Environment Waikato
Best Practice Guidelines for
Waterway Crossings

Bridges
Culverts
Fords

DRAFT

1 Introduction

This best practice guideline has been prepared to assist regional and local authorities, consultants, roading engineers and contractors with the design of appropriate waterway crossings within the Waikato Region.

By following the recommendations in this best practice guideline, proposed waterway crossings:

- Will be designed to have the minimum practicable adverse impact on the environment.
- Will be consistent with the provisions of the Waikato Regional Plan.
- Will not compromise the levels of service provided by Regional and District flood protection or land drainage schemes.

The topics covered by this best practice guideline include:

- The Waikato Regional Plan.
- Flood Control Schemes and Land Drainage Areas.
- Best Practice design guidelines for waterway crossings.

2 The Waikato Regional Plan

The Waikato Regional Plan (WRP) has been developed by Environment Waikato under the Resource Management Act (1991). It provides direction regarding the use, development and protection of natural and physical resources in the Waikato Region.

The plan contains rules that control various activities within the Waikato Region, including the construction of bridges, culverts and fords. Activities are classified by the WRP as follows:

- Permitted Activities, which do not require Resource Consent although there are restrictions on specific aspects of the activity.

- Controlled Activities, which require Resource Consent with controls placed on specific aspects of the activity. These controls are defined in the WRP under the applicable rule.

- Discretionary Activities, which require Resource Consent that may or may not be granted at Environment Waikato’s discretion. Consents that are granted have controls placed on specific aspects of the activity at the discretion of Environment Waikato.

The WRP rules that control the construction of bridges, culverts and fords are included in Section 4.2 of the plan.\(^1\)

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\(^1\) Copies of the plan can be viewed on Environment Waikato’s web site [www.ew.govt.nz](http://www.ew.govt.nz), at Environment Waikato’s Hamilton Office or in your local Library.
3 Flood Control Schemes and Land Drainage Areas

Environment Waikato and some Territorial Authorities are responsible for the management of Land Drainage Areas and Flood Control Schemes within the Waikato Region.

The levels of service provided by the various land drainage and flood control assets may be compromised by the inappropriate installation of waterway crossings. It is therefore essential that either Environment Waikato or the relevant Territorial Authority be contacted to discuss a proposed waterway crossing if it is located within a Land Drainage Area or a Flood Control Scheme².

4 Design Guidelines for Waterway Crossings

4.1 Preferred Types of Waterway Crossings

The type of waterway crossing selected will depend on the physical site constraints and the environmental site constraints. The following descriptions rank the types of waterway crossings in order of preference based on the expected impact on the waterway environment:

**Single span bridge**

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

2 You will know if you are in one of these areas as you will be paying a specific rate related to the service provided. If you are unsure please contact Environment Waikato or your Local Council office.
Multiple span bridge: Lower preference due to the presence of a piers in the waterway which can act to trap debris during high flow events and may result in bed erosion and minor channel restriction.

Single barrel arch culvert: (full round culvert with flattened bottom) The preferred type of culvert because the arch shape allows for a wide base which can accommodate the full width of the waterway.

Single barrel circular culvert: these are the most common form of culvert but are a lower preference than arch culverts. They are still adequate if installed using best practice. The circular pipe concentrates low flows to the centre of the pipe which is important in maintaining a minimum water depth for fish passage. However, circular culverts tend to reduce the water way area and so increase water velocities at high and medium flows. This can be overcome by ensuring the culvert diameter is sufficiently large to accommodate the full bed width of the waterway and by ensuring that the outlet is flooded at all flows.

Multi-barrel circular culvert: Lower preference because multi-barrel culverts have been found to be prone to collecting debris, hence reducing the capacity of the crossing.

Single box culvert: Lower preference because the box culvert results in a thin sheet of water that can result in a water depth that is not sufficient for fish passage during low flows. Box culverts also have no shallow wetted margin.

Multiple box culvert: Lower preference because multi-barrel culverts have been found to be prone to collecting debris, hence reducing the capacity of the crossing.

Fords: These are the least preferred type of waterway crossing because of they significantly disturb the bed of a waterway and are unlikely to achieve the objective of many waterway crossings, which is to prevent vehicles and animals from entering the waterway.
4.2 Maintaining Ecological Values

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.

4.3 Maintaining Fish and Invertebrate Passage

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 the population will 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, shrimps and snails resulting in reduced populations of these organisms upstream of Instream structures (particularly small culverts).

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

- The water velocity is too high and/or there are no resting areas provided.
- There is no low velocity zone or wetted margin provided at the water edge.
- Water turbulence is too great.
- The crossing is too dark (e.g. a culvert that is too long).
- Water depth is too shallow.
- The substrate is too smooth for bottom swimmers.
- The bed level of the crossing is raised (e.g. if a culvert has a perched invert).
- The crossing is too steep.
- Debris has been allowed to build up and has formed a weir.

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

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Note: Environment Waikato freshwater ecological staff should be consulted to determine the fishery 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 deleterious (e.g. Dwarf galaxies in the upper Waihou River).

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

- The crossing is too narrow and reduces the waterway area and restricts 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, (prevent) this migration.

4.3.1 Water Velocity

Problem: Fish can only progress upstream if water velocity is less than the fish’s swimming ability. If velocity and distance exceeds the capacity of the fish, upstream migration will be impeded.

Solution: Stream crossings should not increase the natural stream velocity (i.e. they should maintain the effective waterway area).

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 1 m/s are likely to significantly impede the upstream passage of most fish species.

Waterway crossings can be enhanced 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, maximising the roughness of the crossing by using either baffles or rocks, AND;

- Installing culverts that are sized to exceed the minimum hydraulic requirements.

Constructing multiple culverts with different invert levels for high and low flow situations can also reduce the water velocity created by waterway crossings.

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

4.3.2 Reduced flight path – aquatic invertebrates

Problem: reduced waterway area results in a narrowing of the flight path of adult invertebrates and prevents upstream migration.

Solution: Design the waterway crossing to maximise waterway area (in preference use a bridge). This will also have benefits in terms of maintaining natural substrate and stream velocities.
4.3.3 Flow Turbulence

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

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

4.3.4 Light

Problem: 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.

Solution: Increase the amount of light within a culvert by minimising the culvert length and increase its size. Ensure that the culvert has no bends.

4.3.5 Water Depth and Wetted Margin

Problem: 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 prevalent 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.

Solution: Where possible the natural bed and normal waterway depth should be retained. If this is not possible, arch or circular culverts are preferred. These should be designed so that under normal flow conditions they are \( \frac{1}{3} \) to no more than \( \frac{1}{2} \) full.

4.3.6 Perched Culverts

Problem: When culverts are installed with an invert level that is above the natural bed level of the waterway, the culvert is said to be perched. This creates a barrier that cannot be passed by most indigenous fish 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 also become perched following installation 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 too steep an angle).

Solution: 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 are protected from scour that could potentially cause the culvert to become perched following installation.

Note: Perched culverts are the most common source of artificial barriers to fish migration. In a survey of culverts in the Waikato Region over 50% presented a barrier or partial barrier to fish passage and the majority of these were perched culverts (Speirs and Kelly 2001).
4.3.7 Timing of works

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

Solution: most fish migrate upstream in spring and early summer and 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. This means that the best period for in-stream work is late summer – early autumn.

Note: Refer to McDowall (1995) for details of the migration timing of indigenous fish or contact Environment Waikato freshwater ecological staff.

4.3.8 Structure Location

Problem: Waterway crossings have the potential damage in-stream habitat.

Solution: Locate proposed waterway crossing on a straight section of channel where the channel gradient is lowest. Riffles and rapids should be avoided as they provide important habitat for invertebrate production and fish. However, in the long term, it is preferable to reconstruct the channel upstream and/or downstream rather than install a culvert at the wrong slope or with a poor alignment. Construction should include reinstatement of vegetation along the stream margin and where possible protection from grazing stock.

4.4 Designing Waterway Crossings for Flood Events

Waterway crossings have the potential to restrict high flows during flood events, which 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 flood events and this is impeded if the waterway restriction results in high water velocities (refer to the previous section on maintaining fish passage in waterways).

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 achieve this.

4.4.1 Definition of a Reasonable Flood Event or Design Standard

The WRP 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. Environment Waikato or the local Territorial Authority drainage staff should be contacted regarding local drainage standards.

4.4.2 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, Environment Waikato 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.

- Technical Memorandum 61 or TM61 for the estimation of runoff flows from large or complex catchments.

- Manning’s Formula for the estimation of channel capacity.


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

4.4.2.1 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 waterway crossing design are:

- Area (refer to diagram)

- Land use description (e.g. urban, cultivated, pasture, forest)

- Maximum channel length (refer to diagram)

- Change in elevation over maximum channel length

- Average slope over maximum channel length
4.4.2.2 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’ below). 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 channel, as is demonstrated in the diagram below.

An alternative method is therefore required that generates the slope represented below by ‘slope 2’. There are a number of methods available to generate such a slope. The MWD Culvert Manual contains two options:

- The Equal Area Method
- The Modified Taylor-Schwartz Method

These equations are presented in Appendix 1.

4.4.2.3 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.

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

4.4.2.5 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.
- Technical Memorandum 61 or TM61 (for large and complex catchments) is an empirical rainfall-runoff model for estimating peak runoff flows in ungauged New Zealand catchments. It uses a number of coefficients that are derived using tables and graphs that are included with the memorandum.

Equations for these rainfall runoff models are presented in Appendix 1.

4.4.3 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.

4.4.3.1 Bridges
- Bridges should be designed so that the underside of the bridge beams are at least 0.5 metres above the adjacent floodplain. This allows the adjacent floodplain to attenuate 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.

4.4.3.2 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.

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.

- 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.

Note: If the culvert results in an upstream ponding depth that exceeds 3 metres, the culvert is damming water and is therefore controlled by the WRP 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 (refer to the following table).

<table>
<thead>
<tr>
<th>Culvert Diameter (mm)</th>
<th>Depth Below Waterway Bed Level (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>900</td>
<td>180</td>
</tr>
<tr>
<td>1050</td>
<td>210</td>
</tr>
<tr>
<td>1200</td>
<td>240</td>
</tr>
<tr>
<td>1350</td>
<td>270</td>
</tr>
<tr>
<td>1500</td>
<td>300</td>
</tr>
<tr>
<td>1800</td>
<td>360</td>
</tr>
<tr>
<td>2100</td>
<td>420</td>
</tr>
<tr>
<td>2400</td>
<td>480</td>
</tr>
<tr>
<td>2700</td>
<td>540</td>
</tr>
<tr>
<td>3000</td>
<td>600</td>
</tr>
</tbody>
</table>

- The culvert embankment and, where the risk of bed scour is high, the channel bed, should be armoured at the pipe entrance and exit to reduce the likelihood of scour cause by high water velocity.

4.4.3.3 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 culverts 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 Recommended Reading


Cotterell, E. 1998: *Fish Passage in Streams - Fisheries guidelines for design of stream crossings*. Queensland, Department of Primary Industries, Brisbane. FHG 001.


Appendix 1 - Useful Equations

Water Flow and Velocity Formulae

\[ Q = VA \]

Where:  
\[ \begin{align*} 
Q & \quad \text{Water flow (m}^3/\text{s or cumecs)} \\
V & \quad \text{Average water velocity (m/s)} \\
A & \quad \text{Waterway or culvert area (m}^2) 
\end{align*} \]

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

Where:  
\[ \begin{align*} 
V & \quad \text{Average water velocity (m/s)} \\
A & \quad \text{Waterway area (m}^2) \\
P & \quad \text{Wetted perimeter (m)} \\
S & \quad \text{Channel gradient (m/m)} \\
n & \quad \text{Manning's roughness coefficient} 
\end{align*} \]

Average Slope Formulae

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

Where:  
\[ \begin{align*} 
S & \quad \text{Average gradient (m/m)} \\
A_d & \quad \text{Area under graph of channel length vs. elevation (m}^2) \\
L & \quad \text{Channel length (m)} 
\end{align*} \]

Modified Taylor Schwartz Method: \[ S = \frac{\Sigma l}{\Sigma \frac{l}{\sqrt{S_i}}} \]

Where:  
\[ \begin{align*} 
S & \quad \text{Average gradient (m/m)} 
\end{align*} \]

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

Time of Concentration Formulae

Ramser Kirpich: \[ T_c = 0.0195L^{0.77}S_a^{-0.385} \]

Where:  
\[ \begin{align*} 
T_c & \quad \text{Time of concentration (minutes)} \\
S_a & \quad \text{Average slope over maximum channel length (m/m)} \\
L & \quad \text{Maximum channel length (m)} 
\end{align*} \]
Bransby Williams: 
\[ T_c = \frac{0.953L^{1.2}}{A^{0.7}H^{0.2}} \]

Where:  
- \( T_c \): Time of concentration (hours)  
- \( L \): Maximum channel length (km)  
- \( A \): Catchment area (km\(^2\))  
- \( H \): Difference in elevation over maximum channel length (m)

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

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:  
\[ Q_{\text{peak}} = \frac{1}{3.6} CIA \]

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

Note: Environment Waikato observations indicate that a runoff coefficient of 0.7 should be used when estimating runoff from catchments on the Coromandel Peninsula.

Technical Memorandum 61 (TM61):  
\[ Q_{\text{peak}} = 0.0139CRSA^2 \]

Where:  
- \( Q_{\text{peak}} \): Predicted peak flow in the waterway (m\(^3\)/s)  
- \( C \): Discharge coefficient \((W_{ic} \times W_s)\)  
- \( R \): 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.

Environment Waikato has derived equations for the following TM61 coefficients that are represented by graphs. This was to allow the development of spreadsheets that require a minimum input. It is emphasised that coefficients generated using the equations should always be roughly checked against the graph in TM61 to confirm accuracy.

\[ W_s = 18.82S_a^{0.33}L^{0.368} \]

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

\[ C = 0.42(W_sW_{ic})^2 \]
Where:  
\( C \)  Discharge coefficient  
\( W_s \)  Slope coefficient  
\( W_{IC} \)  Cover coefficient  

\[
R = 13.197d^{0.4274} \quad \text{(for 10 minutes < D < 120 minutes)}
\]

\[
R = 9e^{-8d^2} - 0.0003d^2 + 0.5363 + 43.2 \quad \text{(for 120 minutes < D > 24 hours)}
\]

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

<table>
<thead>
<tr>
<th>Length of Section (L_i)</th>
<th>Elevation (m)</th>
<th>∆ Elevation (m)</th>
<th>Cumulative Distance (m)</th>
<th>Slope (S_i)</th>
<th>S_i^{0.5}</th>
<th>L_i / S_i^{0.5}</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lowest Point</td>
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<td></td>
<td></td>
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<tr>
<td>Highest Point</td>
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<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

\[ S_a = \left( \frac{X}{Y} \right)^2 = \quad (m/m) \]
Worksheet for the Calculation of $Q_{peak}$ using Technical Memorandum 61 (October 1975)

### Step 1: Preliminary data collection

<table>
<thead>
<tr>
<th>Data Parameter</th>
<th>Source</th>
<th>Unit</th>
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<tbody>
<tr>
<td>Catchment area ($A$)</td>
<td>Topographic map of catchment</td>
<td>(km²)</td>
</tr>
<tr>
<td>Maximum channel length ($L$)</td>
<td>Topographic map of catchment</td>
<td>(km)</td>
</tr>
<tr>
<td>Direct length of catchment ($L_d$)</td>
<td>Topographic map of catchment</td>
<td>(km)</td>
</tr>
<tr>
<td>Average channel slope ($S$)</td>
<td>Average channel slope worksheet</td>
<td>(m/m) (%)</td>
</tr>
<tr>
<td>Design rainfall depth ($D_d$)</td>
<td>NZ Met Service or HIRDS site specific rainfall data</td>
<td>(mm)</td>
</tr>
</tbody>
</table>

### Step 2: Define coefficients in equation

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Definition</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>$W_{ic}$</td>
<td>Table 1 on page 2-2</td>
<td></td>
</tr>
<tr>
<td>$W_s$</td>
<td>Figure 1 on page 2-3</td>
<td></td>
</tr>
<tr>
<td>$C$</td>
<td>$W_{ic} \times W_s$</td>
<td></td>
</tr>
<tr>
<td>$D_s$</td>
<td>Figure 3a or 3b on page 2-7 and 2-8</td>
<td>(mm)</td>
</tr>
<tr>
<td>$R$</td>
<td>$D_d / D_s$</td>
<td></td>
</tr>
<tr>
<td>$K$</td>
<td>$A / L_d^2$</td>
<td></td>
</tr>
<tr>
<td>$S$</td>
<td>Figure 4 on page 2-9</td>
<td></td>
</tr>
</tbody>
</table>

### Step 3: Calculate $Q_{peak}$ using one of the following formula

$$Q_{peak} = 0.0139CRSA^{3/4} = (m^3/s \text{ for catchment area > 25km}^2)$$