Best Practice Guidelines for Waterway Crossings

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July 2009

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1 Introduction

These best practice guidelines have been prepared to assist regional and local authorities, consultants, roading engineers and contractors with the design of appropriate waterway crossings within the Tasman District.

By following the recommendations in this handbook, proposed waterway crossings:

- Will be designed to have the minimum possible adverse impact on the environment.
- Will be consistent with the requirements of the Tasman Resource Management Plan.
- Will not compromise the levels of service provided by District flood protection or land drainage schemes.

The topics covered by this best practice guideline handbook include:

- The Tasman Resource Management Plan.
- Flood control schemes and land drainage areas.
- Best Practice design guidelines for waterway crossings.

1.1 What is Best Practice?

Best practice is the most up to date, superior, or innovative practice that contributes to the maintenance or improvement of the existing environment.

These guidelines are intended to aid anyone involved in the installation or maintenance of waterway crossings in ensuring that the structures used are appropriate, installed and maintained appropriately and that the values associated with rivers and streams and their surrounding environment are protected and wherever possible enhanced.

These guidelines may also assist those involved in authorising and auditing stream crossings within the region, as they provide an indication of what should be expected from all crossings.

1.2 Why worry?

Tasman District is home to 20 species indigenous freshwater fish, half of which are migratory. Apart from the degradation of adult habitats, one of the most significant causes of the decline in freshwater fish population in New Zealand is the construction of structures such as dams and culverts that prevent fish from accessing otherwise suitable habitats. Management of the numerous freshwater resources has so far focused ion avoiding, remedying or mitigating the impacts of contaminant discharges, physical activities in streams or abstractions.

Potential migration barriers such as waterfalls, rapids, chutes, and debris jams are natural. However, the majority of in-stream obstructions are manmade and include structures such as culverts, flapgates, dams and weirs. Culverts with overhanging standpipes are the most common barrier in Tasman making up about 60% of all potential barriers. Most of these have resulted from erosion over time at the downstream end of the culvert, particularly from scour from high-velocity floodwaters.

It is possible that the installation of a waterway crossing, or works relating to it, will require Resource Consent therefore it is advisable that Tasman District Council is contacted before work starts. You may need a resource consent to install some culverts and crossings. You should contact the Council before you start work to make sure. Council staff can also give you advice about what you may need.

2 Type of waterway crossings

The type of waterway crossing selected will depend on the physical, economic and environmental constraints of each site / project. For instance, it is unlikely that a culvert or ford will be appropriate in a river or stream with a width greater than 3 meters. Similarly, a single span bridge may not be practical over a river with a span of 100 meters. Notwithstanding these limitations the following sections of this report rank the types of waterway crossings **in order of preference** based on their environmental impact**:**

2.1 Single span bridge

A well constructed single span bridge (Figure 1) is the optimum type of waterway crossing and is preferred by TDC. If single span bridges are constructed according to best practice (see section 4.4) the waterway environment remains largely unchanged and flood flows can easily be accommodated.

Because of the preferred status of single span bridges, and the relatively small impact they have on the stream environment, provision has been made in the Tasman Resource Management Plan to allow for their construction and placement as a permitted activity subject to some conditions.

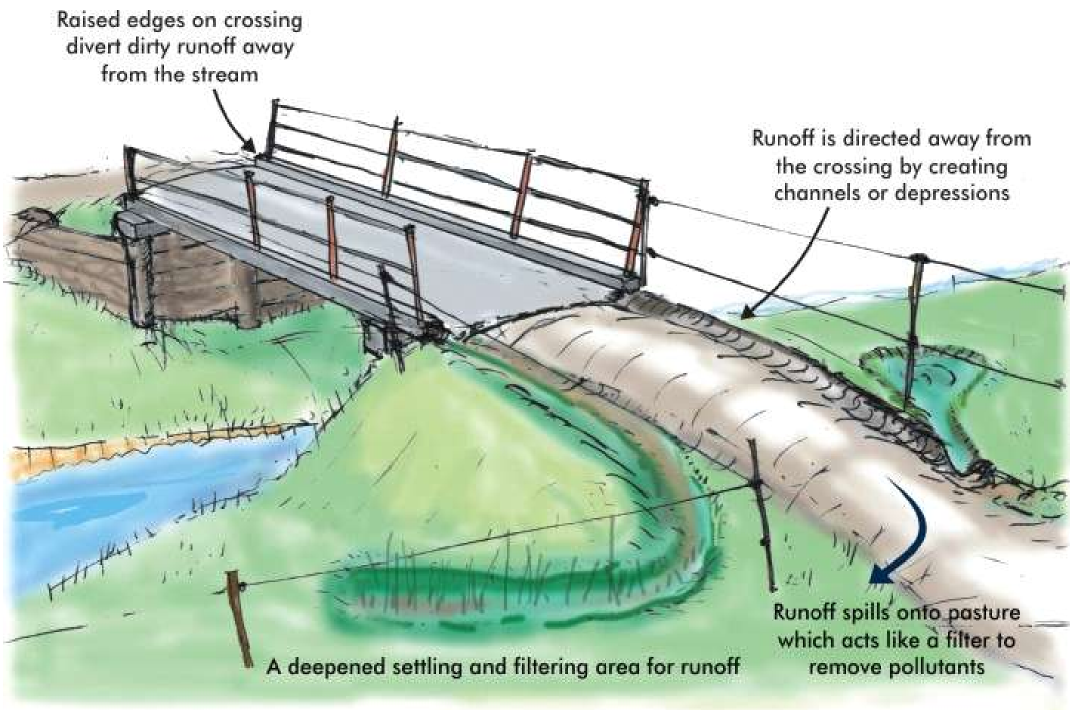

Figure 1   Best Practice single span farm bridge.

Note that the footing of the bridge is well away from the water edge at normal flow such that the natural river bank is retained under the bridge.

2.2 Single barrel arch culvert

If a bridge is not chosen, and the waterway to be crossed is not too wide, a single barrel arch culvert (i.e. a culvert with a flattened floor or a full round culvert with no floor) (Figures 2 & 3) is the next most preferred waterway crossing.

This is the preferred type of culvert because the arch shape allows for a wide base which can accommodate the full width of the waterway and allow for a 'natural' stream bed to develop within the barrel. The large size of the culvert also ensures that light is available throughout its length. Depending on the size of catchment you are in a Resource Consent is likely to be required before construction begins. Contact TDC for further information on consent requirements for culverts (see contacts in Appendix 1)

Figure 2 Single barrel arch culvert

Note the rocks within the barrel.

Note that in both examples shown (Figures 2 & 3) the full width of the stream is accommodated at average flow. The arch culvert shown in Figure 3 has been installed to accommodate not only the full width of the stream bed but also some of the natural bank. Large rocks have been placed in the straight barrel section of the culvert to ensure that high flow velocities do not develop and to provide cover and habitat for fish and the large size of the culvert ensures that light is available throughout its length. In terms of culvert design **this culvert represents best practice**.

Figure 3 Best Practice - single barrel arch culvert

(Photograph – courtesy of ARC)

2.3 Single barrel circular culvert

These are the most common form of culvert but are not as desirable as arch culverts or bridges. They can still be acceptable if installed using best practice; but should only be considered if bridges or arch culverts are not a viable option.

The circular pipe concentrates low flows to its centre which is important in maintaining a minimum water depth in periods of low flow to allow for fish passage. However, unless oversized, circular culverts tend to reduce the waterway area and so increase water velocities at high and medium flows which can prevent fish passage.

This can be overcome by:

- ensuring the culvert diameter is sufficiently large to accommodate the full normal flow bed width of the waterway. To achieve this, the culvert diameter must be larger than the stream width at average flow. The rule of thumb for determining the appropriate barrel diameter is 1.2 x channel width + 0.5m
- ensuring that the culvert floor (invert) is set below stream bed level and the outlet is flooded at all flows.
- using arched culverts. These are available in corrugated iron or can be made from a plastic culvert by cutting in half lengthways.

Appropriate Culvert Diameter = 1.2 x the channel width + 0.5m

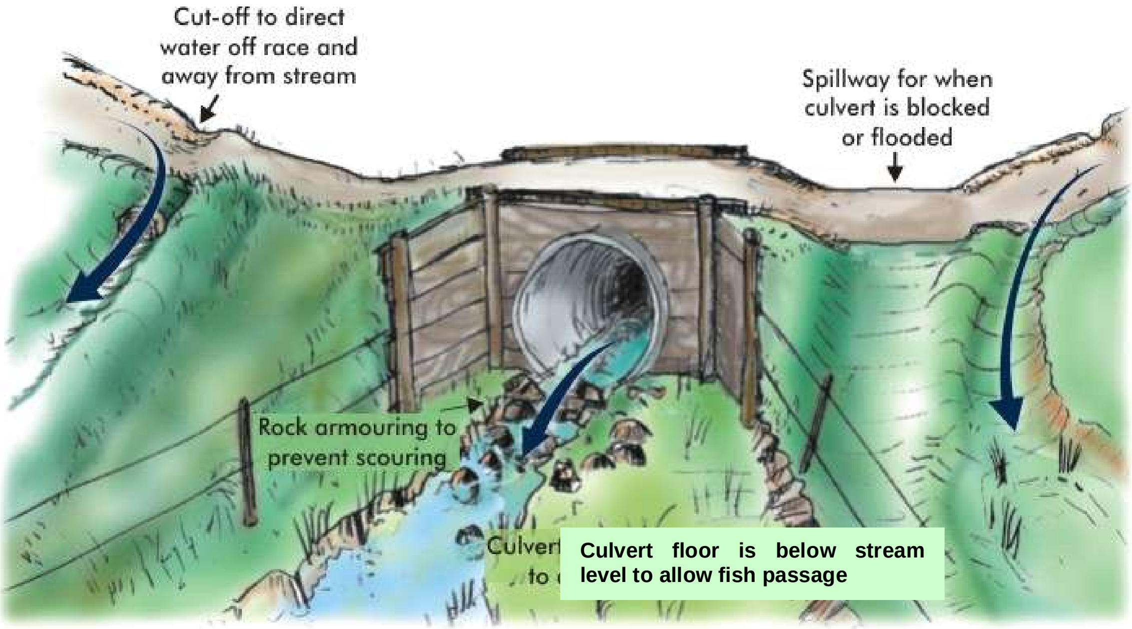

Figure 4 Outlet of typical Best Practice single barrel circular culvert

Figure 5 Typical Best Practice single barrel circular culvert

2.4 Multi-barrel circular culvert

Crossings with multiple culverts placed side by side are common in wide channels that have a relatively low normal flow but occasional very high flow events. These types of crossing are prone to collecting debris and to becoming blocked, therefore reducing the capacity of the crossing.

Figure 6 Typical multi-barrel circular culvert

In cases where streams have low flow volumes for most of the time and relatively high flood flows, multiple barrel culverts set at different levels can be appropriate to ensure that appropriate waterway area is provided for at all flows (Figure 8). Installation of a second culvert at a slightly higher or lower level can also be a useful way to remediate an existing culvert that is too small or is not providing adequate fish passage.

Figure 7 Multi-barrel circular culvert with culvert pipes at different levels to cater for high flows and low flows

2.5 Box culverts

Box culverts are not recommended for use as waterway crossings. While they can often accommodate the full natural width of a waterway they also result in a uniform depth of water and a uniform flow within the barrel. During low flow periods box culverts do not concentrate flows to maintain water depth as circular culverts (and natural stream beds) do, and consequently result in a thin sheet of water covering the full width of the culvert (Figure 9). The outcome can be an insufficient depth of water for the passage of fish during low flows.

During normal and high flows box culverts can accommodate a greater volume of water than the same diameter circular culvert, however because of the vertical sides they do not provide any shallow, low flow areas within the barrel and are more likely than circular culverts to pose a barrier to upstream fish passage.

If they are installed, the base of box culverts should be modified by haunching (filling in the corners of the sides) so that wetted margins are always present at average flows. A low flow channel should also be created to maintain a channel that fish can utilise during dry periods. The most cost-effective design to achieve this is to slope the floor of the culvert to one side.

Figure 8 Single box culvert

Note the very shallow uniform depth of water in the culvert barrel. This is would pose a barrier to the upstream migration of many fish species

2.6 Fords –

Fords are the least preferred type of waterway crossing and are not recommended by the Tasman District Council. Fords significantly disturb the bed of a waterway, often act as barriers to fish and are unlikely to achieve the objective of most waterway crossings, which is to prevent vehicles and animals from entering the water and the resulting contamination.

3 Design, maintenance & restoration ecological values

Inappropriately placed or maintained waterway crossings can have significant adverse effects on the ecological values of rivers and lakes, either individually or in combination with other structures. These can include:

- Interruption of the migration pathways of aquatic organisms (fish and invertebrates).
- Loss of physical space and habitat.
- Changes to fish and invertebrate communities.
- Interference with sediment transport and flow regimes.
- Obstruction and flooding.
- Impacts on water quality.

It is therefore important that these issues are addressed and prevented during the planning phase or, for existing structures, that the appropriate remedial measures are taken.

For a number of native fish species (including the whitebait species), and for trout in some areas, the ability to migrate is critical to their lifecycle. If they cannot migrate to spawning areas or to adult habitat areas the population will eventually disappear.

Traditionally, passage issues have been focused around fish migration. However, badly designed, installed and maintained waterway crossings have also been demonstrated to impact on the migration of aquatic invertebrates such as mayflies, caddisflies[1], and shrimps. This has resulted in reduced populations of these organisms upstream of in-stream structures (particularly small culverts).

Fish migration can be impeded or prevented by a waterway crossing if:

- The **water velocity** is too high and/or there are no resting areas provided within the barrel of the structure. There is no low velocity zone or wetted margin provided at the water edge (normally caused by culverts that are too small for the existing flow conditions, bridges with abutments too close to the stream edge or box culverts).
- **Water turbulence** is too great (normally the result of culverts which are too small or too steep).
- The **floor level of the crossing** is raised above the stream bed (e.g. if a culvert's floor is perched above the stream bed).
- **Light requirements** insufficient (e.g. a culvert that is too small and/or too long).

[1] Blakely, T. Harding, J.S., McIntosh, A.R. 2003. Impacts of urbanisation on Okeover Stream, Christchurch. Christchurch City Council Report. University of Canterbury: Christchurch.

- **Water depth** insufficient (often stream water in box culverts is too shallow and wide during low flow periods).

- The **substrate** (river bed) is too smooth for bottom swimmers (this usually occurs where a structure has a concrete or steel bottom and normal stream bed material has not been able to develop within the structure).

- The **longitudinal bed level** within the crossing is too steep.

- **Debris** has been allowed to build up and has formed a weir and blockages regularly occur.

- **Scouring** occurs causing changes in bed level and steepness.

- **Timing of works**

Aquatic Invertebrate migration can be prevented or impeded by a waterway crossing if:

- The crossing is too narrow and reduces the waterway area thus restricting the flight path of upstream migrating adults. For example, adult caddisflies fly upstream to lay their eggs along a flight path defined by the stream channel. Narrowing this flight path by the installation of a waterway crossing has been demonstrated to significantly reduce, or even prevent this migration from occurring. The end result can be large parts of a waterway with reduced invertebrate and fish species diversity.

> The Tasman District Council resource scientist for aquatic ecology should be consulted to determine the ecological value of the waterway, as in some cases fish migration may not be a necessary design consideration. Where unwanted fish are present a barrier may actually be advantageous. There are also situations where a landlocked population of a rare fish has developed and easing passage for other species would be detrimental (e.g. ??).

The following are guidelines for construction or modification of waterway crossings in order to minimise the adverse effects that waterway crossings have on fish migration.

3.1 Design and construction considerations

Detailed design and retrofit information for culverts, including information on the swimming capabilities of New Zealand fish species, construction of rock rubble weirs and installation of baffles to optimise their effectiveness can be found in the Boubee (1999).

3.1.1 Water velocity

Issue: Fish can only progress upstream if water velocity is equal to or lower than the fish's swimming ability[2]. If the combination of water velocity and

[2] The swimming ability of fish varies according to species and life stage. Over short distances some species such as trout are able to maintain a very fast high energy burst in order to overcome obstacles, however, because this ability

distance to pass a stream or river crossing exceeds the capacity of the fish, upstream migration will be impeded.

Design: Stream crossings should not increase the natural stream velocity (i.e. they should maintain the effective waterway area at normal flows – and if possible at high flows).

If the waterway area is reduced by the construction of a crossing, the water velocity along the banks, at normal flow, should be maintained at **less than 0.3 m/s** to allow for the passage of all indigenous fish and trout. Velocities over 0.3 m/s will impede the passage of some of the weaker swimming fish species and velocities over 1 m/s are likely to significantly impede the upstream passage of most fish species.

Retrofit: Poorly installed waterway crossings can be enhanced or retrofitted by the addition of low velocity areas such as those found at stream edges. These areas can be included in a proposed waterway crossing design by:

- Retaining the natural bed of the waterway, OR;
- Where the natural bed cannot be retained, including woody debris along the stream banks and inside the structure; OR
- maximising the roughness of the crossing by using either baffles or rocks (Figure 9), AND;
- Installing culverts that are sized to exceed the minimum hydraulic requirements.
- If water velocity is an issue then a multiple culvert could be used in some instances. However, a Single Barrel Culvert is still the preferred preference

Equations for determining the flow velocity in a waterway or culvert are included in Appendix 1.

is variable, waterway crossings should be designed to accommodate the species of fish (present downstream) with the lowest swimming ability.

Figure 9 Baffles (these can be of many materials) and rocks can be installed into the base of a waterway crossing to provide cover and low velocity zones to aid with fish passage

The baffles need to be fitted to the culvert walls up to the depth that is submerged at average flow. Baffle size and spacing should cater for the target species so for most indigenous fish species they can be quite small (no more than 120mm x 120mm).

3.1.2 Flow turbulence

Issue: Excessively turbulent flow can make a culvert impassable and may encourage downstream erosion.

Design: Design the waterway crossing to include irregular channel roughness, which prevents excessively fast flow from occurring but without creating excessive turbulence. This is most readily achieved by retaining the natural bed of the waterway or by installing baffles and rocks on the culvert floor.

Retrofit: Where an existing waterway crossing is creating excessively turbulent flow there may be a need to replace the crossing in order to remedy the problem. However, baffles (as described above) may also be an appropriate solution.

Figure 10 Rocks can be cemented into the base of waterway crossings and/or to the aprons of culverts to ensure that there are areas of low water velocity available to aid fish passage and sediment which is appropriates for invertebrates is retained within the structure

3.1.3 Culvert inlet conditions and Sizing

Issue: Poorly sized or placed culverts can reduce the cross sectional area of the stream, restricting flows and increasing water velocity at the inlet. This results in a hydraulic jump at the culvert inlet which can prevent fish from exiting the culvert pipe.

Design: Design the waterway crossing to maximise waterway area (in preference use a bridge or an arch culvert). This will also have benefits in terms of maintaining natural substrate (river bed) and stream velocities. Where using a culvert ensure that the pipe size complies with the rule of thumb given below:

Avoid culverts which project out of the headwall into an inlet pool as these are the most likely to result in concentrated high velocity inlet conditions and prevent fish passage.

Appropriate Culvert Diameter = 1.2 x the channel width + 0.5m

Retrofit: Where a waterway crossing is shown to restrict passage because of inlet conditions there may be a need to replace the crossing in order to remedy the problem. Alternatively, hydraulic conditions at the inlet can be remedied by placing rocks at the inlet to break or re-direct water flow.

3.1.4 Culvert outlet conditions

Issue: Culverts with a culvert floor level that is above the natural bed level of the waterway, are said to be perched. This creates a barrier that cannot be passed by most indigenous fish or migrating shrimp at normal flows. Even those species that can climb significant barriers have difficulty passing the resulting free-fall of water at the culvert outlet.

Culverts can become perched following installation, particularly in soft erodable subsoil or rock (eg Separation Point Granite). This is due to downstream scour occurring as a result of high water velocities from an undersized culvert. A culvert can also become perched if located inappropriately (e.g. on a bend or at a slope that is too steep).

Design: When designing a culvert, ensure that the design invert level is below the natural bed level of the waterway and the base of the culvert is allowed to fill with stream bed material. Also ensure that the culvert inlet and outlet including the banks are protected from scour that could potentially cause the culvert to become perched following installation. Aprons or other outlet passage control should be considered for areas in Separation Point Granite geology or any soft subsoil condition.

Retrofit: The depth of water within a waterway crossing can be increased by constructing a weir and/or rock rubble ramp downstream of the crossing to raise the tail-water level and consequently flood the culvert outlet as shown in Figure 12 below.

This has the effect of remedying the outfall conditions, improving conditions for fish passage at the entry and within the barrel of the culvert and reducing erosion of the stream bed at the outfall (thus increasing the longevity of the culvert structure.

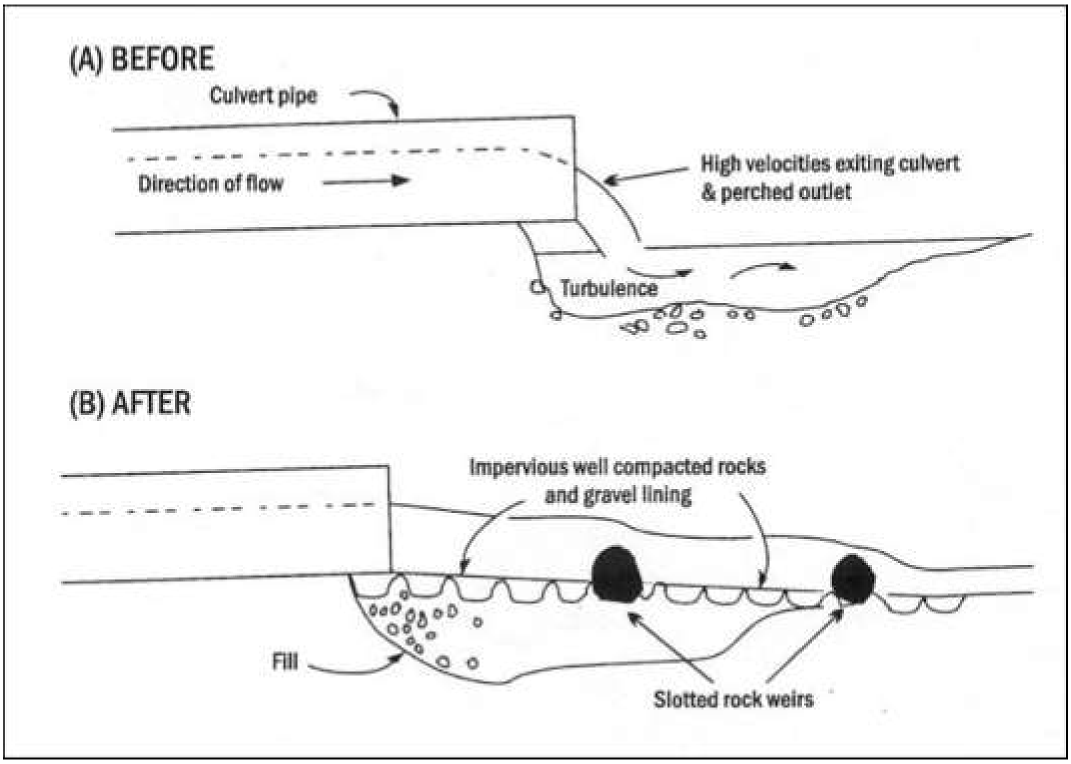

Figure 11 Construction of downstream rock weirs is a useful method for resolving a number of common problems with culverts crossings note that filter cloth should also be used underneath the gravel lining.

Perched culverts are the most common source of artificial barriers to fish migration. In a survey of culverts in the Tasman Region over 60% presented a barrier or partial barrier to fish passage and the majority of these were perched culverts (TDC fish passage database November 2008).

3.1.5 Light requirements

Issue: The migration of certain species can be affected by the amount of light available. Some species will not enter totally dark culverts while others will simply move more slowly.

Design: Increase the amount of light within a culvert by minimising the culvert length and increasing its size (Diameter, Height, or Width). Ensure that the culvert has no bends.

Retrofit: Remediation in this case usually means replacing the culvert. Where a waterway crossing is shown to have inadequate light conditions for successful fish or invertebrate passage there may be a need to replace the crossing in order to remedy the problem. The decision to replace a structure should take into account the nature of the upstream habitat that will be made available and of the species that are likely to benefit from the change.

3.1.6 Water depth and wetted margin

Issue: Low water depths can hinder or even prevent fish passage. Lack of a wetted margin, which can be used for resting and "climbing", can also hinder fish passage. These problems are most common in box culverts and where large flat concrete aprons have been installed, as these often result in a thin sheet of water being produced at low flows. Vertical walls such as in a box culvert, or at the inlet and outlet wing walls, do not provide the low velocity zone necessary for resting or climbing.

Design: Where possible the natural bed and normal waterway depth should be retained as is normally the case with bridges. If this is not possible, arch or circular culverts are preferred. These should be designed so that under normal flow conditions they are less than 1/2 full.

Retrofit: The depth of water within a waterway crossing can be increased by:

- Maximising the roughness of the crossing by using either baffles or rocks (Figures 10 and 11) within the crossing area. This effectively holds water up and increases the wetted depth as well as providing opportunities for resting areas.
- Construction of weirs and or rock rubble ramps downstream of the crossing to raise the tail-water level and consequently the water level within the crossing as shown in Figure 12 below. This is also an appropriate remedy for perched culverts and culverts with high water velocity.

3.1.7 Timing of works

Issue: In-stream works, such as those required to install waterway crossings, may conflict with and hence interrupt the migration of fish.

Design: Most fish migrate upstream in spring and early summer, therefore construction at these times should be avoided. Also, where possible, plan in-stream works for the driest period of the year to minimise erosion and sediment loss to the stream (late summer – early autumn.)

> Refer to McDowall (1995) for details of the migration timing of indigenous fish or contact Tasman District Council freshwater ecological staff. Also available is a migration and spawning calendar for all species of native fish and trout within the region.

3.1.8 Structure location and stream alignment

Issue: Waterway crossings have the potential to damage in-stream habitats, particularly when they are installed incorrectly or in inappropriate locations.

Design: Locate the proposed waterway crossing on a straight section of channel where the channel gradient is lowest. Riffles should be avoided as they provide important habitat for invertebrate production and fish.

Maintaining the natural channel as much as possible is an important consideration in any in stream work however, in the long term, it is preferable to reconstruct the channel upstream and/or downstream of a crossing rather than install a culvert or bridge at the wrong slope or with a poor alignment to the stream flow. All construction work should be accompanied by appropriate sediment control measures, include reinstatement of vegetation along the stream margin and where possible protection from grazing stock.

Retrofit: Where a waterway crossing is shown to be inappropriately located or aligned there may be a need to replace the crossing in order to remedy the problem. The decision to replace a structure should take into account the nature of the upstream habitat that will be made available.

3.1.9 Physical barrier to aquatic invertebrates

Issue: Reduced waterway area results in a narrowing of the flight path of adult invertebrates and may prevent them from finding the crossing entrance (particularly an issue for small culverts).

Design: Design the waterway crossing to maximise waterway area (in preference use a bridge or an arch culvert). This will also have benefits in terms of maintaining natural substrate (river bed) and stream velocities.

Wherever possible access ways such as roads or races to and from the crossing should be as low as possible and should be designed to take up as little of the adjacent flood plain (spillway area) as possible.

The crossing should be designed to minimise the loss of riparian habitat and where practicable riparian planting should be undertaken after the crossing has been completed to provide adult invertebrate habitat.

Retrofit: Where a waterway crossing is shown to restrict upstream invertebrate movement there may be a need to replace the crossing in order to remedy the problem. The decision to replace a structure should take into account the nature of the upstream habitat that will be made available.

4 Designing waterway crossings to accommodate flood events

Waterway crossings have the potential to restrict high flows during flood events. This in turn can increase inundation on adjacent properties and cause the deposition of sediment in low velocity areas upstream of the restriction. Also, some species of fish are stimulated to migrate during or immediately after flood events and this is impeded if the waterway restriction results in high water velocities (refer to the previous section *Maintaining Fish and Invertebrate Passage*).

It is therefore important that waterway crossings are designed so that they can cater for high flows without significantly changing the water velocity and without increasing the upstream water level. This section provides design strategies that aim to achieve this.

4.1 Definition of a reasonable flood event or design standard

The Tasman Resource Management Plan (TRMP) defines a reasonable flood event as an event that has an Annual Exceedence Probability (AEP) of 2%, which is equivalent to a 50 year return period. This should be the minimum design standard adopted for the design of a waterway crossing.

The exception to this rule is if the proposed crossing is located within a drainage area, in which case the design standard adopted should be consistent with the local drainage standard. See Tasman District Council engineering staff should be contacted regarding local drainage standards.

4.2 Estimation of design peak flood flow

There are a number of methods available to estimate design peak flood flows in waterways. These are a combination of theoretical methods and methods that are based on field observations.

In most cases, Tasman District Council uses the methods prescribed by the Ministry of Works and Development (MWD) Culvert Manual to audit proposed waterway crossings. These methods include:

- The Ramser-Kirpich, Bransby-Williams, and USSCS equations for the estimation of catchment time of concentration.

- The Equal Area and Modified Taylor-Schwartz methods for the estimation of catchment slope.

- The High Intensity Rainfall Design System (HIRDS) for the estimation of design rainfall depth.

- The Rational Method for the estimation of peak runoff flows from small homogeneous catchments.

- The Revised Regional Flood Estimation Method

- Technical Memorandum 61 (TM61) for the estimation of runoff flows from large or complex catchments.
- Manning's Formula for the estimation of channel capacity.
- Federal Highway Administration (FHWA) manual for the Hydraulic Design of Culverts for the estimation of culvert capacity.

The recommended steps to estimate the design peak flood flow for a waterway crossing are presented in the following sections:

4.2.1 Define the waterway catchment

The catchment of a waterway is the section of land that drains into that waterway. There are a number of parameters that are used to define a catchment. Those that are necessary for a waterway crossing design are:

- Area (refer to diagram)
- Topography
- Land use description (e.g. urban, cultivated, pasture, forest) and potential for land use change
- Maximum channel and catchment length (refer to diagram)
- Change in elevation over maximum channel length
- Catchment slope and orientation
- Average slope over maximum channel length
- Existing structures both upstream and downstream

Figure 12 Characteristics of a catchment

4.2.2 Calculate the average slope of the main waterway

The average slope of a waterway can be defined using two methods. The first uses the highest and lowest points on the channel (see 'slope 1' in figure 14). This method is suitable only if the channel slope is reasonably uniform along the entire length.

If the channel is not uniform along the entire length (e.g. there is a steep section at the top of the catchment) the first method may over estimate the average slope of a channel, as is demonstrated in figure 14.

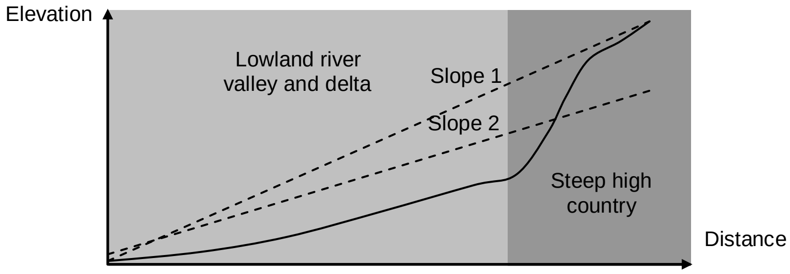

Figure 13 Typical profile of a river

An alternative method is therefore required that generates the slope represented by 'slope 2' in figure 14.

There are a number of methods available to generate such a slope. Three that are included in the MWD Culvert Manual are listed below:

- The Equal Area Method

- The Modified Taylor-Schwartz Method

These equations are presented in Appendix 1.

4.2.3 Calculate the time of concentration for the catchment

The time of concentration for a catchment is defined as the time it takes for a drop of water to travel from the top of the catchment to the bottom of the catchment (where the proposed crossing is to be located). It is also assumed that the time of concentration is equal to the critical storm duration; which is defined as the storm event predicted to produce the highest peak flow in the waterway.

There a number of methods used to calculate the time of concentration for a catchment. Three of these are included in the MWD Culvert Manual:

- The Ramser-Kirpich equation
- The Bransby-Williams equation
- The USSCS equation

These equations are presented in Appendix 1.

4.2.4 Define the design storm for the proposed crossing

The design storm is the rainfall event that is used as input into a rainfall-runoff model to estimate the design peak flood flow that a proposed crossing will be required to pass. The design storm is defined using the critical storm duration and the design standard (refer to previous sections).

The rainfall depth associated with this design storm is obtained either from site specific rainfall records or using the High Intensity Rainfall Design System (HIRDS) software package which is available from NIWA (national Institute of Water and Atmospheric

Research), which produces rainfall depths unique to the geographic location of the proposed crossing.

4.2.5 Calculate the design peak flood flow for the proposed crossing

The design storm is used in conjunction with catchment parameters to estimate the design peak flood flow in the waterway. The design peak flood flow is a reasonable estimation of the highest flow that the crossing should be designed to pass without causing a significant increase in upstream flooding.

The design flow is calculated using a rainfall-runoff model. There are numerous rainfall-runoff models available, all of which may be used with adequate technical justification. Those included in the MWD Culvert are:

- The Rational Method (for small homogeneous catchments) is one of the simplest empirical rainfall runoff models developed. It is best suited to small urban catchments of less than 25 km^2 and small rural catchments of less than 10 km^2 .

- Technical Memorandum 61 (TM61) (for large and complex catchments) is an empirical rainfall-runoff model for estimating peak runoff flows in un-gauged New Zealand catchments. It uses a number of coefficients that are derived using tables and graphs that are included with the memorandum.

Because these two methods are empirical they should only be used to estimate the design discharge when hydrological data are unavailable or insufficient for a precise analysis. Furthermore because of the uncertainties with such methods, both methods should be used and the most conservative result applied.

For catchments less than 25 km2 TM 61 and the rational method are equally suitable for estimating the design discharge. For larger catchments the rational method should not be used, except as an approximate check on the results from TM61.
Equations for these rainfall runoff models are presented in Appendix 1.

4.3 Design strategies using the design peak flood flow

These general design strategies are designed to avoid or remedy the adverse effects that waterway crossings have on the environment.

4.3.1 Bridges

- Bridges should be designed so that the undersides of the bridge beams are at least 0.5 metres above the adjacent floodplain. This allows the adjacent floodplain to ease the flood flow before the bridge becomes a restriction. This also allows a 0.5 metre freeboard for the passage of floating debris.
- Piers associated with multiple span bridges should not reduce the cross sectional area of the waterway by more than 10%.
- Bridge approaches should not reduce the cross sectional area of the adjacent floodplain by more than 10%.
- For fish passage needs it is preferable that the banks under bridges remain in their natural state or if they need to be altered that they are sloped and lined with large rocks.

Figure 14 Typical single span farm bridge

The bridge underside is more than 0.5m above adjacent floodplain level and there is some bank armouring and sloping. ***However as this photograph shows the banks also need re-planting and fencing is required to stop the bank erosion.***

4.3.2 Culverts

The culvert diameter should be selected so that the design peak flood flow can pass without the culvert embankment being overtopped. This reduces the likelihood of the embankment failing due to scour.

Culverts should also be sized so that either the largest bed material in the stream can pass through them or if necessary over them.

Alternatively, a smaller culvert diameter can be selected in combination with a spillway that is sized to pass the design peak flood flow. The spillway should be located in undisturbed ground and be grassed to reduce the potential for scour.

Note: An equation to calculate the required spillway dimensions is presented in Appendix 1.

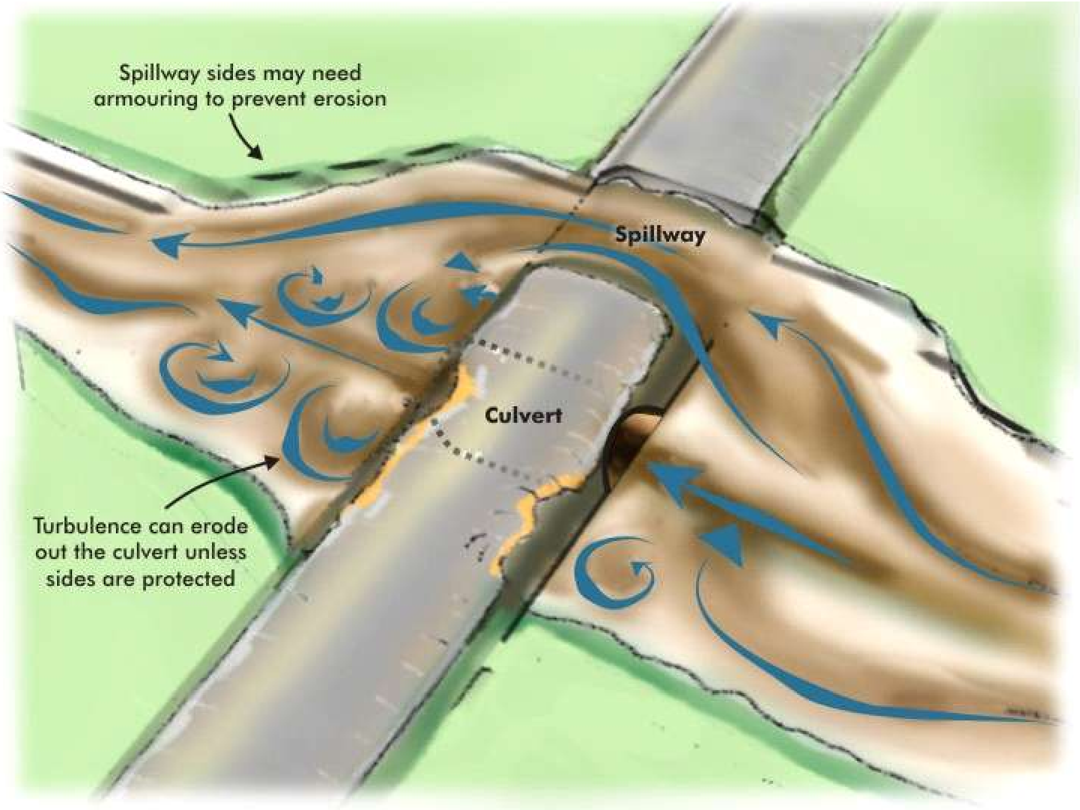

Figure 15 Typical culvert spillway operating during flood event

Culverts are usually designed to pass the design peak flood flow with a certain level of ponding behind the culvert embankment. This ponding should not exceed a depth that is 1 metre above the soffet of the culvert pipe, otherwise high water velocities are likely to cause scour around the culvert entrance and exit.

If the culvert results in an upstream ponding depth that exceeds 3 metres, it is damming water and is therefore controlled by the TRMP rules that control the construction of earth dams on waterways.

The invert of the culvert pipe should be at a level that is below the existing waterway level. The distance between the invert of the culvert pipe and the waterway bed level should be around 20% of the culvert diameter (see table 1).

Table 1 Recommended depth to set a culvert invert at construction

Culvert diameter (mm)	Depth below waterway bed level (mm)
900	180
1050	210
1200	240
1350	270
1500	300
1800	360
2400	480
2700	540
3000	600

The culvert embankment, and the channel bed, should be armoured at the pipe entrance and exit to reduce the likelihood of scour caused by high water velocity, especially where the risk of bed scour is high. This is best done by partially burying large rock material in the stream bed and banks. The appropriate measures and distance required will vary on a case by case basis.

4.3.3 Fords

If the ford is designed at a level that is above the waterway bed level, culvert pipes are required to pass normal to low flows. These pipes should have an invert level that is at least 1.5 times the bedload size (i.e. d_{75}) below the waterway bed level and have a diameter that is at least three times the bedload size.

5 Conclusion

In order to protect the natural environment, these guidelines have outlined the best practices that should be undertaken when installing a waterway crossing.

Before any work on a waterway crossing begins it is advisable to contact either Tasman District Council. This is to establish the extent of the works that will be undertaken and also to verify the need for a Resource Consent Certificate.

Table 1: Best Practice Guideline Summary – Design Criteria

Environmental hazards associated with the installation of a waterway crossing and how to prevent such hazards

Problem	Bridge single span	Bridge multiple span	Circular single barrel culvert	Box single culvert	Multiple barrel culvert	Fords
Interrupt fish passage	Not Applicable	Not Applicable	- Invert 0.2 x diameter below stream bed level - Width 1.2 x average channel width - Length < 10m - Rough culvert floor - Base flow velocity <1m/s - Bank protection particularly at the outlet and in highly erodable land	*Same as for single barrel culvert but also:* - Provide a small channel within culvert for low flow	*Same as for single barrel culvert but also:* - set one culvert slightly lower than the rest - Culverts diameter > d_{75} sediment size	- Culverts length: <10m -Base flow velocity: <1 m/s
Flooding upstream	- Invert 500mm above floodplain - Approach embankment not blocking floodplain	- Invert 500m above floodplain -Embankment does not block floodplain -Piers not trapping debris	-Capacity to cope with flood flow -Adequate upstream heading up -Spillway provided	*Same as for single barrel culvert*	-Capacity to cope with flood flow -Adequate upstream heading up -Spillway provided -More regular maintenance to remove flood debris	Not Applicable
Erosion	- Protection around bridge abutments	-Protection around bridge abutments - Protection of pier foundations	- Outlet velocity < velocity of bed material re-suspension - Inlet protection -Heading up < 1m	*Same as for single barrel culvert*	-Outlet velocity < velocity of bed material re-suspension -Inlet protection -Heading up < 1m	Not Applicable

6 Recommended reading

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Federal Highway Administration. 2001: *Hydraulic Design Series Number 5: Hydraulic Design of Highway Culverts.*

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(1): 517-526.

Mitchell, C. P. 1990: *Fish Passes for Native Fish: A Guide for Managers.* MAF Fisheries, Rotorua. New Zealand Freshwater Fisheries Miscellaneous Report No. 45. 20 p.

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Speirs, D. A., Kelly, J. 2001: *Fish Passage at Culverts - A Survey of the Coromandel Peninsula and Whaingaroa Catchment (11/00 - 04/01).* Environment Waikato, Hamilton. Environment Waikato Technical Report, 2001/08.

Thompson, C. S. 2002: *HIRDS High Intensity Rainfall Design System.* National Institute of Water and Atmospheric Research, Wellington.

Tasman District Council. 2002*: Proposed Tasman Resource Management Plan (Decision Version – February 2002).*

Appendix 1 Useful equations

Water Flow and Velocity Formulae

Q = VA

Where: Q Water flow (m^3/s or cumecs)
V Average water velocity (m/s)
A Waterway or culvert wetted area (m^2)

Manning's Formula: $$V = \frac{(A/P)^{2/3} S^{1/2}}{n}$$

Where: V Average water velocity (m/s)
A Waterway area (m^2)
P Wetted perimeter (m)
S Channel gradient (m/m)
n Manning's roughness coefficient

Average Slope Formulae

Equal Area Method: $$S = \frac{2A_d}{L}$$

Where: S Average gradient (m/m)
A_d Area under graph of channel length vs. elevation (m^2)
L Channel length (m)

Modified Taylor Schwartz Method: $$S = \frac{\Sigma}{\Sigma \frac{l_i}{\sqrt{S_i}}}$$

Where: S Average gradient (m/m)

Refer to the worksheet in Appendix 2 for the use of this formula.

Time of Concentration Formulae

Ramser Kirpich: $$T_c = 0.0195 L^{0.77} S_a^{-0.385}$$

Where: T_c Time of concentration (minutes)
S_a Average slope over maximum channel length (m/m)
L Maximum channel length (m)

Bransby Williams: $$T_c = \frac{0.953 L^{1.2}}{A^{0.1} H^{0.2}}$$

Where: T_c Time of concentration (hours)
L Maximum channel length (km)
A Catchment area (km2)
H Difference in elevation over maximum channel length (m)

USSCS: $$T_c = \left(\frac{0.87 L^3}{H}\right)^{0.385}$$

Where T_c Time of concentration (minutes)
L Maximum channel length (km)
H Difference in elevation over maximum channel length (m)

Rainfall Runoff Formulae

The Rational Method: $Q_{peak} = \frac{1}{3.6} CIA$

Where: Q_{peak} Predicted peak flow in the waterway (m^3/s)
C Runoff coefficient (dimensionless)
I Rainfall intensity (mm/hour)
A Catchment area (km^2)

Technical Memorandum 61 (TM61): $Q_{peak} = 0.0139CRSA^{\frac{3}{4}}$

Where: Q_{peak} Predicted peak flow in the waterway (m^3/s)
C Discharge coefficient (W_{ic} x W_s)
R Rainfall coefficient
S Catchment shape coefficient
A Catchment area (km^2)

Refer to the worksheet in Appendix 3 for guidance on using this rainfall-runoff model.

It is emphasised that coefficients generated using the equations should always be roughly checked against the graph in TM61 to confirm accuracy.

$$W_s = .8.82 S_a^{0.33} L^{0.368}$$

Where: W_s Slope coefficient
S_a Average slope (%)
L Maximum channel length (km)

$$C = 0.42(W_s W_{IC})^2$$

Where: C Discharge coefficient
W_s Slope coefficient
W_{IC} Cover coefficient

$R = .3.197d^{0.4274}$ (for 10 minutes < D < 120 minutes)

$R = [illegible]e^{-d^2} - 0.0003d^2 + 0.5363d + 43.2$ (for 120 minutes < D > 24 hours)

Where: R Standard rainfall depth (mm)
d Storm duration (minutes)

Notes for the use of technical memorandum No. 61 (TM61) in pumice catchments for short duration high intensity storms:

The method for the use of TM61 as set out below is only applicable to:

a) Catchments of area 100 - 2000 hectares (1 - 20 km^2)
b) Catchments with less than 50% bush or scrub cover.
c) Catchments where the gully floors are clean of scrub or bush. Where this is not so the catchment is unlikely to realise its full potential.

$\mathbf{Q_p = 0.0139 \times C \times R \times S \times A^{0.75}}$
Where $\mathbf{Q_p = m^3/s}$

Coefficients

C i) W_{IC}

0.6	0 - 10% bush, scrub etc
0.6 - 0.5	10 - 30% bush, scrub etc
0.5 - 0.4	30 - 50% bush, scrub etc
0.25	90% permanent forest cover/controlled clearing

some interpolation is required between 10 - 50% bush etc.

ii) W_S

Slope is calculated by the Taylor-Schwarz method.

W_S is then calculated by the relation

$$\mathbf{C = 0.42 \times (W_S \times W_{IC})^2}$$

R The rainfall factor for short duration high intensity storms is not sensitive to the Time of Concentration. The factors used in the Taupo region are the maximum found for durations of 0 - 120 minutes using rainfall data from the experimental Otitira catchment along with the Kelburn standard graph

ie.

Return period	R
10 years	0.5
20 years	0.59
50 years	0.67
100 years	0.74

S The shape factor $k = A/L^2_d$ is calculated as set out in Ref.3 using K the value of S can then be determined by graph (see ref 3 of the MWD Culvert Manual)

A Self-explanatory.

These notes are to be used in conjunction with the NWASCO publication 'Metric version of technical memorandum No.61 - A method for estimating design peak discharge'.

Appendix 2 Average slope worksheet

Worksheet for the calculation of average channel slope using modified Taylor-Schwartz Method

Step 1: Completed the following table using a survey of the main channel or a topographic plan

Length of Section (L_i)	Elevation (m)	Δ Elevation (m)	Cumulative Distance (m)	Slope (S_i)	$S_i^{0.5}$	$L_i / S_i^{0.5}$
0	Lowest Point					
	Highest Point					
Total length of channel (X)		Total Change in Elevation				Sum of $L_i / S_i^{0.5}$ (Y)

Step 2: Calculate the average slope of the channel using the following formula

$S_a = \left(\frac{X}{Y}\right)^2 =$ (m/m)

Appendix 2 Technical memorandum 61 work sheet

Worksheet for the calculation of Q_{peak} using technical memorandum 61 (October 1975)

Step 1: Preliminary data collection				
Catchment area (A)	Topographic map of catchment	A		(km^2)
Maximum channel length (L)	Topographic map of catchment	L		(km)
Direct length of catchment (L_d)	Topographic map of catchment	L_d		(km)
Average channel slope (S)	Average channel slope worksheet	S	(m/m)	(%)
Design rainfall depth (D_d)	NZ Met Service or HIRDS site specific rainfall data	D_d		(mm)

Step 2: Define coefficients in equation			
Define W_{ic}	Table 1 on page 2-2	W_{ic}	
Define W_s	Figure 1 on page 2-3	W_s	
Calculate C	W_{ic} x W_s	C	
Define standard rainfall depth	Figure 3a or 3b on page 2-7 and 2-8	D_s	(mm)
Calculate R	D_d / D_s	R	
Calculate K	A / L_d^2	K	
Define S	Figure 4 on page 2-9	S	

Step 3: Calculate Q_{peak} using the following formula	
$Q_{peak} = 0.0139CRSA^{\frac{3}{4}} =$	(m^3/s for catchment area > 25km^2)