, the effect and performance of controls such as weirs and sluice gates, the effect of changes in direction, slope or cross-section of the channel, including controls such as culverts, unsteady flow, including the movement of tides into estuaries and rivers, changes in flow from artificial control or dam collapse and the behaviour of ocean waves, and tracing the course of flood waves to predict the effects of engineering changes to the channel.

Howie, W.R. 1968. *A Design Procedure for Gully Control by Check Dams.* Water and Soil Division, Ministry of Works, New Zealand. 45 p.

A report outlining the design of check dams to control gully erosion. Contains design curves for determining minimum slope and channel width for a given discharge and bed material size, and corresponding uniform flow depths. Calculation of flow conditions at the dam is also included, allowing the depth of pools and resulting scour holes to be determined. An example is used to show how the distance between dams and the base and crest level of each can be calculated.

Hume Industries (N.Z.) Limited. *Humespun. Concrete Pipe Design.* Wellington. 57 p.

A handbook containing guidelines for the selection of appropriate concrete pipes, bedding and fill conditions given known factors such as pipe diameter, traffic load, soil type, fill height, bedding type and discharge. Extensive use of tables and graphs for design choices are provided. Includes worked examples of calculations for velocity, discharge and peak design discharge.

Hunter, L. A. and Mayor, L. 1986. *Analysis of fish swimming performance data.* Report for Dept. of Fisheries and Oceans, Govt. of Canada and Alberta Dept. of Transportation.

Based on comprehensive review of fish swimming performance, the authors fitted logarithmic curves to swimming speed data to give two formulae that modelled the red muscle (sustained) swimming ability of fish and the white muscle (burst) swimming ability.

Jordan, M.C. and Carlson, R.F. 1987. *Design of Depressed Invert Culverts.* State of Alaska Department of Transportation and Public Facilities, Fairbanks. 64 p.

Based on the use of depressed invert culverts to facilitate fish passage, this report was compiled to develop a proper design procedure for such structures. The report is directed at engineers and hydrologists rather than biologists.

Jowett, I.G. and Richardson, J. 1994. Comparison of habitat use by fish in normal and flooded river conditions. *New Zealand Journal of Marine and Freshwater Research* 28: 409–416.

An investigation into the depth and velocity preferences of indigenous New Zealand fish species and their response to changes during flooding. Possible reasons for observed responses are suggested.

Jowett, I.G. and 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.

An investigation of the preferred habitat of eight New Zealand indigenous fish species in 34 rivers, based on densities in areas of varying water velocities, depths and substrate size. Four habitat guilds were described, and the results may be used to determine minimum flow requirements and the impact of flow changes on each group.

Katopodis, C., Robinson, P.R. and Sutherland, B.G. 1978. *A Study of Model and Prototype Culvert Baffling for Fish Passage.* Fisheries and Marine Service Technical Report No. 828. Western Region Fisheries and Marine Service, Department of Fisheries and the Environment, Winnipeg. 78 p.

The results of field tests on prototype baffle systems, based on previously developed models. Includes a brief description of culvert and baffle hydraulics. Hydraulic conditions for each prototype and the control are described and compared to the models. Appendices contain numerous figures, photographs and tables illustrating hydraulic information. Observations on the timing of fish activities are related to culvert conditions and impacts on behaviour noted. An assessment is made of the impact of flow on the culvert itself with regard to damage and blockages, and recommendations are given for the design and use of baffle systems.

Kay, A.R. and Lewis, R.B. 1970. *Passage of Anadromous Fish Through Highway Drainage Structures.* Highway Research Report, Final Report. State of California Division of Highways, District 01, Hydraulics Section. 15 p.

*Authors discuss factors that impede passage of migrating fish and establish design criteria for fish passage. Graphs and tables are included. A field investigation of 40 existing culverts was conducted and their fish-passage characteristics were evaluated.

Kerr Wood Leidal Associates Ltd. and D.B. Lister and Associates Ltd. 1980. *Stream Enhancement Guide.* Province of British Columbia Ministry of Environment, Vancouver. 82 p.

A guide to the enhancement of streams for salmonids. It includes information on improving: vegetation, erosion control, physical conditions in channels, rearing and spawning habitats, flow control, food, and control of competitors and predators. Also covered is the removal of natural and anthropogenic obstructions, including those created by culverts, for which a brief description is given of problems and possible solutions with a table illustrating migration requirements and design criteria.

MacPhee, C. and Watts, F.J. 1976. *Swimming Performance of Arctic Grayling in Highway Culverts.* Bulletin Number 13, Final report to U.S. Fish and Wildlife Service. University of Idaho, College of Forestry, Wildlife and Range Sciences, Moscow, Idaho. 41 p.

This report investigates specific features pertaining to the ability of Arctic grayling to negotiate culverts. Growth and timing of migration and spawning, were monitored, and the maximum velocities at which fish of differing lengths were able to negotiate culverts of differing lengths were determined. Swimming speeds of different sized fish were investigated in relation to temperature and fork length. The effects of different culvert designs and use of supplementary structures were not included in this study.

Mallen-Cooper, M., Stuart, I. G., Hides-Pearson, F. and Harris, J. H. 1995. *Fish Migration in the Murray River and Assessment of the Torrumbarry Fishway.* Final report for National Resources Management Strategy Project N002. NSW Fisheries Research Institute and the Cooperative Research Centre for Freshwater Ecology. 149 p.

This report investigates the migratory behaviour of several freshwater fish species present in the Murray River at Torrumbarry, NSW, Australia. The report also presents information regarding the effectiveness of the Torrumbarry fishway.

McCleave, J. D. 1980. Swimming performance of European eel *(Anguilla anguilla* (L.)) elvers. *Journal of Fish Biology 16*: 445–452.

This paper reports the results of tests on burst swimming speeds of European elvers. Endurance times are identified for a range of swimming speeds, and a relationship is found between the two. A logarithmic equation is calculated to predict this relationship, and could be further sub-divided into two separate equations to illustrate a natural change between slower and faster speeds. Burst swimming distances at a range of swimming speeds in still water, could be predicted from the logarithmic equations. Maximisation of distance in flowing water, by the choice of an optimal swimming speed, is discussed. The author emphasises the presence of a number of factors causing bias in the experiment, which require the results to be treated as conservative estimates. The relevance of the results for the migration of elvers in estuaries and streams or at obstacles is discussed.

McClellan, T.J. 1970. *Fish Passage Through Highway Culverts. A Field Evaluation.* United States Department of Transportation Federal Highway Administration and Oregon State Game Commission, Portland. 16 p.

*A review of 62 culverts installed by several agencies in Oregon was made to determine the effectiveness of the installation to pass fish, evaluate which types were most effective, simplest, and least expensive to install and easiest to maintain. The review included round pipe, single and double culverts with baffles or other special devices, plated arches (with both open and closed bottoms), and a few non-culvert installations. The author concluded that the condition of the stream at inlet/outlet may override design in importance. Controlling factors for fish passage were velocity, length, slope, and headwater/tailwater conditions. Description of culverts reviewed, problems and comments on fish passage are given. Evaluation forms with photographs are provided in its Appendix.

McDowall, R.M. 1979. Freeway for Fish. *Soil and Water*: pp. 10-12.

This paper outlines the natural history, conservation and commercial value of New Zealand's freshwater fish fauna, both indigenous and introduced. The extent of migratory activity is discussed, and the barriers created by culvert installation outlined under two sections – access to, and passage through, the culvert. Design factors are recommended to eliminate these problems.

McDowall, R.M. 1990. *New Zealand Freshwater Fishes. A Natural History and Guide.* Heinemann Reed, Auckland. 553 p.

As the title suggests, this book describes the species of indigenous and introduced fish found in New Zealand's freshwaters, including those which enter lower reaches of streams and rivers from the sea. Grouped by family, the description, distribution, coloration, size, distinguishing characteristics, taxonomy and biology of each species are given, along with any other relevant notes. Diagrams, photographs, graphs and maps are included to illustrate these features. The book also includes sections on fish communities, zoogeography, feeding, parasites and diseases, discovery and augmentation of the fauna, Maori and modern fisheries, management, and the impact both of exotic species and humans.

McDowall, R.M. 1995. Seasonal pulses in migrations of New Zealand diadromous fish and the potential impacts of river mouth closure. *New Zealand Journal of Marine and Freshwater Research* 29: 517–526.

Gives the timing of entry into estuaries of several indigenous freshwater fish species.

McDowall, R.M. and Eldon, G.A. 1980. *The Ecology of Whitebait Migrations (Galaxiidae: Galaxias sp.).* Fisheries Research Bulletin No. 20. Fisheries Research Division, New Zealand Ministry of Agriculture and Fisheries. 172 p.

Provides some extensive observations on the ecology, migration patterns and requirements of whitebait species.

McKinley, W.R. and Webb, R.D. 1956. A proposed correction of migratory fish problems at box culverts. *Washington Department of Fisheries Fish Research Papers* 1: 33–45.

This paper describes a study aimed at correcting the barriers to fish passage created by box culverts, based on outlined design criteria. The results of the trials of varying baffle arrangements are included, as is the process by which modifications to the final design were made. The application of the design in the field is outlined. Design choice was based on qualitative observations of

hydraulic performance and fish movements in trials, not on velocity measurements or mathematical formulae in either the laboratory or field.

Metsker, H.E. 1970. *Fish Versus Culverts. Some Considerations for Resource Managers.* Technical Report ETR-7700-5. United States Department of Agriculture Forest Service, Ogden, UT. 19 p.

*This publication provides general guidelines for the resource manager in considering crossings. Considerations mentioned are crossing locations, channel gradients, water velocity, stream alignment, type and age of fish, identifying migration routes, fishery food source, and type of fish habitat. Barriers to migration are discussed which include culvert outfall area, insufficient water depth and light, and water velocity. Streambed stability importance is also presented for consideration as resting needs for fish. Swimming ability with respect to size and species is also discussed. The author suggests use of multiple culverts, outlet control, downstream weirs, and baffles to facilitate fish passage.

Overall, this publication is in general terms for the manager and does not provide technical data for the engineer and biologist.

Ministry of Works and Development. 1975. *Metric Version of Technical Memorandum No. 61.* Planning and Technical Services Group, Water and Soil Division, Wellington. 19 p.

Guidelines for determining the design flood peak discharge in ungauged New Zealand catchments greater that 1000 km^2 in area, depending on catchment physiography and rainfall characteristics.

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

A hydraulic flume was used to measure the swimming performance of the juveniles of five species of New Zealand indigenous fish. Maximum water velocities allowing passage over obstacles of differing lengths were determined, as were minimum velocities to prevent migration. One species (*Mugil cephalus*) appeared to have a lower velocity tolerance than the others. The behaviour exhibited by other species allowed them to move through higher velocities, through periods of resting.

Mitchell, C.P. 1993. Fish Passes For Native Freshwater Fishes in New Zealand: Changing Attitudes, Politics and Approaches. *Fish Passage Policy and Technology. Proceedings of a Symposium*. Bioengineering Section of the American Fisheries Society, Portland, Oregon. pp. 109–115.

A paper which outlines fish pass design features which enable indigenous New Zealand freshwater fish species to pass through or over obstacles, given their swimming ability and behaviour. The impact of hydroelectric power stations on downstream migration of adult eels is briefly discussed; and a short account is given of the cultural, ecological and legislative situation in New Zealand .

[Charles] Mitchell and Associates. 1993. *Fish Passage Issues at the Otaika Weir.* Report prepared for the Golden Bay Cement Company. Rotorua.

A report describing the planned fish pass design aimed at enabling passage of weak swimming New Zealand indigenous species to negotiate a weir used by a cement production company. The water abstraction and discharge activities of the company are outlined, along with their importance and planned reductions. The impacts of the weir on the stream environment, and the consequences of removing it, are discussed. Previously utilised and potential pass designs are compared to the swimming abilities and behaviours of the target species, and the installation of a rock slope imitating the natural channel identified as the most appropriate design. The likelihood of success, and its benefits, and a brief description of a monitoring program are included.

[Charles] Mitchell and Associates. 1994. *Fish Passage Problems and Options for Fish Passage at Mararoa Weir.* The Electricity Corporation of New Zealand and the Waiau River Working Party. Rotorua. 28 p.

This report examines options for a fish pass at an existing structure. The impacts on upstream recruitment resulting from the blockage were studied, and the advantages and disadvantages of various design options given, with a recommendation for a preferred solution.

[Charles] Mitchell and Associates. 1994. *Recommendations for a Fish Pass on the Braemar Lagoon Water Control Weir.* Report prepared for the Department of Conservation. Rotorua. 6 p.

This report looks at a weir constructed to manage a wetland habitat, primarily for waterfowl. A brief description of the weir and habitat is given. The impact of the weir is identified by outlining a survey of the stream to determine the species present above and below the structure. In this way, the target species are identified, with the others being expected once passage of these weak swimming, non-climbers is achieved. The theory behind the passage of such species is discussed with their flow requirements and the design features necessary to satisfy them. Construction details of the pass itself (a rock lined flume imitating the natural channel) are given.

[Charles] Mitchell and Associates. 1996. *Opunake Power Station Fishpass.* Raglan. 12 p.

This report examines the problem of fish passage over a weir which is part of a hydroelectric power scheme. The process by which the final design was reached, through testing and altering design variations on the wide range of species which had to be passed, is outlined. Important features of the sizing, siting and water supply of the pass are included, along with points on maintenance, construction and monitoring. The final design consisted of a composite structure with a baffled flume on one side for trout and a shallow rock filled flume on the other for indigenous New Zealand species.

Mitchell, C.P. and 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.

A report which examines fish passage, primarily of indigenous New Zealand species, over hydroelectric dams. A brief description is given of the form and effectiveness of fish passes which have been used at specific locations around New Zealand. The authors then present a variety of possible designs, ranked by feasibility, which may be of use for indigenous New Zealand fish. The physical transfer of fish and downstream migration problems are also discussed, and matters which require further knowledge outlined.

Mitchell, C.P. and Boubée, J.A.T. 1995. *Evaluation of materials to allow fish passage past Huntly Power Station.* Report to ECNZ by Mitchell & Associates. 10 p.

This report describes the results of field trials aimed at determining the best materials for use as baffles in an in-river fish pass. The type of sheet metal which provided the best profile in terms of the creation of boundary layers and areas of low velocity, thus enabling fish to move up stream, was identified. Velocities conducive to swimming , feeding and maintenance were apparent, as were those causing impingement. Recommendations were made for areas of further investigation before implementation of the design.

Moffat, R. 1986. A Note on the Swimming Performance of Two Species of Teleost fish, the Trout, *Salmo trutta* and the Koaro, *Galaxias brevipinnis. Mauri Ora 13:* 71–79.

A paper reporting work from a BSc Hons thesis (Moffat, R. 1984. Aspects of spatial segregation of adult koaro (*Galaxias brevipinnis*) and juvenile trout

(*Salmo trutta* and *Salmo gairdnerii*) in the Rhyton River. University of Canterbury). Observations were made of koaro and brown trout in holding tanks and exercise tunnels. The swimming behaviour and position in the water column was noted for each species in the holding tanks. Zero maintenance and critical swimming speeds (and any relationships with size) were determined for each. The observations were used to compare the speed and stamina of the two species, and show how physiology and position can affect the impact of water velocity, and thus behaviour in the natural habitat.

Mundie, J.H. and Traber, R.E. 1983. Movements of Coho Salmon (*Oncorhynchus kisutch*) Fingerlings in a Stream Following Marking with a Vital Stain. *Canadian Journal of Fisheries and Aquatic Sciences* 40: 1318–1319.

A note describing the use of staining to estimate the population size of coho salmon through mark and recapture experiments. The authors provide a cautionary word for others who might use this method, having found unexpected distributions of fish following staining. Whereas a random distribution might be expected, fish instead seemed to gather in particular, and differing, directions within studied stretches of stream.

Odeh, M., Haro, A., Norieka, J. and Castro-Santos, T. 1997. *Evaluation of a Uniform Acceleration Weir for Downstream Bypass Entrances.* Proceedings of the Milwaukee Fish Passage Workshop, May 6–8, 1997. Milwaukee, Wisconsin.

This paper describes the performance of a surface bypass entrance that employs uniform flow acceleration to improve fish passage. This concept could be applied to the inlets of culverts to minimise entrance contraction.

Powers, P.D. and Orsborn, J.F. 1985. *Analysis of Barriers to Upstream Fish Migration. An Investigation of the Physical and Biological Conditions Affecting Fish Passage Success at Culverts and Waterfalls.* Final project report (Part 4 of 4). Department of Civil and Environmental Engineering, Washington State University, Pullman, Washington. 120 p.

*This research paper analyses both natural and artificial barriers to the upstream migration of salmon and trout, and offers solutions to fish passage through barriers. Analytical methods are presented to study barriers using site geometry, hydrology, and hydraulics, the relationship between these factors and the swimming capabilities of fish are examined. Using this information, a classification system is developed to classify waterfalls, cascades, chutes and culverts, based on four components: class, type, magnitude, and discharge, extending from general to specific. A degree of difficulty rating is also determined for each barrier class to rank the relative difficulty of a barrier for successful fish passage. This paper offers "parameter-specific" solutions to

assist fish past natural barriers without the installation of a typical fishway, and offers suggestions to improve fish passage through culverts.

Rajaratnam, N. and Katopodis, C. 1990. Hydraulics of culvert fishways III: weir baffle culvert fishways. ***Canadian Journal of Civil Engineering*** **17: 558–568.**

The results of a study into the use of weir baffles in culverts. Baffles of various dimensions and spacing were tested, and there effects on velocity and water depth studied. Equations were developed for dimensionless discharge, relative depth and barrier velocity. Weir baffles were compared with slotted weir baffles.

Rajaratnam, N., Katopodis, C. and Fairbairn, M.A. 1990. Hydraulics of culvert fishways V: Alberta fish weirs and baffles. ***Canadian Journal of Civil Engineering*** **17: 1015-1021.**

This paper outlines the performance of certain types of fish weirs and fish baffles used in culverts by Alberta Transportation. The fish weirs were better than the fish baffles, and equal in pool depth and barrier velocity to other weir and baffle structures, when spaced longitudinally at 0.6-1.2 times the diameter of the culvert.

Rajaratnam, N., Katopodis, C. and Lodewyk, S. 1988. Hydraulics of offset baffle culvert fishways. ***Canadian Journal of Civil Engineering*** **15: 1043–1051.**

The results of a study into the use of offset baffles in culverts. Baffles of various dimensions and spacing were tested, and their effects on water depth and velocity studied. Equations were developed for dimensionless discharge, relative depth and barrier velocity.

Rajaratnam, N., Katopodis, C. and Lodewyk, S. 1989a. ***An Experimental Study of Culvert Fishways with Spoiler Baffles.*** **Technical Report WRE-89-4. Department of Civil Engineering, University of Alberta, Edmonton. 19 p.**

The report on the same work outlined in Rajaratnam et al. (1991), but containing a great deal more tabular and graphical information. This includes raw data for the measured parameters under varying experimental conditions and differing baffle designs, and the graphical representation of these and other results.

Rajaratnam, N., Katopodis, C. and Lodewyk, S. 1991. Hydraulics of culvert fishways IV: spoiler baffle culvert fishways. ***Canadian Journal of Civil Engineering*** **18: 77–82.**

The results of a study into the use of spoiler baffles in culverts. Baffles of various dimensions and spacings were tested, and their effects on water depth and velocity studied. Equations were developed for dimensionless discharge, relative depth and barrier velocity. Spoiler baffles were compared to similar baffle systems.

Rajaratnam, N., Katopodis, C. and McQuitty, N. 1989b. Hydraulics of culvert fishways II: slotted-weir culvert fishways. *Canadian Journal of Civil Engineering* 16: 375–383.

The results of a study into the use of slotted-weir baffles in culverts. Baffles of various dimensions and spacing were tested and there effects on velocity and water depth studied. Equations were developed for dimensionless discharge, relative depth and barrier velocity. Slotted-weir baffles were compared to offset baffles.

Stancliff, A.G., Boubée, J.A.T., Palmer, D. and 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, Rotorua. 44 p.

Report on the study of whitebait migration in the Waikato River. Provides information on migration rate and timing.

Tappel, P.D. 1986. Limitations on the Use of Gabions to Improve Fish Passage. *North American Journal of Fisheries Management* 6: 131–132.

A brief article which, as the title suggests, notes limitations in the use of gabion weirs (as opposed to concrete and/or boulder weirs) to create pools below culverts or waterfalls to assist fish passage. The article is based on field observations of a gabion constructed below a waterfall. The authors recommendations arising from this experience are given.

Thorncraft, G.A. and Harris, J.H. 1996. *Assessment of Rock-Ramp Fishways.* NSW Fisheries Research Institute and the Co-operative Research Centre for Freshwater Ecology. 24 p.

This report studies the effectiveness of four experimental fishways built on existing weirs in streams in NSW, Australia. It describes each weir and the fishway constructed on it, and the sampling methods used to assess the fish population above and below the fishways. The species present, and their length-frequency distributions, are discussed and analysed to determine the effect of each fishway, from which conclusions on design and performance are drawn. Specific design criteria are outlined and statements made on the ability of particular groups of fish to negotiate these rock-ramps.

United States Department of Agriculture. 1975. Making Culverts Good Fish Passages. ***Equip Tips*****. Forest Service Equipment Development Centre, Missoula. 4 p.**

This bulletin briefly reviews an investigation of fish passage problems and solutions at culverts in United States National Forests. Recommendations are made concerning water velocity, culvert length, water depth, resting pools, and drops caused by erosion. Steep pass fishways and varieties of culverts are also mentioned, as is the necessity of a good fisheries knowledge.

Watts, F.J. 1974. ***Design of Culvert Fishways.*** **Water Resources Research Institute, University of Idaho, Moscow, Idaho. 62 p.**

*Types of fish migration and typical fish-blockage problems associated with culverts are reviewed. Swimming capabilities of fish as a function of species, fish length, and water temperature are discussed. Also reviewed are: hydrological characteristics of streams and the importance of the timing of fish runs and peak discharge, procedure for analysing culverts of corrugated metal pipe and pipe arches for recommended swimming velocities, slot-orifice fishways for box culverts placed perpendicular to the velocity and skewed wingwall slot orifice, design aids developed for hydraulic analysis, and instream construction in or near prime fish habitat.

WDFW 1999. ***Fish Passage Design at road Culverts. A design manual for fish passage at road crossings.*** **Washington Department of Fish and Wildlife, Olympia, WA. 49 p + Appendices.**

A manual for the design of permanent new, retrofits, or replacement road crossing culverts to ensure passage of salmonids. Proposes and fully describes 3 options to allow fish passage: the no-slope design option, the hydraulic design option, and the stream simulation option. Methods for the evaluation of culverts, including examples are presented.

Webb, P.W. 1975. ***Hydrodynamics and Energetics of Fish Propulsion.*** **Bulletin of the Fisheries Research Board of Canada. Department of the Environment Fisheries and Marine Services, Ottawa. 158 p.**

A report which presents the many aspects involved in swimming in fish, with an emphasis on bringing together both biological and physical approaches. Subjects covered include swimming speeds and modes, body and fin movements, energy, metabolism, drag, thrust, power and hydrodynamics. A range of models and methods of calculating various parameters are examined for accuracy and suitability. The author stresses deficiencies in knowledge and methodology and encourages the integration of biological and physical methods to further the understanding on this topic.

Webb, P. W., Sims, D. and Schulz, W. W. 1991. The effects of an air/water surface on the fast-start performance of rainbow trout (*Oncorhynchus mykiss*). *Journal of Experimental Biology 155*: 219–226.

This paper uses turning radius and distance travelled to measure the fast-start performance of rainbow trout in varying water depths. It discusses the effects of the air/surface interface on a moving fish, in terms of energy dispersion, resistance, drag and thrust, and relates this to water depth and predator-prey interactions.

Welch, H.E. 1979. *Swimming Performance of Arctic Char from the Saqvaqjuac River, Northwest Territories.* Fisheries and Marine Service Technical Report No. 854. Western Region Fisheries and Marine Service, Department of Fisheries and the Environment, Winnipeg. 7 p.

A very brief account of an experimental study, the results of which are compared to other local species. Contains species specific tables and figures relating swimming performance parameters, fish size, water velocity and culvert length.

WORKS. 1988. *Culvert Manual. Volume 1.* Report No. CDP 706/B. Technical Services, Works and Development Services Corporation (NZ) Ltd. - Civil Engineering, Wellington.

A manual which provides information to enable engineers to determine flood flows, best designs and construction methods for culverts in New Zealand.

Ziemer, G.L. 1961. *Fish transport in waterways.* Alaska Department of Fish and Game, 2 p.

*The mechanics of fish passage at/in pipe culvert waterways under highways are given. Illustrations of stylised models demonstrate stress-level patterns of a migrating fish through time compared with normal performance, for example, the work required of a fish to navigate through a culvert where the upstream end head is less than one pipe-diameter. Hydrodynamics are examined for the following: total opposing force on swimming fish, gradient vector, drag force on the fish, weight of fish, angle of inclination of hydraulic gradient, length of fish, mass density of fluid, velocity of fish relative to the water, rate at which fish expends energy, transit time through culvert, length of culvert and velocity of fish relative to the channel. The report gives a checklist of controlling factors to consider when designing the culvert.

APPENDIX C

Proposed culvert evaluation form (6 pages).

Ref. No: …………

EVALUATION SHEET FOR FISH PASSAGE

Date: ………………..…….. Observer: …….……...……………. Organisation: ……………………………

Location: ………………………….……………………..……………………………………………………...

Access: …………………………………………………….… NZMS 260 Map No: ……………….……….

Co-ordinates: …….…..……..……….… Altitude (m): ...….…..…...…… Inland distance (km):……….…..……

Catchment Area (km^2): …….……….. Catchment No: ………....……… Stream No: ……..…………...……..

Stream name: ……………………..…….…………. River System: ……………………………………………

Water flow (m^3/s): min: ……….….… max: ……….……… mean: ……………… actual: ……….…………

Stream Characteristics*	0 m	5 m	10 m	15 m	20 m	25 m	30 m	35 m	40 m	45 m	50 m
UPSTREAM											
Channel width											
Wetted width											
Depth											
Velocity											
Bed elevation											
Calculated slope											
DOWNSTREAM											
Channel width											
Wetted width											
Depth											
Velocity											
Bed elevation											
Calculated slope											
Control structure											

* if possible measure at 5 m intervals 50 m upstream and downstream of existing/proposed structure.

At Barrier:

Known fish species upstream: …………………………………………………………….……………………...

Known fish species downstream: ……………………………………………………………………….……..

Upstream: Dominant catchment vegetation[a]: ………………………………………..……………………...

Dominant riparian cover[b]: ……………………………………………………………..…...………

Downstream: Dominant catchment vegetation[a]: ……………………………………………………...……….

Dominant riparian cover[b]: ……………………..……………………………………….……………

[a] e.g. native/exotic forest, farming, urban, wetland
[b] e.g. native/exotic trees, grass¸ scrub

Dominant substrate type: Upstream: ……………………………… Downstream: …………………….…………

Barriers: Upstream: ☐Yes ☐ No ☐ Unknown Description: ……………………..……......……
.

Downstream: ☐ Yes ☐ No ☐ Unknown Description: ..………...………………...….…

Tidal? ☐ Yes ☐ No ☐ Unknown ☐ Tide/flood gate

Type of Barrier:

☐ **Waterfall** Height (m): ……..……… Slope (m/m): ……..……..…

☐ **Rapids** Height (m): ……..……… Slope (m/m): ……………… Length (m): ……………...…

☐ **Weir** ☐ V-notch ☐ Vertical Water drop height (m): ………………………...…

☐ **Other (state):** ……………………………………………………………………………………………..

☐ **Culvert**

Type: ☐ Circular/oval Height: …………….. Width: ……………..
☐ Rectangular Height: ……….……. Width: ……………..
☐ Trapezoidal Height: ……………… Width: …………….. Side slope (H/V): ……….……..…
☐ Other (specify): …………………………...…. Height: ……….……..…. Width: ………………….

Materials: ☐ Smooth metal ☐ Corrugated ☐ Smooth concrete ☐ Rough concrete

Corrugation depth (m): ……………………….….. Distance between corrugations (m): ……………….....….…

Culvert length (m):…………………………….. Change of alignment within barrel: …………………………

No. pipes/culverts: ……………………...…. Difference in level between pipes/culverts (m): ...…………….……

Sediment deposition in channel: ☐ None % cover: ………………
☐ Fine gravel % cover: ………………
☐ Coarse gravel % cover: ………………
☐ Debris % cover: ………………

	Downstream end (outlet)			**Culvert characteristics***						Upstream end (inlet)
Distance										
Water depth										
Wetted width										
Gravel depth										
Velocity										
Bed elevation										
Calculated slope										
Change in slope / break in culvert										

* measurements at centre of culvert every 5 m if possible

Outlet Conditions (downstream):

Water level control at outlet: ☐ Normal (uniform) flow ☐ Critical flow (free outfall)
☐ Outlet pond Depth of water above invert (m): …………

Outlet type: ☐ Projecting from fill (m): ……..… ☐ Flush with vertical headwall ☐ Bevelled and flush

Headwall horizontal angle: ☐ Sharp transition ☐ Angled (º): ….… ☐ Smooth transition (rounded)
(Outlet losses)

Alignment of culvert relative to downstream channel (°): …………………

☐ Apron present Length (m): …………...…… Slope (m/m): ……...…...…… Drop (m)***: ………….….....

***if stepped outlet

Inlet Conditions (upstream):

Water level control at inlet: ☐ Normal (downstream) flow
☐ Inlet pond Depth of water (m): …………………

Inlet type: ☐ Projecting from fill (m): ………… ☐ Flush with vertical headwall ☐ Bevelled and flush

Headwall horizontal angle: ☐ Sharp transition ☐ Angled (º): …... ☐ Smooth transition (rounded)
(Inlet losses)

Alignment of culvert relative upstream channel (°): ……….………………..…..

☐ Apron present Length (m): ……….….…… Slope (m/m): ………......…… Drop (m)***: ……………..…......

***if stepped inlet

Bank Protection:

Presence of: Rip rap: ☐ Inlet pool ☐ Outlet pool ☐ Inlet banks ☐ Outlet banks

Erosion: ☐ Inlet ☐ Outlet ☐ Inlet banks ☐ Outlet banks

Culvert Barrel:

Blockages: ☐ Inlet ☐ Outlet ☐ Barrel

Any breaks in culvert? (Describe)………………………………………….……………………...

Baffles etc:

Baffles: Length (m): ………..….. Height (m): ………..…… Width (m): …………….. No. of rows: ………..….

Spacing (m): …………… Downstream angle: …….. Material: ………………………………………….

Spoilers: Length (m): ………..…. Height (m): …………….…. Width (m): ………….……. No. of rows: …………...

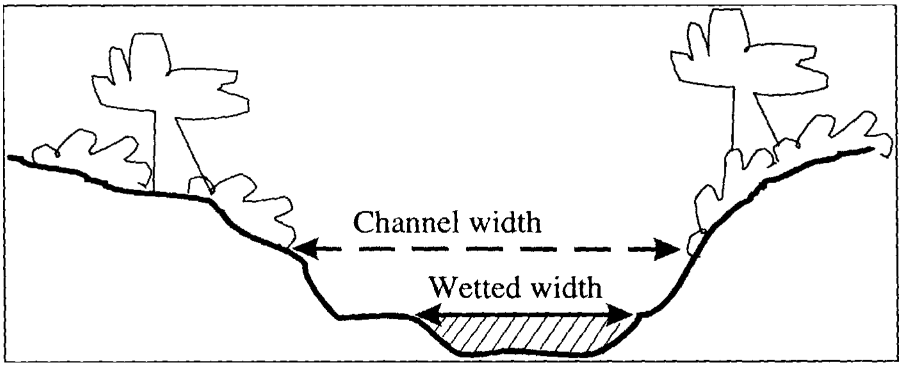
Transverse spacing (m): …………... Longitudinal spacing (m):………..… Central row? ☐ Yes ☐ No

Sketch map and include photos of installation. **Photo No. ………………………..**
Include a plaque in photo with scale and location marked on it.
For culverts: –include photographs of upstream and downstream ends (label each end)
–draw longitudinal section of culvert showing dimensions of apron (angle/height)

Instructions for using the culvert evaluation sheet

Stream characteristics

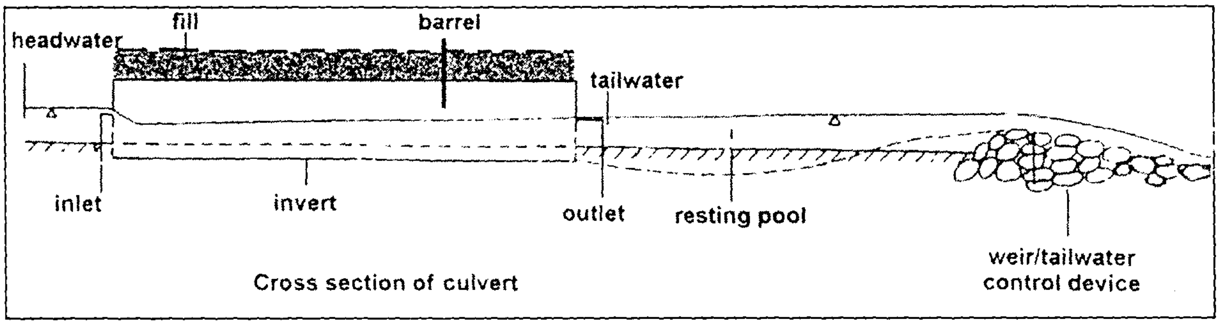
- Characteristics of a minimum 50 m reach, upstream and downstream of the proposed/existing barrier are needed to set/assess culvert conditions. Sufficient information should be obtained to fully describe the site and although the form suggest 5 m intervals, spacing will need to vary to describe for example, a drop off, or apron structure. The characteristics to be measured are: channel width, wetted width, water depth, mid channel water velocity (measured at 0.6 of water depth in water less than 0.6 m deep, and at 0.2 and 0.8 m depth in deeper streams), bed elevation (height from reference point and can be + or -). Plan for, or presence of, a weir/tailwater control device downstream also needs to be recorded. Calculate slope as rise over distance (e.g. 0.5 m rise in 10 m = 0.05)



At barrier

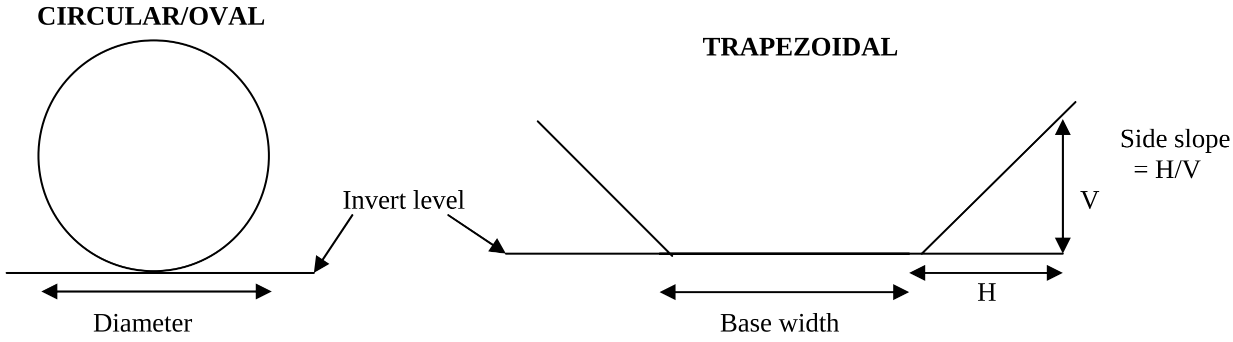
- Dominant catchment vegetation is an estimate of the vegetation type or land use in the catchment upstream of and including the site (e.g., native/exotic forest, farmland, urban, wetland).
- Dominant riparian vegetation refers to the immediate (within 5 m of water's edge) zone along the reach of interest (e.g., native/exotic trees, grass, scrub, etc.).
- Dominant substrate type identifies the main type of stream bed material present (e.g., mud (<I mm in size), sand (1-2 mm), fine gravel (2-20 mm), coarse gravel (20-60 mm) cobble (60-260 mm), boulders (> 260 mm), bedrock, concrete. etc.).

Culvert characteristics



Culvert characteristics are to be measured in the centre of the culvert channel, at about 5 m intervals, for the length of the culvert. The characteristics to be measured or noted are water depth, wetted width, gravel depth, water velocity, bed elevation, calculated slope, change in slope/break in culvert.

- Side slope measurements are used for trapezoidal culverts only. It is the ratio of the horizontal distance to the vertical distance of the channel sides.
- Culvert length should exclude the aprons.
- Any change of alignment in the barrel should be given as the approximate angle between the sections.
- Calculate slope from invert elevation if the floor of the culvert is exposed or on bed elevation if the invert is completely buried.



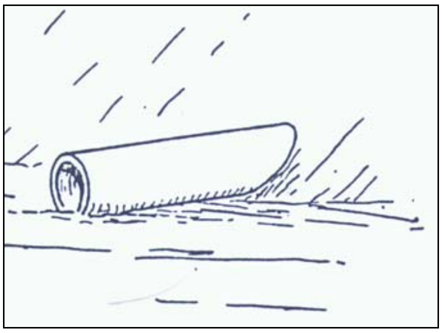
Inlet and outlet conditions
Water level control at outlet:

- Normal (uniform) flow typically occurs when the stream below the culvert is of similar slope, depth and width to the culvert.
- Critical flow (free outfall) occurs where a stream falls away sharply at the outlet (e.g. overhang or drop off).
- Pond level is measured from the invert at the toe of the culvert.

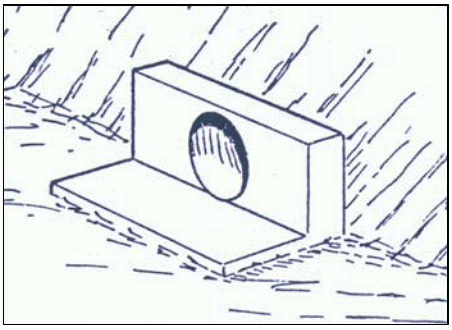
The condition of the inlet and outlet headwall need to be described as this affects the turbulence (and therefore energy losses) and ease of fish ingress and exit from the barrel. This is particularly important for anguilliform locomotors and climbers.

Inlet/outlet type:

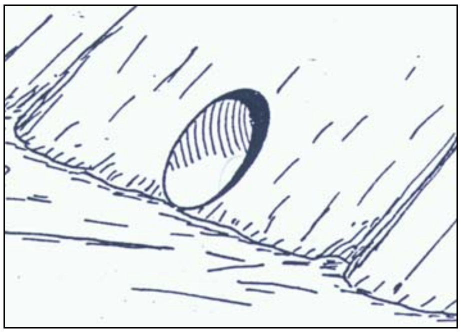
A. Projecting from fill



B. Flush with vertical headwall



C. Bevelled and flush



The alignment of culvert is required to assess potential erosion problem and to provide an indication of flow patterns. Measure angle of culvert relative to downstream/upstream channel.

Bank protection
Record the presence of rip rap (rocks or broken up concrete) used to protect the banks against erosion. If erosion is noted record where remedial action is required.

Baffles etc.
Baffles (or low head weirs) made of concrete, steel or wood can be fitted across the culvert floor to increase bed roughness. This not only slows water flows but also provide resting areas for fish.

Spoilers are blocks of wood or concrete held firmly on the culvert floor. They can markedly increase bed roughness and provide resting areas for fish. At low flows, upstream passage of fish through a field of spoilers is easier than through rows of baffles.

APPENDIX D

Culvert construction checklist for sites where fish passage is required (2 pages).

Culvert construction checklist for sites where fish passage is required

(Use ✓ or X)

☐ **Culvert can accommodate flood flows**
If the culvert is too small to cater for flood flows or if it can be blocked by debris, can the culvert be overtopped without risk of erosion or wash out.?…………………..…………………….……..

Group of fish that are or could be present.

☐ **J**umpers (e.g. trout)
☐ **S**wimmers (e.g. inanga)
☐ **A**nguilliforms (e.g. eels)
☐ **C**limbers (e.g. koaro, elvers)

☐ **Culvert aligned with stream.** (J, S, A, C)
If no, are bank side erosion control measures in place?:...…………………………………………

☐ **Culvert diameter larger than stream channel.** (J, S, A) **and/or,**
☐ **Culvert invert buried.** (J, S, A)
If no: - Streambed erosion control taken down stream:.……………….……………………......
- Steps taken to increase energy dissipation in barrel:…………………….……..……………

☐ **Barrel velocity below 0.3 m/s** (J, S, A)
(Note, it would be preferable for passage to be provided at all times but realistically allowing passage at average and low flows during the migration period is acceptable.)

If no: - Is there a continuous 50–100 mm wide zones along the sides with velocities below 0.3 m/s or, can fish swim through the culvert without becoming exhausted?…….…….……
- If not, what resting areas are provided (type and spacing or means of retaining bed material in barrel)...…………..………………………………..……..……..………..

☐ **Slope of culvert same as stream.** (J, S, A)
If steeper:
- Streambed erosion control taken down stream:...…………………………...……….....
- Steps taken to increase energy dissipation in barrel:……………….………………..……
- Steps taken to retain bed material on invert:…………………………………..……....

If flatter:
- Steps taken to prevent erosion and ensure passage up stream.………………...………….
- And/or steps to ensure passage down stream……………………………………….….

☐ **Slope constant?** (J, S, A)
If no: - Can swimmers or jumpers negotiate the steepest section?………...…….…………………..
- If a weir is present is it notched for low flows and is it impermeable?…………….…………..
- Is there any vertical drop and if so can jumpers negotiate the height?.………..…………

☐ **Low flow channel provided.** (J, S, A, C)

☐ **Low flow channel required?** (J, S, A, C)
If yes, describe:……………………..…………………………………………………………..……

☐ **Continuous wetted margin with no sharp angles available for climbing species** (C)
If breaks are present, is a climbing media or similar installed?……….……………..……….……

☐ **Is water depth adequate especially over apron** (J, S, A)
If no, is floor dished or sloping to concentrate water:………………….……….…………..…

☐ **Turbulence or back eddying not a problem for target species**(J, S, A, C)
If water is turbulent, are there areas of quiet waters available along the floor or sides of the channel? …….……………………………………………………………………...…….……..

☐ **Culvert short and lighting not an issue** (species?)
If no, measures taken to provide passage of species that migrate in daylight:…………………..…
(Note this is an unknown factor but light is not an issue for elvers and eels. Possibly not a problem for kokopu and koaro either. A bend in a long culvert can reduce the amount of light present and should be avoided)

☐ **Bankside and overhead cover replanted at entry and outlet.** (J, S, A, C)
If no, specify type of in-stream cover provided?…………………………………………………...

If any of the above cannot be met what are the mitigation actions offered:……………...……...…
…………………………………………………………………………………………………..….
…………………………………………………………………………………………………..….
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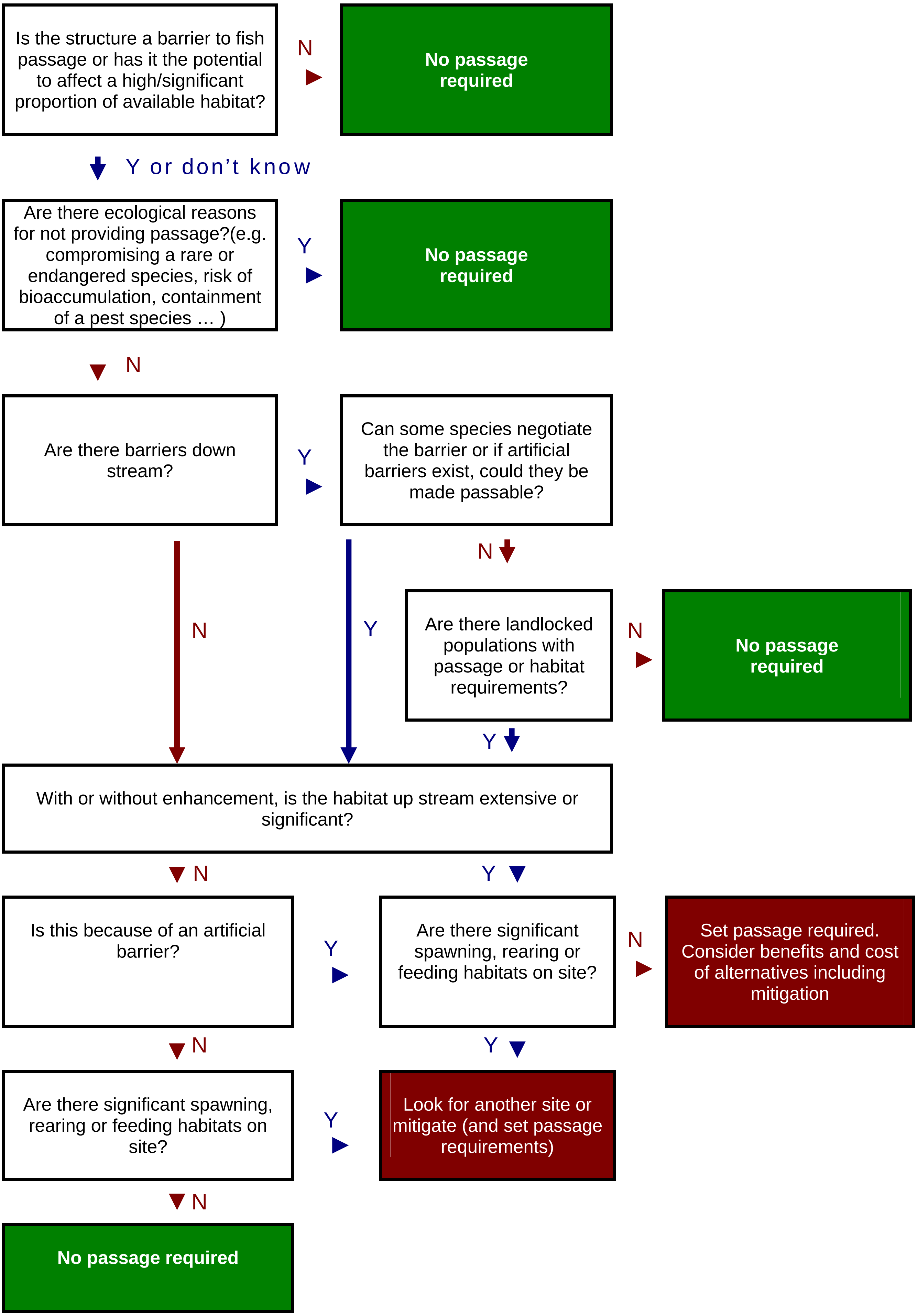
APPENDIX E

Priority decisions for installation of a new in-stream structure.

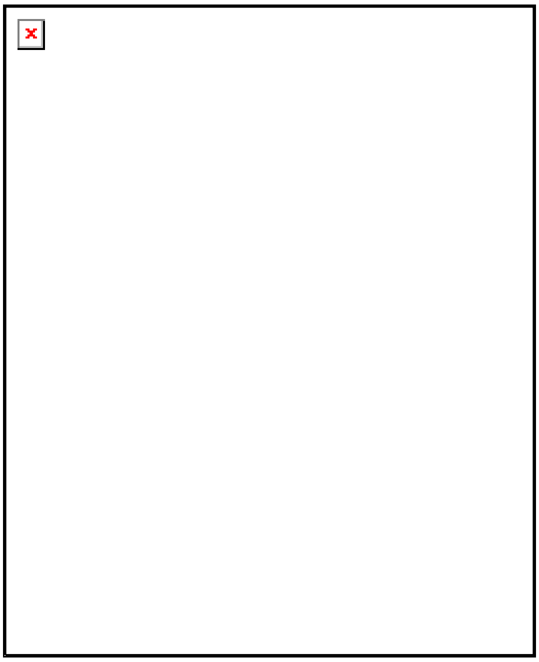
PRIORITY DECISIONS FOR INSTALLATION OF A NEW IN-STREAM STRUCTURE



APPENDIX F

CULVERT. EXE software documentation.

Fish passage through culverts



Software documentation

September 1999

Table of Contents

1 INTRODUCTION

1.1 Program Description

CULVERT.EXE was developed to provide biologists and engineers with an integrated solution to some of the more common problems associated with fish passage through culverts and channels. CULVERT.EXE calculates the water velocities flowing through existing or newly designed culverts/channels flowing partially full and determines whether fish passage is possible for common New Zealand fish species. The program models both uniform (for definition see page 14) and non-uniform sub-critical flow and assumes that fish passage is unlikely if flow is super-critical. The programme does not evaluate passage below the culvert outlet or up stream of the inlet.

Programme users are able to model culvert characteristics in order to determine how different conditions may influence fish passage. For example, a user can model the effects of varying gradient or outlet conditions (i.e., the effects of a free outfall compared to a pool). Manning's N (the index of channel roughness used in the program), is difficult to estimate, especially for low-flow conditions. Therefore, when assessing existing culverts, the program allows entry of culvert flow, water velocity and depth to calculate actual values of "N". With experience, it is anticipated that estimates of "N" in new and existing culverts will become more accurate.

Fish swimming criteria are incorporated in the programme for different fish species. The user is able to alter these criteria to suit. Maximum passage distances are determined for each species of a specific length using relationships between maximum swimming time, fish length, and velocity. These relationships differ between species groups, such as salmonids, eels, and galaxiids. The climbing ability of fish species, such as elvers and koaro, is not taken into account in this programme.

1.2 About This Manual

This manual describes the basics features of CULVERT.EXE and helps the user to become more familiar with the procedures specific to the program. The manual begins by briefly describing all menu options, and then goes through the actual use of the program. The user is encouraged to read this manual thoroughly before using CULVERT.EXE.

1.3 System Requirements

Minimum: Culvert.exe requires a 386 (or higher) PC compatible running Microsoft Windows 95 (or later).

Disk Space:	Culvert.exe	696 KB
	Culvert.hlp	207 KB

A mouse or other similar input device is required for negotiating menus and dialogue boxes. However, the commands can also be chosen using the command underline option.

2 PROGRAM SETUP

2.1 Installing CULVERT.EXE

a) If CULVERT.EXE has not been used before, make a complete backup copy of the original floppy disk and keep in a safe place.
b) Insert the original disk into your floppy disk drive and copy the entire contents onto the hard drive.
c) Verify the successful transfer to the hardrive. If it has been performed correctly, you should have a directory/folder named CULVERT.

3. HOW TO USE THE PROGRAM

a) Enter measured values of flow, water depth and velocity to calculate Manning's N. Else estimate "N" based on experience or existing published values (see Appendix 1 for example).
b) Use the chosen value of "N", and the average flow during the migration period to predict fish passage for the target fish (species and length).

Passage can be achieved:

a) With low velocity across the entire channel,
b) With low velocity and sufficient depth along the channel margins,
c) With **resting** areas at intervals less than the distance the target fish can swim before exhaustion. These resting areas can be provided by baffles or spoilers and at low flows by large corrugation. (Descriptions of baffles and spoilers suitable for indigenous fish are given in Boubée et al. 1998)

4 DESCRIPTION OF PROGRAM

4.1 Menu Options

4.1.1 File Menu

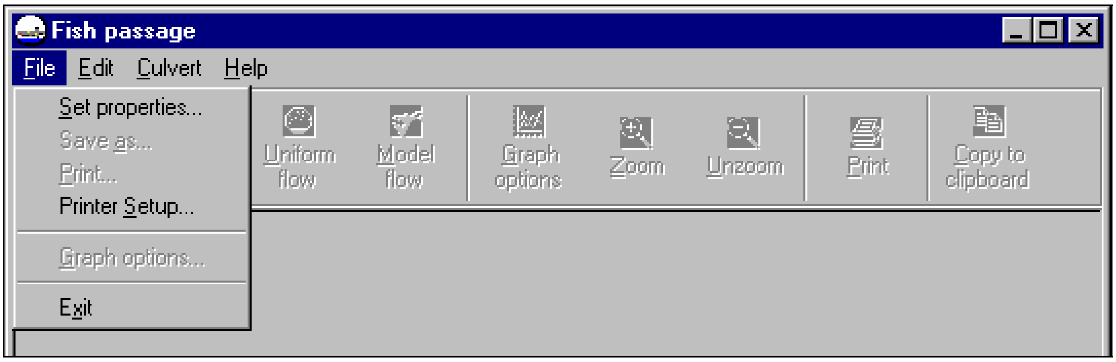
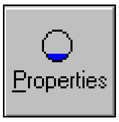


Figure 1: *File* pull down menu.

Set Properties

The *Set properties* command allows the user to specify the basic culvert characteristics and choose the target fish (species and length). This dialogue box can also be activated using the following icon:

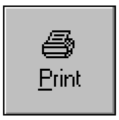


Save As

The *Save as* command is used to save the results of the analyses and graphs.

Print

The *Print* command is used to print the results of the graphs and analyses. This can also be done using the following icon:

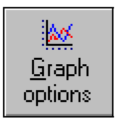


Printer Setup

Use the *Printer setup* command to set printer and paper options.

Graph Options

The *Graph options* command allows the user to alter the display of the graphs produced. Using this command it is possible to add titles to graphs and alter the scale of the *x* and *y* axes. This dialogue box can also be activated using the following icon:



Exit

The *Exit* command allows you to quit CULVERT.EXE.

4.1.2 Edit Menu

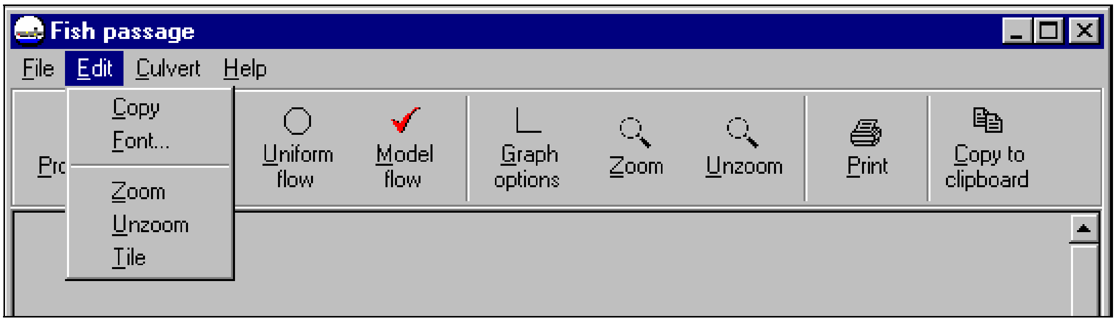
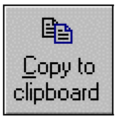


Figure 2: *Edit* pull down menu.

Copy

Text and graphs can be copied to the clipboard for export to other applications. The *Set Manning's N* dialogue box can also be copied and exported this way. Text windows cannot be edited until they are exported into another application. Items can also be copied using the following icon:

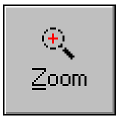


Font

Text fonts can be altered using the *Font* command.

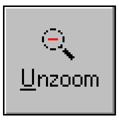
Zoom

Selected regions of the graphs can be enlarged on screen by selecting a portion of the graph and using the *Zoom* command. This can also be done using the following icon:



Unzoom

The *Unzoom* command restores the graph back to its original scale after the *Zoom* command has been used. This can also be done using the following icon:



Tile

The *Tile* command allows you to display more than one graph on the screen at one time.

4.1.3 Culvert Menu

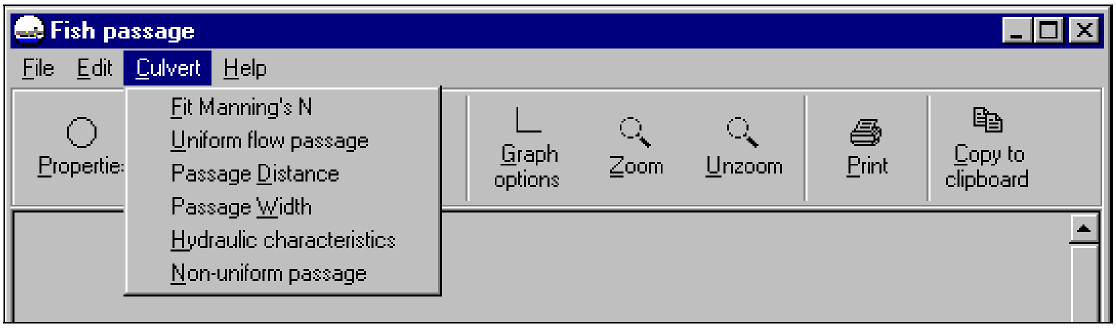
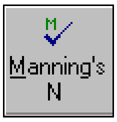


Figure 3: *Culvert* pull down menu.

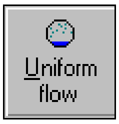
Fit Manning's N

Manning's N is calculated using measurements of culvert channel characteristics. This dialogue box can also be activated using the following icon:



Uniform Flow Passage

This activates the 'fish passage with uniform flow' results sheet. This command can also be activated using the following icon:



Passage Distance

This command produces the graph illustrating the maximum darting distance versus water depth for the target fish.

Passage Width

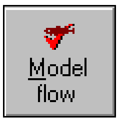
The command produces a graph illustrating passage width for velocity versus water depth for the target fish.

Hydraulic Characteristics

This command produces graphs illustrating the various hydraulic characteristics (discharge, velocity, area, width, hydraulic radius, and wetted perimeter) of the culvert against water depth.

Non-Uniform Passage

This activates the 'fish passage with non-uniform flow' results sheet. This command can also be activated using the following icon:



4.1.4 Help Menu

Figure 4: *Help* pull down menu.

Index

The *Index* command loads the help file. Topics are displayed alphabetically and upon selection are displayed and can be printed as required. A *Find* option is also available.

Contents

The *Contents* command loads the help file. All help topics are grouped into relevant sections and upon selection are displayed and can be printed as required.

4.2 Running CULVERT.EXE

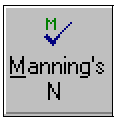
The following outlines the required and optional tasks required to complete the analysis of fish passage through a particular culvert or channel.

4.2.1 Units

The units used throughout this program are metric:

- Depth, length, width, distance – metres (m)
- Flow – cubic meters/second (m^3/s)
- Velocity – meters/second (m/s)
- Slope – meter/meter (m/m)

4.2.2 Manning's N Calculation



Values of Manning's N that are published are often for culverts flowing near full. Values of Manning's N for shallow water flows tend to be higher than conventional values, especially when the size of gravel or corrugations is greater than 0.1 times the water depth. This means that the value of Manning's N can change with flow and in a culvert flowing partially full is often higher at low flows than at high flow. Ideally, experience in estimating values of Manning's N should be gained by measuring flows and depths in existing culverts and calculating N using the dialogue box.

The relevant characteristics that need to be entered into the *Fit Manning's N calculation* dialogue box include:

- Discharge
- Water depth and velocity in centre of culvert
- Culvert diameter
- Side slope (for trapezoidal culverts)
- Slope
- Depth of gravel
- Culvert type
- Water surface width

The program itself does not require all of the above information, however the redundancy in some of these values provides a check on the data accuracy. For example the program automatically calculates the water surface width based on the culvert type, diameter, water depth and gravel depth. The calculated water surface width should agree with field measurements. Similarly, the water velocity times the cross-sectional area multiplied by a velocity reduction factor of about 0.8 should equal the discharge.

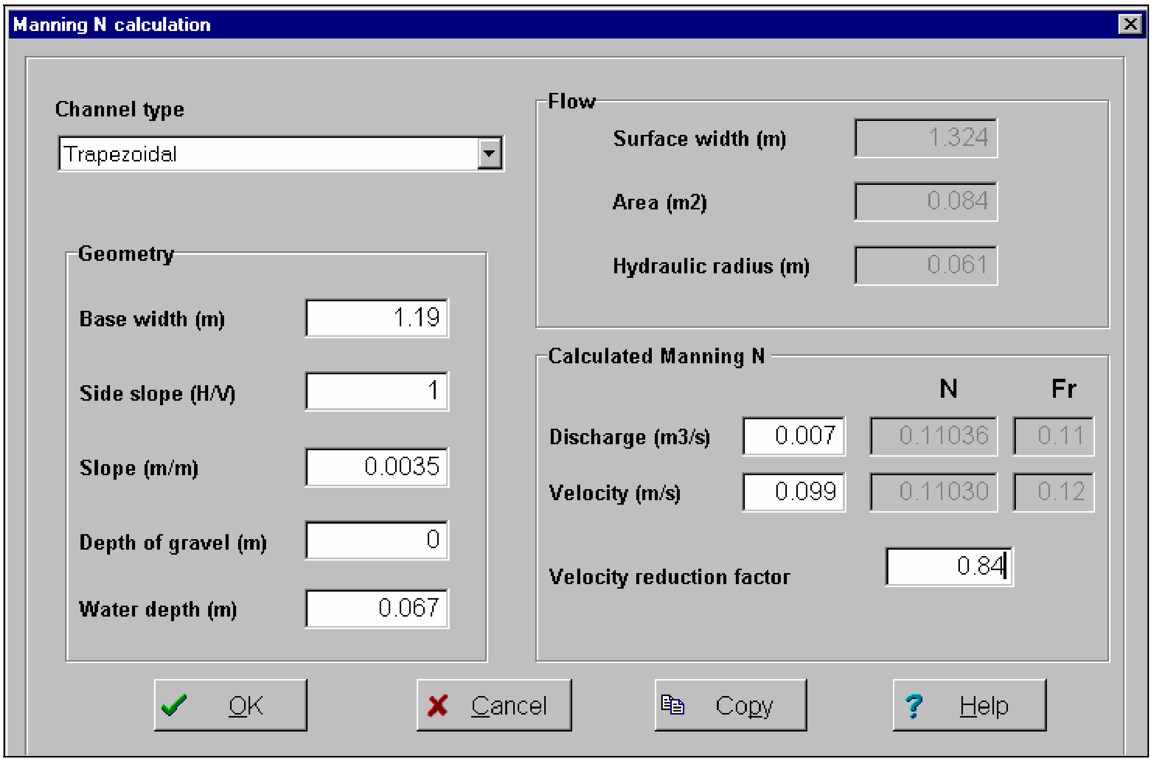


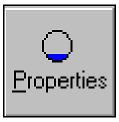
Figure 5: *Fit Manning's N* calculation dialogue box.

Figure 5 shows an example of the form used for this calculation. Froude number (Fr) is located alongside the value of Manning's N. The Froude number has a value of 1 for critical flow, <1 for subcritical flow, and >1 for supercritical flow. When flow is critical or supercritical, the program assumes that water velocities will be too high for fish passage.

Measures of velocity and discharge both allow values of Manning's N to be calculated and this provides a check on the measured velocity and discharge. If they do not agree the velocity reduction factor can be altered slightly until similar values are obtained. (As mentioned above, this reduction factor is usually about 0.8 but can vary between about 0.6 and 1 depending on the uniformity of the velocity distribution across the channel).

Select 'OK' button to the bottom left of the dialogue box once finished entering the data.

4.2.3 Specify Channel Geometry



Enter the basic culvert/channel dimensions and fish species into the *Culvert characteristics* dialogue box (see Figure 6). The relevant dimensions that need to be entered into the dialogue box include:

- Base width
- Side slope (for trapezoidal culverts)
- Height
- Depth of gravel
- Slope
- Manning's N (base and sides). Use calculated value or refer to a table for an estimate
- Length
- Fish species and length
- Minimum water depth
- Inlet and outlet conditions
- Flow

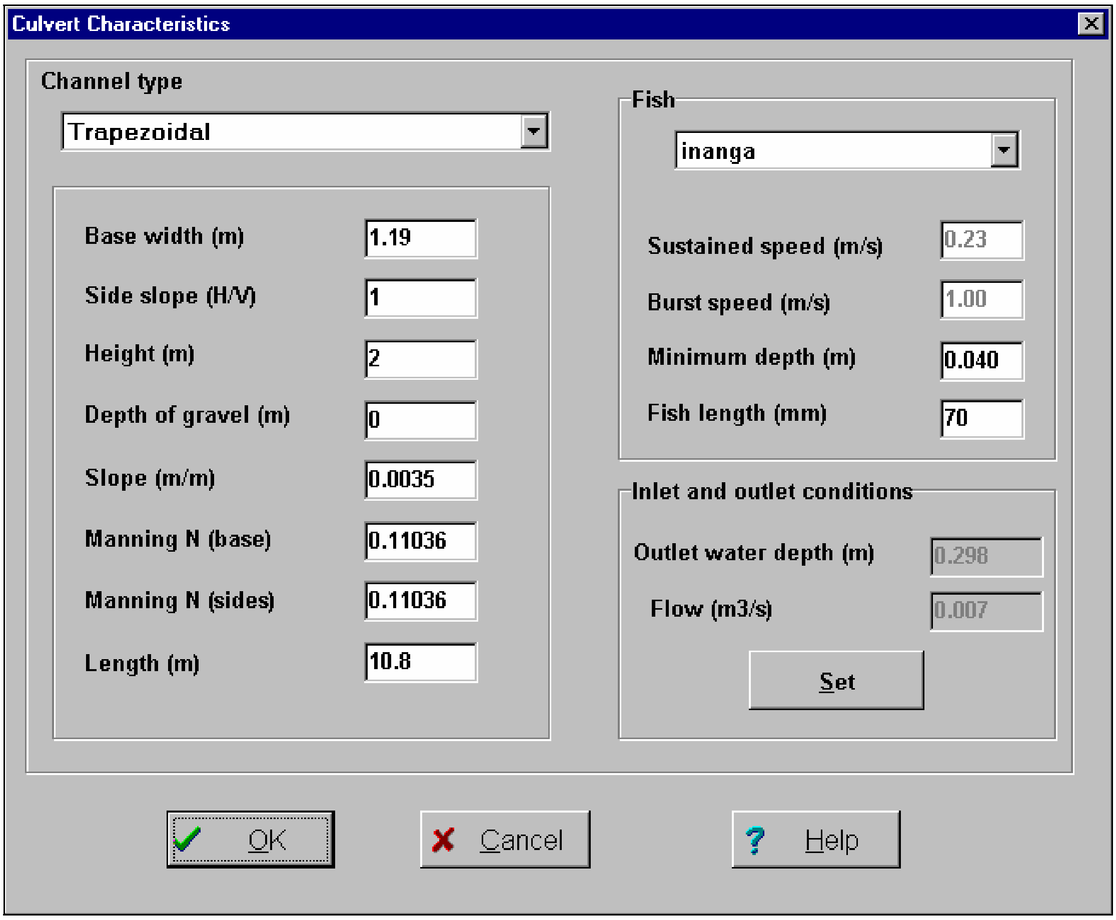


Figure 6: *Set properties - culvert characteristics* dialogue box.

Some of these entries will automatically be carried over from the *Set Manning's N* dialogue box (Figure 5).

The *Manning's N* value that appears in this dialogue box (Figure 6) is taken from the "N" value calculated from discharge. Two values of Manning's N can be specified, one for the base and the other for the walls or sides of the culvert/channel. Typical values of "N" are 0.04 for shallow gravel bed stream and large corrugation culvert, and 0.01–0.02 for concrete. Values for spoilers and baffles will be dependent on type and spacing but the few measurements made on spoilers installed in New Zealand indicate that a figure between 0.05 and 0.07 may be appropriate. The default values in the program are 0.04 for the base and 0.025 for the sides. Based on experience and/or existing information, other values can be entered as required.

Fish swimming criteria are incorporated in the programme for different fish species, including trout, eels, inanga, smelt, and bullies. The user can vary the criteria. Maximum passage distances are determined for each species and fish length using relationships between maximum swimming time, fish length, and velocity.

The inlet and outlet conditions can be altered by pressing the *set* button in the dialogue box shown in Figure 6. Various hydraulic conditions can be modelled depending on the factors determining the flow and the water levels at the inlet and/or outlet (Figure 7).

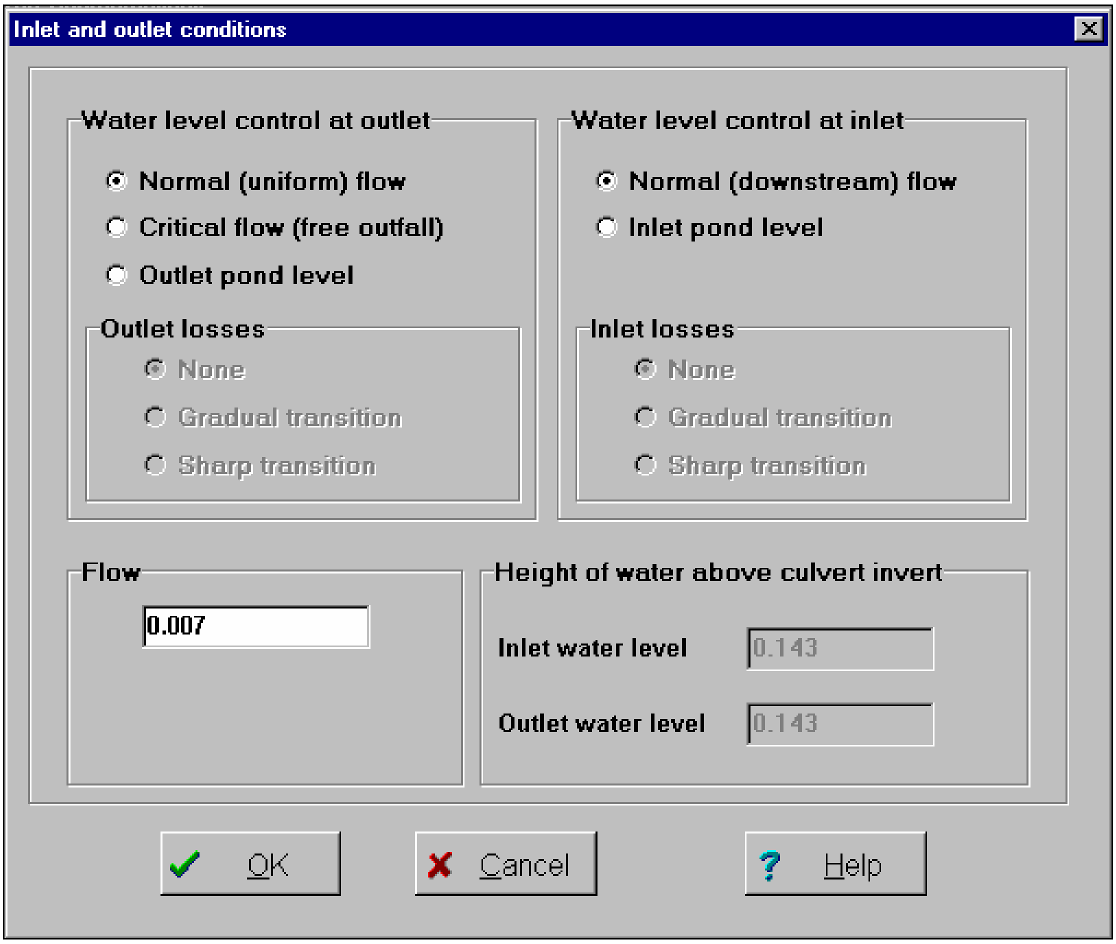


Figure 7: *Inlet and outlet conditions* dialogue box.

Water level control at inlet and outlet (Figure 7):

- Normal (uniform) flow occurs when water levels through the culvert are controlled by friction. This results in the same water level through the full length of the culvert. If the stream flowing below the culvert is of similar slope, depth, and width to the culvert, then the outlet conditions are probably normal (uniform).
- Critical flow, or a free outfall occurs when the stream drops away sharply at the outlet, and implies that the water level at the outlet pipe is not influenced by small changes in the water level down stream. When the flow is critical at the outlet, the depth that is displayed is the critical depth. This condition should be avoided where possible, as it often creates a barrier to fish passage below the culvert outlet.
- A drowned outlet (pond) occurs when a pool has been formed at the outlet and the water backs up into the culvert. In this situation the water level at the outlet is determined solely by the downstream pond level and the outlet hydraulic losses.
- Water level at the inlet determines the flow through the culvert. An example is a head pond or lake-fed channel.

Inlet and outlet losses (Figure 7):

Inlet and outlet losses can occur where there is a sharp transition at the inlet or outlet and turbulent eddies are created. In general losses will only be significant when velocity is high. To reduce this potential fish barrier, a large-diameter culvert with a gradual (contoured) head wall should be installed.

Select 'OK' button to the bottom left of the dialogue box to enter the data.

4.2.4 Fish Passage Results Analysis

After the appropriate hydraulic conditions and culvert dimensions are specified, the user can select the type of analysis to be carried out on the data. The choices include:

- Graphs of how the hydraulic properties of the culvert/channel vary with water level above the invert. To do this, select either *Passage width*, *Passage distance*, or *Hydraulic characteristics* from the *Culvert* pull down menu. A select button is visible on the bottom of most of these graphs to allow different variables to be displayed.

- Evaluation of fish passage through a culvert/channel for specified flow and outlet conditions. To do this select either *Uniform flow passage* or *Non-uniform flow passage* from the *Culvert* pull down menu.

Fish passage is checked by:

- Calculating the water depth and velocity at points across and along the length of the culvert.
- A weighted average velocity is used to calculate the maximum distance that a fish could swim up the centre of the culvert.

If the passage distance is less than the total culvert length, the velocity along the culvert margin is checked to see whether there is sufficient total width (0.08 m) with both:

- A velocity less than the fish species sustained swimming speed, and
- A depth greater than the minimum swimming depth.

If passage along the culvert margin is not possible then the following options are suggested:

- Reduce the gradient.
- Increase culvert roughness by installing baffles or weirs (see Boubée et al. 1998).
- Install resting areas.

5 REFERENCES

Boubée, J., Jowett, I., Nichols, S. and Williams, E. 1999. *Fish Passage at Culverts: A Review, with Possible Solutions for New Zealand Indigenous Species*. DOC Science Publications, Wellington, New Zealand.

Clay, C. H. 1995. Fish passage through road culverts. In *Design of Fishways and Other Fish Facilities*. Lewis Publishers, Boca Raton. 248 p.

Henderson, F. M. 1966. *Open Channel Flow*. Macmillan Series in Civil Engineering. Macmillan Publishing Co. Inc., New York. 522 p.

Hume Industries (N.Z.) Limited. *Humespun.Concrete Pipe Design*. Wellington. 57 p.

6 GLOSSARY

Burst swimming speed: A fish's swimming speed which is maintained only for a matter of seconds. Usually used for feeding or to escape predation. Also known as darting speed.

Depth of gravel: The depth of gravel above the invert (lowest point) of the culvert.

Discharge: The total flow through the culvert/channel.

Froude number (Fr): Characterises the state of the flow relative to the critical velocity. Fr has a value of 1 for critical flow, <1 for subcritical flow, and >1 for supercritical flow.

Height: The height of a channel or culvert taken from the invert to the point where the culvert or channel becomes full.

Manning's N: Index of channel roughness.

Resting areas Pockets of water with velocities below 0.05 m s^{-1}. Because indigenous fish are small even a 100 x 50 mm area of quiet water can be sufficient for fish to rest after swimming close to exhaustion. Resting areas can be pools up stream of weirs or the shelter provided down stream of weirs, rocks or spoilers.

Scour: Localised erosion caused by flowing water.

Side slope: Only determined for trapezoidal shaped channels/culverts and is the ratio of the horizontal distance to the vertical distance of the culvert/channel. (e.g., the side slope of a channel with 2:1 sides, 1 m rise for 2 m width increase, is 2).

Sustained swimming speed: The swimming speed a fish can maintain indefinitely without fatigue.

Uniform flow: Occurs when the water surface of the flow is parallel to the base of the culvert. The easiest way to determine if flow is uniform flow is to check that the water depth does not vary along the culvert.

If flow through the culvert is uniform or "normal", water depth and velocities are controlled by the slope and the friction exerted on the water by the bed and sides of the culvert or channel. If the culvert is long enough, flow will eventually become uniform, provided the culvert is not flowing full. If the stream flowing below the culvert is of similar slope, depth, and width to the culvert, then the outlet conditions are probably normal or uniform.

Velocity: The mean column (0.6 depth) velocity at the centre of the culvert/channel.

Velocity reduction factor: Converts the centre channel velocity to the mean cross-section velocity. This is normally about 0.8.

Water depth: The depth of water above the gravel, or above the invert if there is no gravel present, in the centre of the culvert/channel.

Weir: A small dam of rock, logs or concrete used to control the water depth and flow in streams.

Appendix F1

Values of Manning's N, roughness coefficient for channels and pipes of varying bed materials.

Type of pipe/channel	Manning's N
Concrete*	0.012
Plastic*	0.012
Clay*	0.012
Ductile iron/Cast iron*	min. 0.013
Corrugated metal†	
68 mm x 13 mm	0.029
76 mm x 25 mm	0.032
152 mm x 51 mm Struct. Plate	0.04
229 mm x 64 mm Struct. Plate	0.044
Rubble set in cement ‡	0.017
Earth, smooth, no weeds ‡	0.02
Earth, some stones and weeds ‡	0.025
Clean, straight natural river channel ‡	0.025–0.030
Weedy and winding natural river channel ‡	0.075–0.150
Shallow gravel channels (similar to salmon spawning grounds) §	0.025

* Design values for storm water pipes from Hume Industries (NZ) Ltd

† Design values from Hume Industries (NZ) Ltd., includes steel and aluminium, helical corrugations, and coated and paved pipes

‡ from Henderson (1966)

§ from Clay (1995)