Culvert Design for New Zealand Forestry

CAUSES OF VARIABLITY USING EMPIRICAL CALCULATIONS

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1 Executive Summary

Forestry culverts are an important part of modern forestry in New Zealand as they allow for safe passage over waterways. The appropriate sizing of culverts is important because they must remain cost effective whilst still being able to withstand the design storm they were built for. Culverts are designed using empirical formulas such as the TM61 and Rational Method. This report compares these two empirical flood flow methods commonly used and investigates the preferences and attitudes that culvert designers have within the industry which cause variations in culvert performance and design.

The recommended application for empirical methods varied greatly between sources. No information was found regarding the preferred method for culvert designers in the forestry industry. There was literature found which stated which materials culverts should be constructed from, which was mostly dependant on the catchment characteristics. Multiple sources also stated the suitable area threshold for these empirical methods, however they were all conflicting.

After assessing 50 catchments through Canterbury and the West Coast using the TM61 and Rational Methods, it was found that the Rational Method estimated higher flood flows for 47 of the 50 catchments. Rational Method flows still varied by up to 5.7m^3/s even with similar TM61 flows. The relationships between the Rational Method and TM61 flows along with regression values were:

$$\text{Rational Method} = 1.07*(\text{TM61}) + 1.71 \quad R^2 = 0.83$$

Catchment area was found to have the strongest relationship to the flow rate out of all inputs for both empirical methods. The relationships between area and flow along with regression values were:

TM61	$Q = 2.86*\text{Area} + 0.05$	$R^2 = 0.65$
Rational Method	$Q = 3.37*\text{Area} + 1.34$	$R^2 = 0.66$

The most common cause of highly variable flows was the coefficient value. The largest outlying values from the following plots were investigated to determine the cause of significant flow variability which are shown below:

TM61 Q vs Rational Method Q		**TM61 Q vs Area**		**Rational Method Q vs Area**	
Flow Rate	Cause	Flow Rate	Cause	Flow	Cause
Low	C Factor	High	C Factor	High	Rainfall Intensity
High	Area	High	S Factor	Low	C
-		Low	C Factor	-	

By adjusting the ground cover coefficient W_{IC} for the TM61 method from completely covered catchments (0.7) to a clear-felled catchment (1.1), flows increased by an average of 249% with a standard deviation of 23%.

Surveying culvert designers in the forestry industry revealed that the Rational Method was the most frequently used empirical method. It was found that the designer's most common concern was selecting the correct ground cover coefficient for empirical methods. It was also found that the majority of designers do not incorporate headwalls or wings into their culvert designs and instead prefer to construct makeshift headwalls with locally sourced materials. None of the designers surveyed responded saying that they made adjustments to flow rates depending on the culvert material. The most common method of determining the appropriate culvert size from flow rates was by using a chart, these being sourced from various and often unknown sources.

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2 Introduction

Culverts are used to transport water through water crossings within forestry plantations by allowing the flow to pass underneath the roadway through an often cylindrical form. The size and material composition of these culverts are highly variable depending on the terrain characteristics around the culvert location. It is critical that the sizing of the culvert is effective because it contributes greatly to the cost of establishing a water crossing.

Culverts provide improved access to locations within forests which allows for a more efficient harvest with cost saving benefits. The other reason that requires culvert sizing to be effective is that if the culvert is too small then it can be washed out during a large storm event that it was not designed for. This will result in the water crossing being destroyed and possible damage done to the environment, aquatic life with reparation costs involved. The recommended sizes for a culvert can be calculated using many methods such as the Rational and Technical Memorandum 61 (TM61) method. These methods calculate the peak flood flows from designed storm events which are then used to determine the appropriate culvert size using a chart or spreadsheet.

These methods carry high uncertainties due to the discretion required from the designer using them and the naturally variable input values which means that the resulting sizing of the culvert is also variable.

3 Literature

3.1 National Environmental Standards (NES)

The NES are regulations made under the Resource Management Act 1991 (RMA) in order to set out technical standards, methods or requirements relating to a matter under the RMA. They also provide consistent rules across the country by setting planning requirements for certain specified activities.

The NES states that approaches to and abutments of river crossings must be stabilised to avoid erosion and sedimentation and that the culvert must be designed to pass a 5% Annual Exceedance Probability (AEP) flood event without heading.

Flood flow estimations must be calculated for all river crossings using one or more of the following:

- Flood Estimation – A Revised Design Procedure
- Technical Memorandum Number 61
- Comparison of a regional method for estimating design floods with two rainfall-based methods (Reddy, 2017)

3.2 New Zealand Forest Road Engineering Manual

The manual states that the selection of the required size for a culvert is based on:

- The size of the catchment area
- The expected flood flows and the probability of these occurring during the period the culvert is in place
- The average rainfall intensity in a specific return period
- The importance of the road (short-term shunt road or arterial route)
- The likelihood of damage should the culvert capacity be exceeded in a major storm event
- The potential to provide overflow paths
- The risk of adverse upstream and downstream effect
- The height of heading up of the stream upstream of the culvert that can be tolerated without causing adjacent property damage or adverse environmental effects
- The flow capacity of the culvert pipe selected, which is a function of its cross section area, surface roughness and length
- Specific rules in the relevant Regional Plan. Culverts larger than 1200mm may require a resource consent.

The manual also states that the type of pipe depends on service life, ease of construction, relative cost, importance of fish passage and ground and soil conditions.

Culverts on forestry roads should be designed to carry the estimated 50-year flood flow without overtopping the roadway, which is a larger flood flow event than the NES states. It is also stated that there are some circumstances where the design is more suitable for a lesser flood event such as when temporary harvesting roads are being built.

The flood flow characteristics for a stream or river can be estimated by using the following considerations, which are similar guidelines to the NES:

- Investigation of existing culverts on the same stream near the proposed culvert site. This approach is not suited for large culvert installations as long-term flood flow events may not have occurred since the existing structures were installed.

- Estimation using an empirical method such as TM61 or the Rational Method, which predict flows for flood events based on rainfall frequency, catchment characteristics and stream channel characteristics.
- Estimation using statistical analysis methods. These models predict flows on the basis of expected flood frequency for given catchment areas such as the Regional Flood Frequency Analysis.

Using empirical or statistical methods is not an exact science and the selection of a design value for a particular site should be done by an experienced designer. This is because they must take into account a range of factors such as catchment characteristics, appropriateness of the model for the site and local knowledge of any historic flood events.

The commonly used methods are the Technical Memorandum No. 61 (TM61), Rational Method and the Synthetic Unit Hydrograph Method. (NZ Forest Owners Association Inc, 2011)

3.3 Culverts

The most common closed conduit shapes for culverts are circular, box elliptical and pipe arch. The shape is selected based on the construction cost, limitation on upstream water surface elevation, roadway embankment height and hydraulic performance. This study does not incorporate embedded and open-bottomed culverts into the design.

The material used for the culvert may depend on structural strength, hydraulic roughness, durability and constructability. The most commonly used culvert materials are concrete, corrugated metal, and plastic.

Commonly used inlet configurations include culvert cylinders projecting beyond the embankment, concrete headwalls or wings and culvert ends mitered to conform to the fill slope. The hydraulic capacity of the culvert can be improved by selecting the appropriate inlet. A contraction of flow occurs at the inlet because the channel is often wider than the culvert barrel, which is the primary flow control. A depression (dip in elevation) can increase the effective head on the flow control section, thereby increasing culvert efficiency.

Inlet control is when the culvert cylinder is capable of conveying more flow than the inlet can accept. Outlet control flow is when the cylinder is not capable of conveying as much flow as the inlet opening will accept. Table one below shows the factor that influence culvert design:

Table 1: Factors Affecting Culvert Design

Factor	Inlet Control	Outlet Control
Headwater	X	X
Area	X	X
Shape	X	X
Inlet Configuration	X	X
Cylinder Roughness	-	X
Cylinder Length	-	X
Cylinder Slope	X	X
Tailwater	-	X

(Schall, Thompson, Zerges, Kilgore, & Morris, 2012)

Figure one below shows a chart used for determining the size of the culvert which is affected by the calculated flow discharge and entrance type. This chart is from the Concrete Pipe Association of Australia 1986 which therefore means that flows passing through a culvert made of a different material mentioned earlier in this report, may perform differently. There is no chart supplied in the New Zealand Forest Road Engineering Manual for other materials such as plastic or metal.

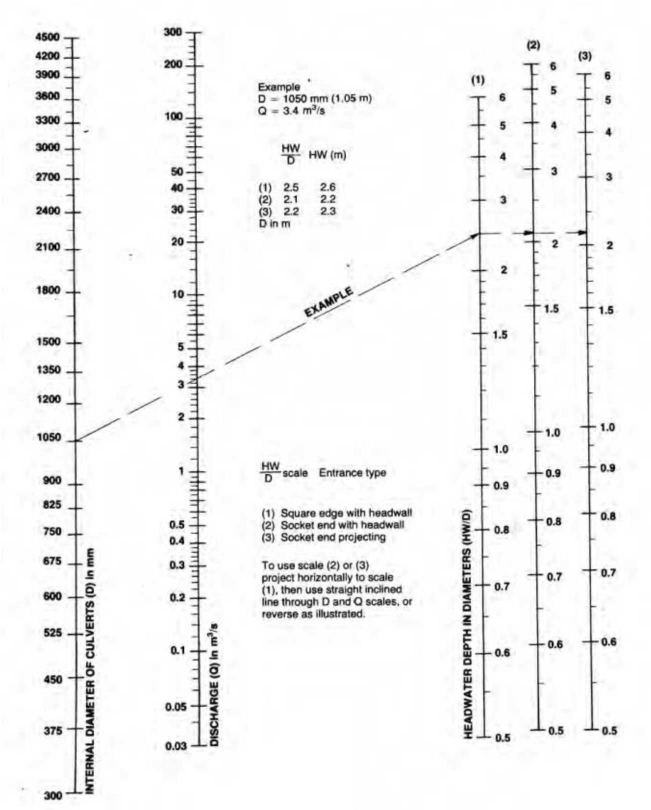

Figure 1: Culvert Diameter Classification Chart from Flow Rate

3.4 Ministry for the Environment

The Ministry for the Environment Culvert Guidelines follow a simple criteria which only requires extrapolation from figures and tables. These guidelines are specifically designed for dairy farmers in order to simplify the process for gaining a resource consent. Figure two below displays the rainfall bands throughout the upper South Island. The selected category and catchment area are then used to determine the size of the culvert required.

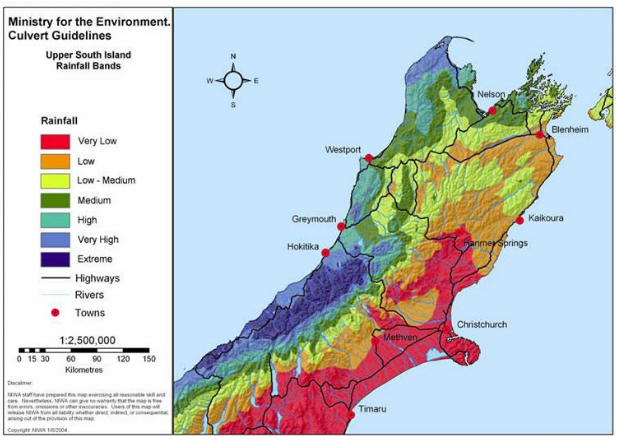

Figure 2: Regional Rainfall Intensity Distribution

Figures three and four below determine the required singular culvert size and the equivalent, multiple, smaller culvert setups. The aim of this alternative setup is a reduction in cost by not requiring a resource consent from the Regional Council due to large culvert diameters.

	Very low	Low	Low-medium	Medium	High	Very high	Extreme
5 ha	300 mm	300 mm	375 mm	375 mm	450 mm	450 mm	525 mm
10 ha	375 mm	450 mm	450 mm	525 mm	600 mm	600 mm	675 mm
15 ha	450 mm	525 mm	600 mm	600 mm	675 mm	675 mm	825 mm
20 ha	525 mm	600 mm	675 mm	675 mm	750 mm	825 mm	975 mm
30 ha	600 mm	675 mm	825 mm	825 mm	900 mm	975 mm	1200 mm
40 ha	675 mm	825 mm	900 mm	975 mm	1050 mm	1200 mm	1350 mm
50 ha	825 mm	900 mm	975 mm	1050 mm	1200 mm	1200 mm	1600 mm
100 ha	975 mm	1200 mm	1350 mm	1350 mm	1600 mm	1600 mm	1800 mm
150 ha	1200 mm	1350 mm	1600 mm	1600 mm	1800 mm	1950 mm	2550 mm
200 ha	1350 mm	1600 mm	1800 mm	1950 mm	2100 mm	2550 mm	2550 mm
250 ha	1600 mm	1800 mm	1950 mm	2100 mm	2550 mm	2550 mm	n/a
300 ha	1600 mm	1800 mm	1950 mm	2100 mm	2550 mm	2550 mm	n/a
350 ha	1600 mm	1800 mm	2100 mm	2550 mm	2550 mm	2550 mm	n/a
400 ha	1800 mm	1950 mm	2100 mm	2550 mm	2550 mm	n/a	n/a
450 ha	1800 mm	2100 mm	2550 mm	2550 mm	n/a	n/a	n/a
500 ha	1950 mm	2100 mm	2550 mm	n/a	n/a	n/a	n/a

Figure 3: Culvert Diameter Derivation Table

Pipe diameter	Equivalent to		
300 mm			
375 mm	2 x 300 mm		
450 mm	2 x 375 mm	3 x 300 mm	
525 mm	2 x 450 mm	3 x 375 mm	4 x 300 mm
600 mm	2 x 450 mm	3 x 375 mm	4 x 375 mm
675 mm	2 x 525 mm	3 x 450 mm	4 x 375 mm
750 mm	2 x 600 mm	3 x 450 mm	4 x 450 mm
825 mm	2 x 675 mm	3 x 525 mm	4 x 450 mm
900 mm	2 x 675 mm	3 x 600 mm	4 x 525 mm
975 mm	2 x 750 mm	3 x 600 mm	4 x 525 mm
1050 mm	2 x 825 mm	3 x 675 mm	4 x 600 mm
1200 mm	2 x 900 mm	3 x 750 mm	4 x 675 mm
1350 mm	2 x 1050 mm	3 x 825 mm	4 x 750 mm
1600 mm	2 x 1200 mm	3 x 975 mm	4 x 900 mm
1800 mm	2 x 1350 mm	3 x 1200 mm	4 x 975 mm
1950 mm	2 x 1600 mm	3 x 1200 mm	4 x 1050 mm
2100 mm	2 x 1600 mm	3 x 1350 mm	4 x 1200 mm
2550 mm	2 x 1950 mm	3 x 1600 mm	

Figure 4: Equivalent Multiple Culvert Table

The Ministry for the Environment also makes note of which materials are suited for certain scenarios, giving a range of reasoning for the material of choice when combined with the Road Engineering Manual guidelines.

- Lighter material should be used in locations difficult to access
- Steel culverts suffer from accelerated corrosion in areas where agricultural and fertilizer runoff occurs
- With softer soils, single length flexible pipes cope better than multiple rigid sections. This is because of the increased settlement that occurs.

3.5 Technical Memorandum 61 Method (TM61)

The TM61 Method is most commonly written as $Q = 0.0139CRSA^{0.75}$

Q = estimate of the design peak discharge (m^3/s)
C = a coefficient which depends on the physiography of the catchment
R = a rainfall factor which depends on the design storm
S = catchment shape factor
A = catchment area (km^2)

There are multiple literature sources which state the area limit up to which this method is suitable for. The TM61 Method is often used for the design of small structures like culverts in ungauged New Zealand catchments that are less than or equal to $1000km^2$ (Griffiths & McKerchar, 2008) while (Environmental Hazards Group, 2012) stated that this method is suitable for all catchment sizes.

The application of the TM61 Method requires spatial uniformity in the physiography and rainfall characteristics of the catchment in focus, as the coefficients used in the equation have to represent the whole catchment. This is difficult to achieve in reality because every catchment is shaped naturally and usually has a large amount of variability.

The determining of some of these variables requires the extrapolation of values from tables and graphs. For the two parameters W_{IC} and W_S which are associated with the surface and slope characteristics of the catchment, it is recommended that this information is sourced from local agencies who will have a better knowledge of the area in terms of soils characteristics and ground cover. This way the selection of these parameters are much more likely to be an accurate representation of the catchment in focus (Ministry of Works and Development, 1980).

This method was found to overestimate peak flood flows on pumice catchments as well as on steep and larger catchments (Lewthwaite, 1971).

There is no literature which states that the values of the equation caused the overestimation and by what factor the overestimation is from the appropriate value. Due to this method having the largest number of input variables, it is likely that this method will have the most accurate results for flow rates because of the larger number of catchment characteristics considered.

3.6 Rational Method

The formula is most commonly written as Q = CiA/362

Q = peak discharge at recurrence interval (m^3/s)
C = rational runoff coefficient
i = rainfall intensity (mm/hr)
A = catchment area (ha)
(C. Bryan Young)

There are multiple literature sources which state the area that this method is limited to which is shown in Table two below:

Table 2: Rational Method Area Limits

Source	Lower Limit	Upper Limit
Gordon Keller	0 ha	120 ha
New Zealand Forest Road Engineering Manual	$1km^2$	$25km^2$
Environmental Hazards Group	0 ha	50 ha

With the correct selection of the "C" value for this equation, the frequency of occurrence for the design peak runoff and rainfall intensity are the same. The problem however is that the "C" value is not adequately based on measurements of rainfall and runoff which can create large errors when using the Rational Method. These observations were also taken from an urban catchment where the land cover is much more uniform and infiltrations rates are much smaller. Therefore a more accurate "C" value is likely to be obtained in an urban environment than within a forest catchment as the variability of the land cover is expected to be much greater. (Geyer, Knapp, & Schaake Jr., 1967)

There are also certain considerations which have to be taken into account such as, the "C" value may change over the design life of the culvert. An example of this would be if the forest were to be clear-felled leading to the characteristics of the land changing greatly. (Gordon Keller, 2003)

The Rational Method also includes the list of assumptions below which are similar to the TM61 and may not always lead to an accurate estimation (Tolland, Cathcart, & Dennis Russell):

- The peak rate of runoff at the basin is a function of the average rainfall rate for a duration equal to the time of concentration
- The rainfall intensity is constant for the duration of the storm
- The rainfall is uniformly distributed over the entire basin
- The frequency of rainfall is equated to the frequency of runoff
- The runoff is primarily by overland flow
- The storm duration equals or exceeds the time of concentration
- The watershed system is linear.

The rational method was found to slightly overestimate larger catchments and greatly overestimate very flat catchments (Lewthwaite, 1971). However there was again no mention of which values within the equation were responsible for the overestimation.

The Rational and TM61 Methods are empirical and therefore should be only be used to estimate the design discharge when hydrological data is 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 in practice. (Spiers & Ryan, 2006)

3.7 Adjusted Rational Method

The Adjusted Rational Method is generally useful for catchments greater than 50 hectares. This method is considered slightly more rigorous than the Rational Method because of the consideration of more catchment characteristics. Figure five below shows the coefficient description table with the inclusion of how slope steepness affects the coefficient. (Environmental Hazards Group, 2012)

Description of Surface	C
Natural surface types	
Bare impermeable clay with no interception channels or run-off control	0.70
Bare uncultivated soil of medium soakage	0.60
Heavy clay soil types:	
• pasture and grass cover	0.40
• bush and scrub cover	0.35
• cultivated	0.30
Medium soakage soil types:	
• pasture and grass cover	0.30
• bush and scrub cover	0.25
• cultivated	0.20
High soakage gravel, sandy and volcanic soil types:	
• pasture and grass cover	0.20
• bush and scrub cover	0.15
• cultivated	0.10
Parks, playgrounds and reserves:	
• mainly grassed	0.30
• predominantly bush	0.25
Gardens, lawns etc	0.25
Developed surface types	
Fully roofed and/or sealed developments	0.90
Steel and non -absorbent roof surfaces	0.90
Asphalt and concrete paved surfaces	0.85
Near flat and slightly absorbent roof surfaces	0.80
Stone, brick and precast concrete paving panels:	
• with sealed joints	0.80
• with open joints	0.60
Unsealed roads	0.50
Railway and unsealed yards and similar surfaces	0.35
Land use types	
Industrial, commercial, shopping areas and town house developments	0.65
Residential areas in which the impervious area is less than 36% of gross area	0.45
Residential areas in which the impervious area is 36% to 50% of gross area	0.55
Source: Table 1 from DBH (2011) document	

The runoff coefficients are to be modified for slope as follows[1]:

- -0.05 for Slope < 5%
- No adjustment for 5%<Slope<10%
- +0.05 for 10%<Slope<20%
- +0.10 for Slope>20%"

Figure 5: Adjusted Rational Method Classification Table

The allocation of values for the slope along with a larger number of ground cover types makes the coefficient derivation process easier and most likely more accurate than the Rational Method.

3.8 Talbot Method

The Talbot Method directly calculates the cross-sectional area of the culvert instead of using the peak flood flow from a storm, like the other two methods.

The formula is written as: $A = 0.183CM^{0.75}$

A = required culvert size (m^2)
C = runoff coefficient
M = catchment area (ha)

The Talbot Method directly uses aspects of the Rational Method and can be used for making the preliminary estimate of the required pipe size for the drainage area. However, this method does not consider the variability of rainfall intensity or return period. Therefore this method is not as precise as the others that take rainfall characteristics into account which is why it can be used in desert landscapes. (Gordon Keller, 2003)

Therefore the Talbot Method should only be used when there is no rainfall data available for the catchment. Because of this lack of data, it is likely that this method will be the most conservative of all the methods.

3.9 TP108

The TP108 document is a guideline for the application of the U.S. Soil Conservation Service (SCS) rainfall-runoff model for catchments within Auckland. They are based largely on the Technical Release No. 55 (TR55). The model uses design 24 hour rainfall depths in the form of rainfall maps. There are shorter duration rainfall bursts with a range of durations within the temporal pattern. The runoff depth is then derived using SCS rainfall runoff curves. Using the time of concentration and area inputs, a unit hydrograph is created which leads to the creation of the catchment hydrograph which produces the peak flow rate required for sizing culverts.

Validation of the model against six gauged catchments in Auckland gave a standard error of 21% for all annual exceedance probabilities. For 2 to 100 years the model can be expected to be within ±25% at a confidence level of 90%. The parameters required for land cover types such as forest and scrub have been provided based on the standard SCS guidelines. (Beca Carter Hollings & Ferner Ltd, 1999)

4 Objectives

The aim of this study is to determine which features of the empirical formulas cause these large variations and how rates vary between different empirical methods. A survey will also be conducted to understand the preferred methods of designing and constructing culverts in the industry along with determining the problems that foresters encounter during these processes. This will allow engineers within the forestry industry to design more appropriate culverts as they will have greater awareness about the implications involved which are currently being experienced. The aim for this project is to analyse 50 culverts throughout the Canterbury and West Coast regions. The considered variables will be:

- Catchment area
- Catchment steepness
- Land cover characteristics
- Rainfall intensities and depth durations

The secondary objective of this project is to conduct a phone survey with culvert designers within the forestry industry. The aim of the survey is to identify the preferences and habits that these designers have with regards to culverts along with any issues that they encounter during the design process. A total of ten designers will be surveyed.

5 Methodology

The data collection was done using Google Earth with the assistance of Topo50 map overlays to determine the boundaries and river flow path of the selected catchments. The first method to be used for each catchment will be the TM61 method, followed by the Rational Method. Catchment Selection Guidelines

The Annual Exceedance Probability (AEP) will be held constant for all calculations at a value of 0.05 (20-year storm event) as this is the stated probability in the NES.

Each catchment that is deemed acceptable for the study will have to be saved. This can be done by noting the coordinates of the outlet point for any future reference if needed.

The catchment selection process will have to be well defined. This is because there will be no reason for analysing a catchment that has no possibility of requiring a culvert as the catchment will never be used for forestry operations. These types of catchments features will be:

- Extremely steep
- Poor soil characteristics
- Exposed to extreme climates
- Not economically viable (location too remote or difficult to access)

For the data collection of each catchment, the calculated flow rate from the TM61 Method and Rational Method will be recorded along with the characteristics of each catchment on an Excel Spreadsheet. The analysis of these graphs will provide the information on any trends that are present in the findings.

The catchment area was selected based on the literature review that specified the acceptable area ranges for each flow method. Following the phone surveys, it was found that the majority of the catchments that people were working in were smaller than 4 km^2 which is why there was a large number of samples taken for these sizes.

5.1 TM61 Method

An example of this data collection process for a catchment in the Banks Peninsula is shown with the figures and calculations. The tools within the Google Earth application can be used to determine the direct and river lengths, total area and river elevation profile of the catchment. The surface cover type can be determined using Google Earth as the satellite imagery quality is high enough to distinguish what the features are. The calculation of each of these catchment characteristics are shown in figures six, seven and eight below.

Figure 8: Catchment Area Classification

Figure 7: Direct Path Classification

Figure 6: River Path Classification

The slope of the catchment is determined using the equal area method which is explained in Figure nine below and calculated using Excel graphs.

Figure 10: Catchment Elevation Profile

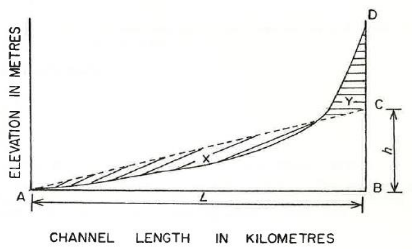

Figure 9: Equal Area Method Diagram

Once the slope is calculated the ground surface cover will have to be determined so that the W_{IC} value can be assigned. With the average channel slope and channel length known, the slope factor W_S can be calculated. With both W_{IC} and W_S, the values can be multiplied together to give the overall W value. This value is then put into the graph to calculate the discharge coefficient 'C'. Figures 11, 12 and 13 are used for determining these values.

Soils	Ground Surface-Cover		W_{IC}
Impervious soils (such as clay soils with poor structure e.g. northern yellow brown earths). Any soil, if saturated, is included in this group.	Urban Catchments	high density development	1.8
		moderate to low density development	1.5
	Mainly bare surfaces		1.2
	Average shortgrazed catchments		1.1
	30% of area in long grass, scrub or bush		1.0
	60% of area in long grass, scrub or bush		0.9
	100% of area in long grass, scrub or bush		0.8
Moderately absorbent soils (such as medium textured soils with good structure e.g. southern yellow brown earths).	Urban Catchments	high density development	1.7
		moderate to low density development	1.3
	Mainly bare surfaces		1.1
	Average shortgrazed catchments		1.0
	30% of area in long grass, scrub or bush		0.9
	60% of area in long grass, scrub or bush		0.8
	100% of area in long grass, scrub or bush		0.7
Absorbent soil (such as deep yellow brown sands and pumice soils).	Urban Catchments	high density development	1.5
		moderate to low density development	1.2
	Mainly bare surfaces		1.0
	Average shortgrazed catchments		0.9
	30% of area in long grass, scrub or bush		0.8
	60% of area in long grass, scrub or bush		0.7
	100% of area in long grass, scrub or bush		0.6
Very absorbent pumice soil.	Mainly bare surfaces Average shortgrazed catchments 30% of area in long grass, scrub or bush		0.5
	60% of area in long grass, scrub or bush 100% of area in long grass, scrub or bush		0.4

Figure 11: TM61 Ground Cover Coefficient Classification Table

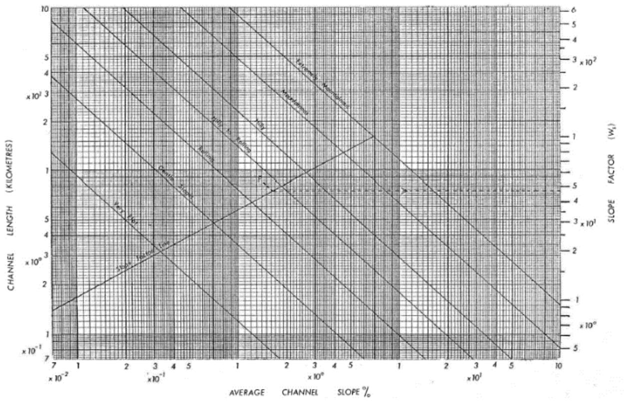

Figure 12: Slope Factor Classification

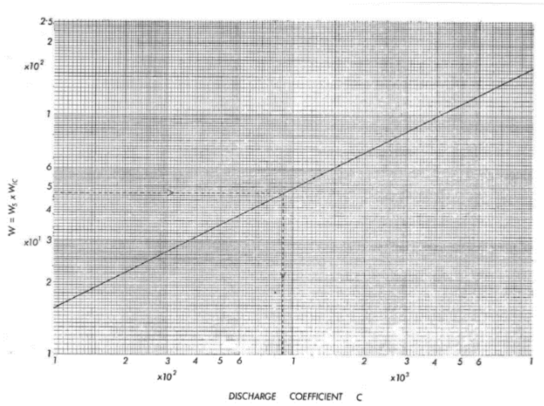

Figure 13: Discharge Coefficient Classification

For the calculation of the time of concentration for the selected catchment, the equation below can be used. The value from this equation can then be used to determine the rainfall depth from the design storm where the annual exceedance probability (AEP) has already been chosen by the user, in accordance with the NES. These rainfall depths are sourced from the High Intensity Rainfall Design System (HIRDS) website https://hirds.niwa.co.nz/ and presented in Figure 14.

$$T_C = 0.0195*L^{0.77}*S_a^{-0.385}$$

Rainfall depths (mm) :: Historical Data

ARI	AEP	10m	20m	30m	1h	2h
1.58	0.633	3.61	5.10	6.38	9.62	14.9
2	0.500	4.09	5.77	7.20	10.8	16.7
5	0.200	5.89	8.25	10.3	15.4	23.5
10	0.100	7.37	10.3	12.8	19.0	29.0
20	0.050	9.02	12.5	15.5	23.0	35.0
30	0.033	10.1	14.0	17.3	25.6	38.8
40	0.025	10.9	15.0	18.6	27.5	41.6
50	0.020	11.5	15.9	19.6	29.0	43.8
60	0.017	12.0	16.6	20.5	30.2	45.7
80	0.012	12.9	17.8	21.9	32.3	48.7
100	0.010	13.6	18.7	23.1	33.9	51.1
250	0.004	16.7	22.8	28.1	41.0	61.5

Figure 14: Historic Rainfall Depths

The time of concentration can then be used again in Figure 15 below to determine the standard rainfall depth. The standard and design rainfall depths are then used in following the equation below to calculate the R factor for the TM61 Method.

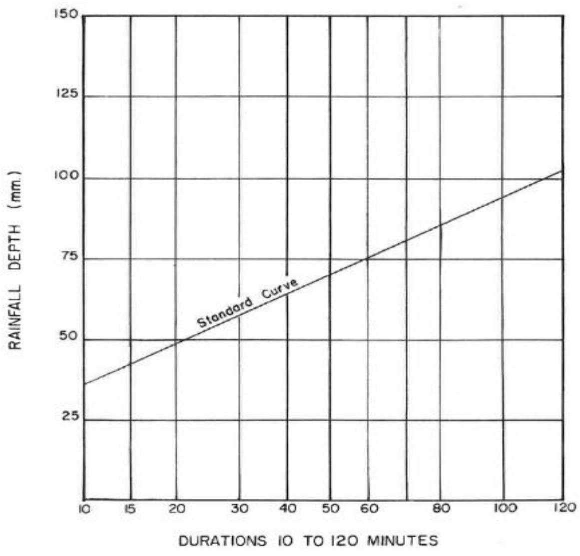

Figure 15: Standard Rainfall Depth Calculation

$$R = \frac{design\ rainfall\ depth}{standard\ rainfall\ depth}$$

The catchment area and direct length from the furthest point of the catchment to the outlet are then used in the equation below to calculate the K value. This value is then used in Figure 16 below to calculate the shape factor 'S'.

$$K = A/L_d^2$$

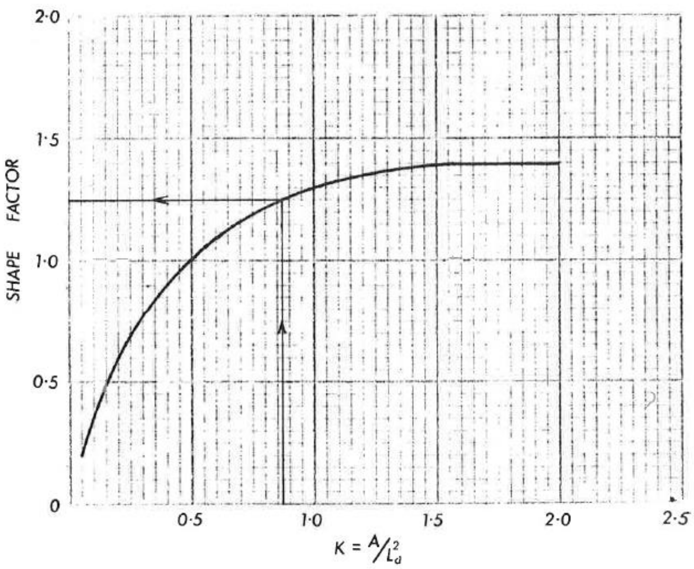

Figure 16: Shape Factor Graph

The flow rate can now be calculated.

5.2 Rational Method

The land cover coefficient 'C' is selected out of the table in Figure 17 below.

RATIONAL METHOD VALUES OF "C"	
Land Use or Type	**"C" Value**
Agriculture	
Bare Soil	0.20-0.60
Cultivated Fields (sandy soil)	0.20-0.40
Cultivated Fields (clay soil)	0.30-0.50
Grass	
Turf, Meadows	0.10-0.40
Steep Grassed Areas	0.50-0.70
Woodland/Forest	
Wooded Areas with Level Ground	0.05-0.25
Forested Areas with Steep Slopes	0.15-0.40
Bare Areas, Steep and Rocky	0.50-0.90
Roads	
Asphalt Pavement	0.80-0.90
Cobblestone or Concrete Pavement	0.60-0.85
Gravel Surface	0.40-0.80
Native Soil Surface	0.30-0.80
Urban Areas	
Residential, Flat	0.40-0.55
Residential, Moderately Steep	0.50-0.65
Commercial or Downtown	0.70-0.95

Figure 17: Rational Method Coefficient Table

The historic rainfall intensities can be calculated from Figure 18 below which is also available on the HIRDS website. The time of concentration is going to be the same as the TM61 method because the same catchment is being used for the calculation of both flow rates.

Rainfall intensities (mm/hr) :: Historical Data

ARI	AEP	10m	20m	30m	1h	2h
1.58	0.633	21.6	15.3	12.8	9.62	7.43
2	0.500	24.5	17.3	14.4	10.8	8.36
5	0.200	35.3	24.8	20.5	15.4	11.8
10	0.100	44.2	30.8	25.5	19.0	14.5
20	0.050	54.1	37.6	31.1	23.0	17.5
30	0.033	60.4	41.9	34.6	25.6	19.4
40	0.025	65.2	45.1	37.2	27.5	20.8
50	0.020	69.0	47.7	39.3	29.0	21.9
60	0.017	72.2	49.9	41.0	30.2	22.8
80	0.012	77.4	53.4	43.9	32.3	24.3
100	0.010	81.6	56.2	46.2	33.9	25.6
250	0.004	100	68.5	56.1	41.0	30.7

Figure 18: Historic Rainfall Intensities

The design flow rate can now be calculated. Figures 19 and 20 below show how the design flow rate is used to calculate the required size of the culvert, depending on the Headwater Depth in Diameters and the culvert type.

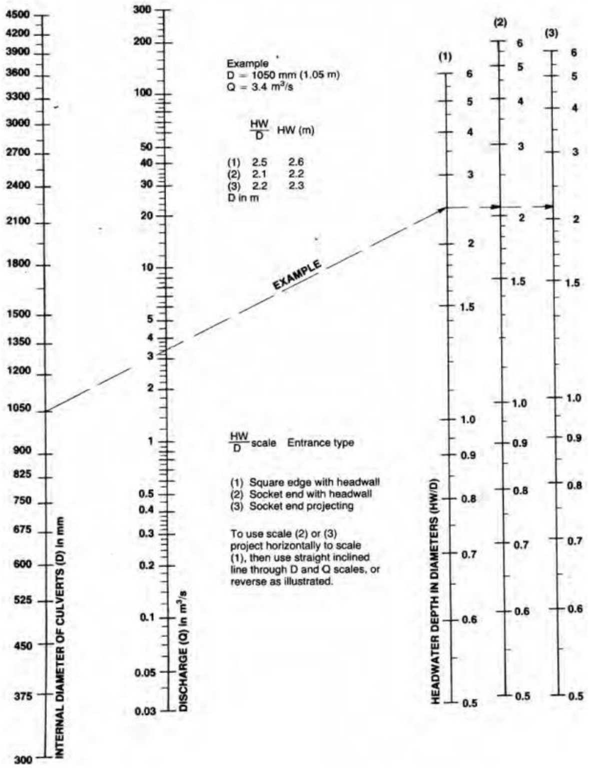

Figure 19: Culvert Diameter Classification Chart from Flow Rate for Precast Concrete

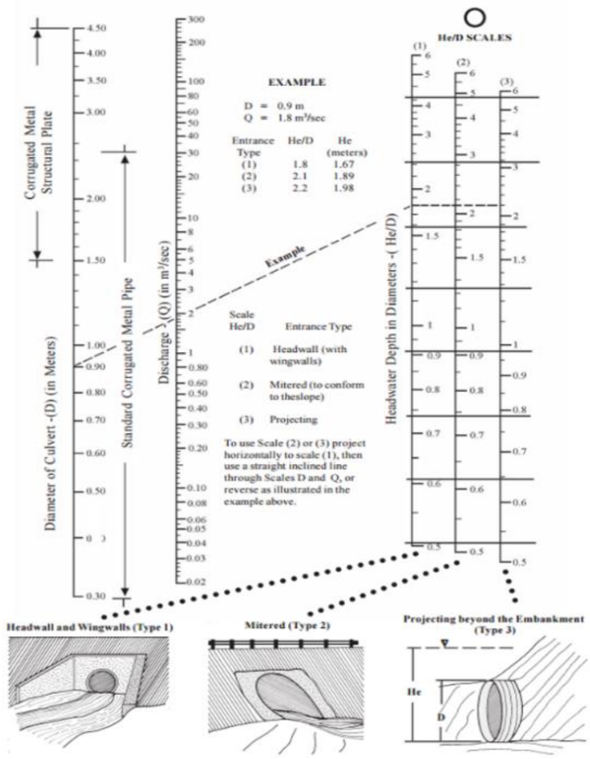

Figure 20: Culvert Diameter Classification Chart from Flow Rate for Corrugated Metal Pipe Culverts

5.3 Phone Survey

The following survey will be conducted with ten culvert designers.

Position within the company and region they work within:

Design Process Questions:

1. What flow calculation(s) method do you use for the sizing of your culverts?-

2. Do you design headwalls and wings to increase the flow capacity through your culvert?-

3. Do you adjust your flow capacity calculation depending on culvert material?-

4. Do you calculate the required culvert size from your flood flow calculation using a chart?-

5. Which part in the culvert design process do you find the most difficult to generate an accurate answer for? i.e. Requires the largest amount of discretion from the engineer-

This survey will be conducted with culvert designers in various regions throughout New Zealand as it is likely that terrain characteristics will be highly variable along with the council regulating of forestry operations. All survey responses will be confidential.

6 Results

6.1 Catchment Characteristics

The location of each catchment analysed can be seen in part 11.2 of the appendices which gives the northing and easting of the water crossing location along with the closet significant landmark or town.

The variability of each catchment played an important part in establishing any relationships throughout the data. Figures 21 to 28 below show the range and spread of the catchment characteristics in the analysis.

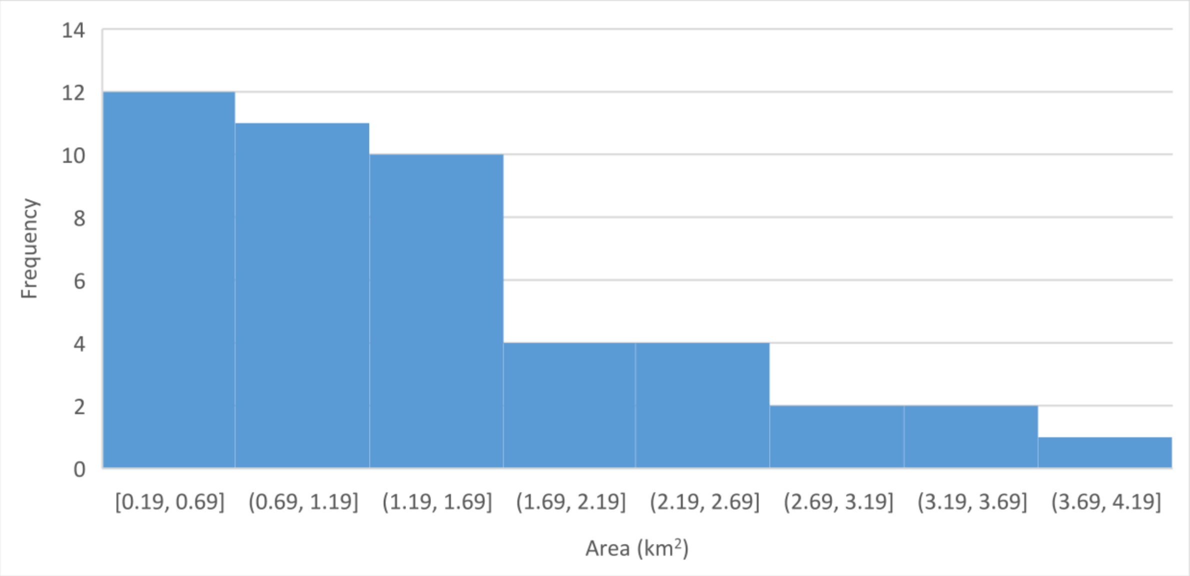

Figure 21: Catchment Area Distribution

The variation in slope steepness was achievable because the contour lines from the Topo50 map which were used to overlay the natural land layout. This allowed for the easy visualisation of slope steepness and therefore, a large variety of catchment slopes were collected and analysed.

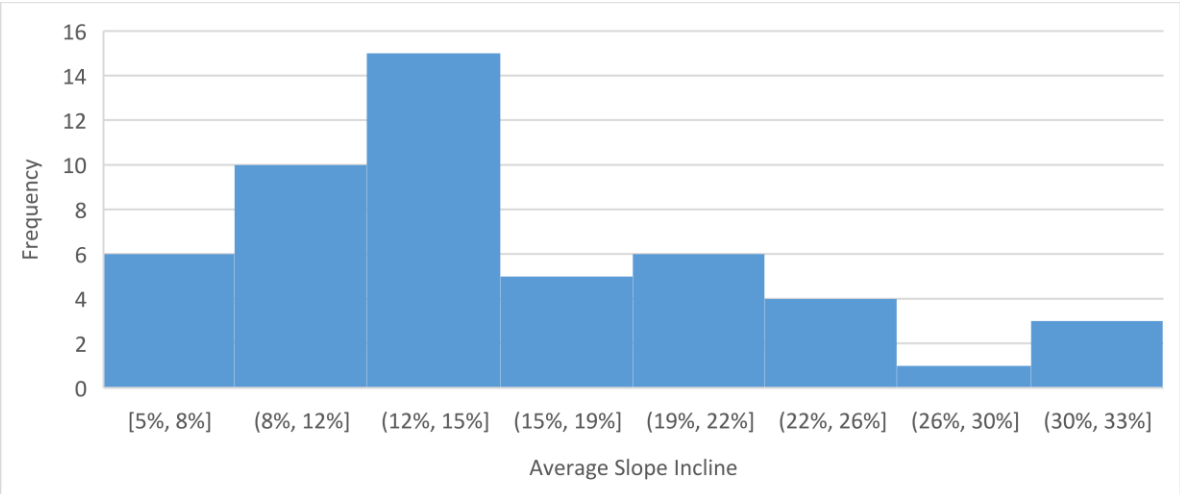

Figure 22: Catchment Slope Distribution

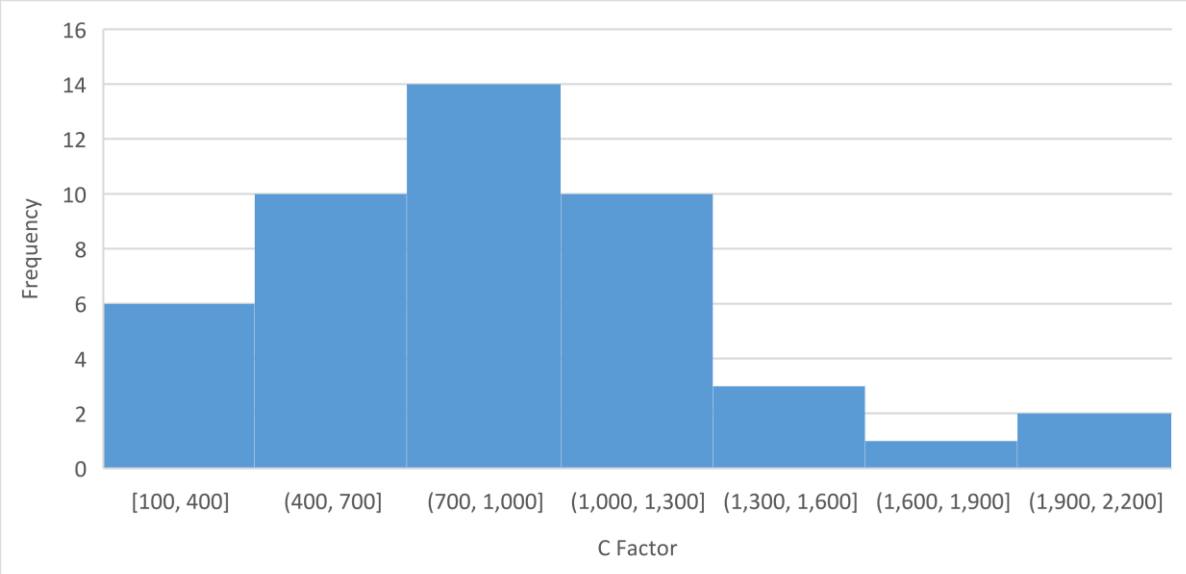

Figure 23: C Factor Distribution

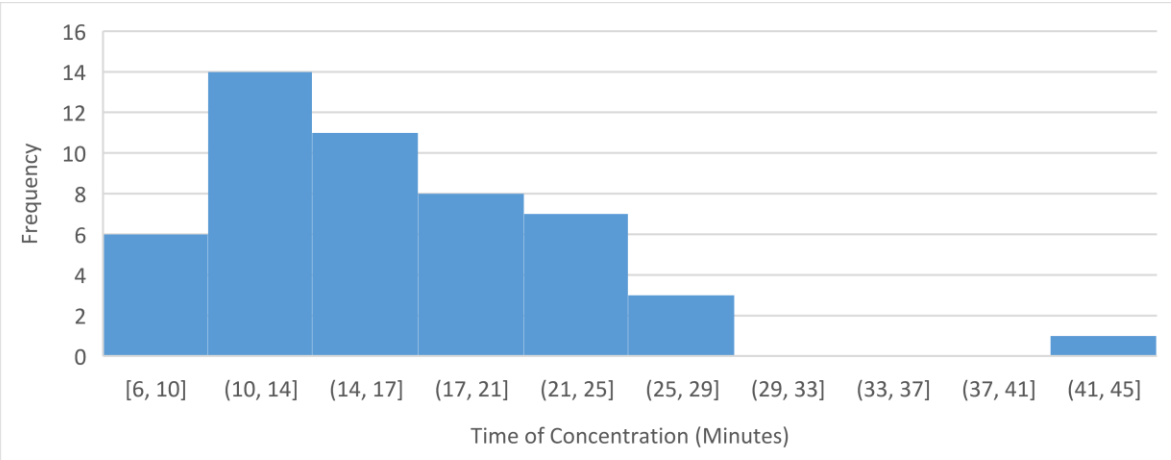

Figure 24: Catchment Time of Concentration Distribution

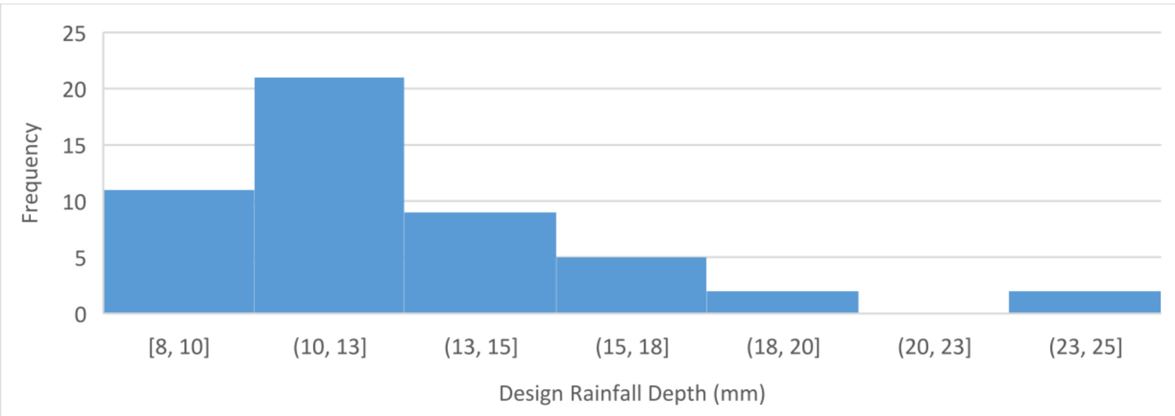

Figure 25: Catchment Rainfall Depth Distribution

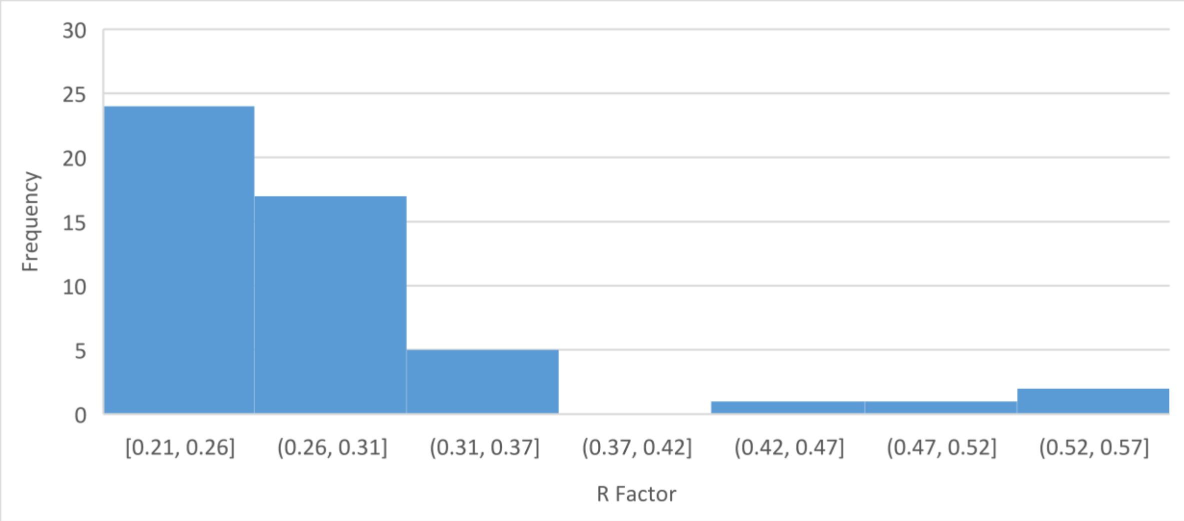

Figure 26: Catchment R Factor Distribution

It is worth noticing that the R factor values are skewed towards the smaller end even though the rainfall depth distribution is more bell-shaped. This suggests that the R factor for the TM61 may not be as impactful on flow values compared to rainfall intensity values used for the Rational Method. The highest and lowest R factor values vary by a factor of 2.7 whereas the highest and lowest rainfall intensity values vary by a factor of 4.1.

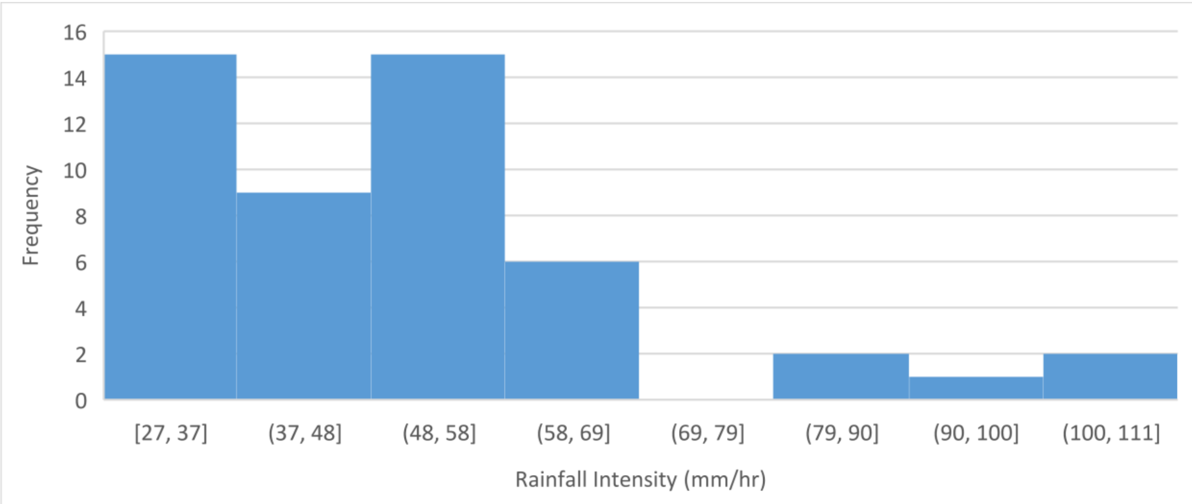

Figure 27: Catchment Rainfall Intensity Distribution

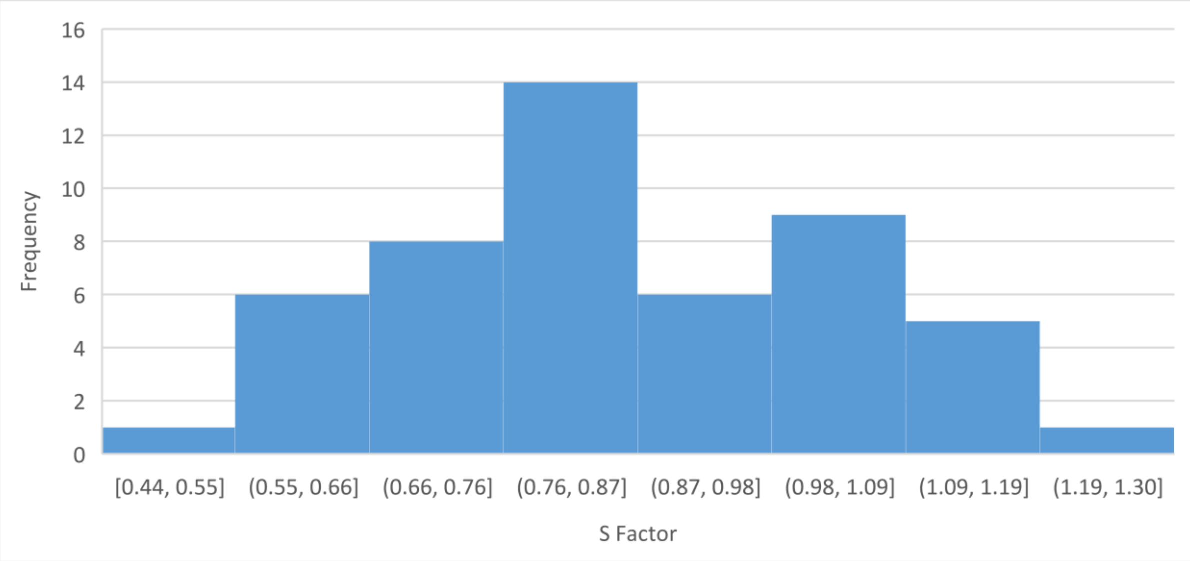

Figure 28: Shape Factor Distribution

Upon completing the data collection, four catchment flow calculations were removed from the data analysis as these flows were extremely high, which caused very high skews in the trends and were considered too large for a forestry specific study.

6.2 TM61 and Rational Method Flow Comparison

When looking at Figure 29 below it can be seen that 47 out of the 50 flows are above the line which represents the same calculated flow from both methods. This shows that the Rational Method estimates higher flow rates compared to the TM61. This was expected as the literature stated that the Rational Method is conservative due to the limited number of inputs. It can also be seen that catchments with larger areas generally have larger flow rates. There is some inconsistency with this trend towards the largest flows and this is due to the other input variables not being consistent.

The inputs for the three points being referred to in Figure 29 have the variable inputs and calculated flows for these points shown in Table three below as examples of how all the data points are plotted. All remaining data points can be seen in section 11.3 of the appendices.

Table 3: Example Data Point Values

TM61					**Rational Method**			
C	**R**	**S**	**A (km^2)**	**Q (m^3/s)**	**C**	**i**	**A (ha)**	**Q (m^3/s)**
730	0.30	0.57	1.50	2.36	0.3	54.15	150	6.73
1130	0.30	0.77	3.29	8.81	0.35	32.3	329	10.27
2000	0.22	1.14	2.46	13.49	0.5	52	246	17.67

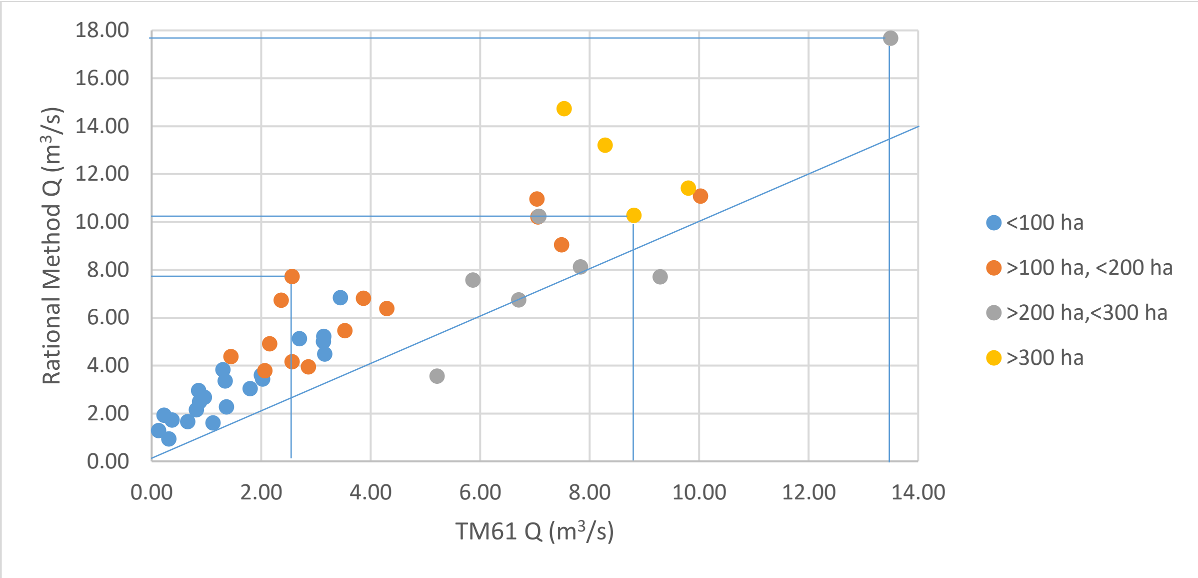

Figure 29: Rational Method and TM61 Flow Comparison with Area Categorization

Figure 30 below shows the flow calculated for each catchment using both methods. It can be seen from the equation that the flow rate from the TM61 Method increases at a steeper rate than the Rational Method. It can also be seen that the spread of the data increases greatly when the flow rates increase. This highlights the inconsistencies between these two methods and reinforces the importance of the recommended area limit for these methods, as larger flows will correspond with larger catchments. The equation for this data series is:

$$\text{Rational Method} = 1.07*\text{TM61} + 1.71$$

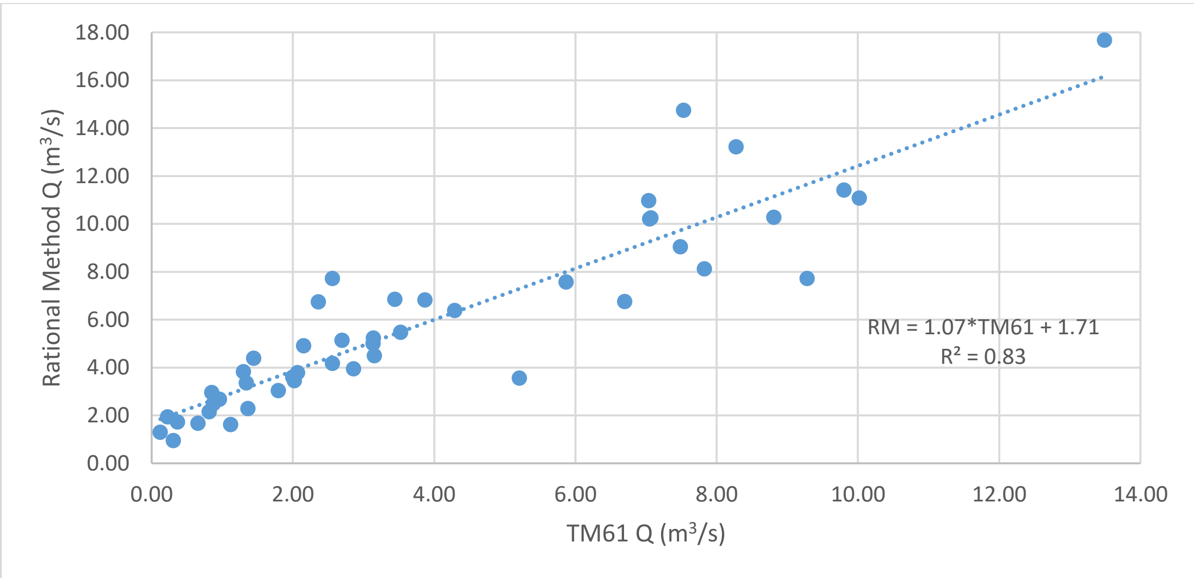

Figure 30: Rational Method and TM61 Flow Comparison

Table four below shows the catchment characteristics and flows from four data plots in Figure 30. The first two plots have similar TM61 flows but have highly contrasting Rational Method flows. This is the same for the other two plots which are further along the graph showing higher TM61 flows.

Table 4: Highly Varying Flow Rate Catchment Characteristics

Catchment Flow	Low	Regular	High	Regular
Area (km^2)	2.71	2.25	3.82	1.68
Direct Path (m)	2542	2915	3158	1652
River Path (m)	3073	3536	3186	2137
Average Slope	0.1241	0.1615	0.1215	0.3314
W_{IC}	0.7	0.7	0.8	0.7
W_S	65	75	65	80
W	45.5	52.5	52	56
C	900	1150	1075	1300
AEP	0.05	0.05	0.05	0.05
T_C (min)	21.10	21.24	21.88	10.93
Design Rainfall (mm)	10.6	13.5	10.6	9.7
Standard Rainfall (mm)	50	50	50	38
R	0.21	0.27	0.21	0.26
K	0.42	0.26	0.38	0.62
Shape Factor	0.93	0.74	0.87	1.1
TM61 Q (m^3/s)	**5.21**	**5.87**	**7.53**	**7.49**
C	0.15	0.3	0.35	0.4
Rainfall Intensity (mm/hr)	31.7	40.6	39.9	48.7
Rational Q (m^3/s)	**3.56**	**7.57**	**14.74**	**9.04**

For the low flowing catchment the area is 20% larger and the S factor is 26% larger. The other two TM61 inputs, C and R factors are smaller by either 21% or 22%. These small differences cancel each other out to generate similar TM61 flows. The rainfall intensity for the low flowing catchment is 22% smaller than the regular flowing catchment which offsets the catchment area which is 20% larger. Therefore the cause of the significantly low flow is the Rational Method coefficient which is half of the regular flowing catchment. The low value was given to this catchment because it was entirely forested and had a shallower gradient.

For the high flowing catchment the area is 2.3 times larger than the regular flowing catchment. All other TM61 inputs are smaller by a percentage between 21% and 26%. The larger area offsets these other inputs which are slightly smaller to create similar TM61 flows. The Rational Method coefficient is smaller along with the rainfall intensity for the higher flowing catchment. Therefore the difference in area is the leading cause of the larger flow.

6.3 TM61

The range of W_{IC} coefficients used in this investigation ranged from 0.7 to 1.05 with catchments varying from 100% of area in long grass, scrub or bush to average short grazed catchments/mainly bare surfaces. No urban catchments were analysed for this investigation as they were not suitable for a forestry study. This coefficient selection process is more structured compared to the Rational Method as each catchment characteristic is considered once at a time rather than the whole catchment being evaluated as a whole.

During the data gathering phase, all catchments analysed were within either the Canterbury or West Coast region. This means that for the TM61 calculations, only moderately absorbent soils (southern yellow brown earths) were considered. These W_{IC} coefficients are all smaller than the impervious soils (northern yellow brown earths) by a value of 0.1 which led to a slightly smaller TM61 flow rate. It is likely that this difference will be minimal and the adjusting of this coefficient to northern soils can easily be done.

The input variable that had the highest regression value with the flow rate was the catchment area. The regression value is still relatively low at 0.66 which can be seen when looking at the plots towards the larger catchments as the flow rate is largely distant from the trend line. This will be because of the other characteristics of the catchment which contribute to the overall flow. Figure 31 shows this plot between flow rate and area. The equation for this data series is:

$$TM61\ Q = 2.86*Area + 0.05$$

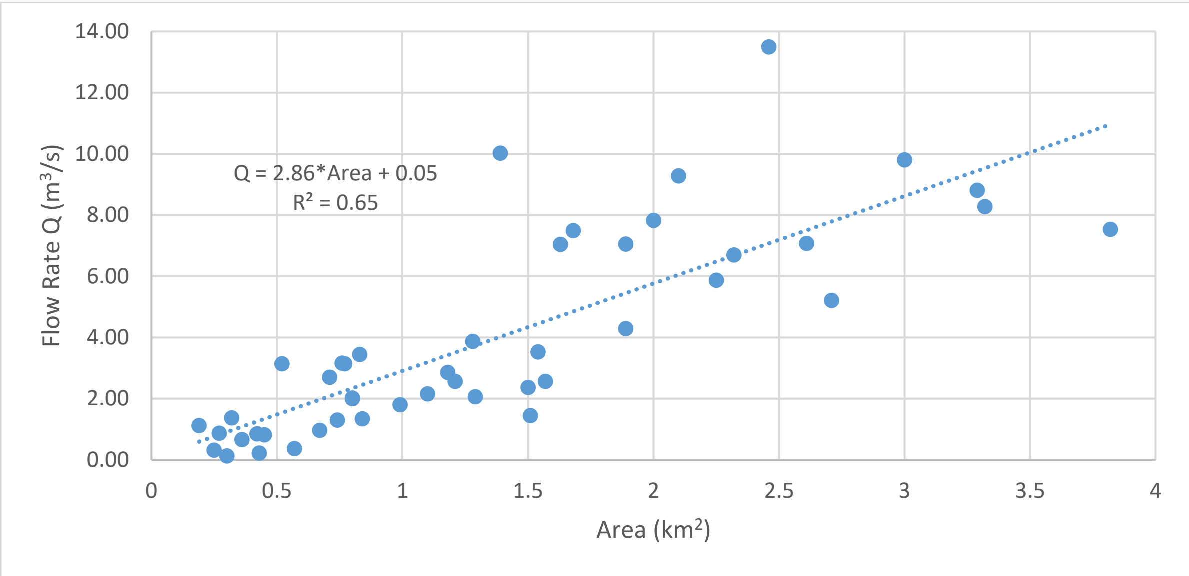

Figure 31: TM61 Flow Rate and Area Relationship

Table five below shows the catchment characteristics and flows from six data plots in Figure 31. Two significantly high flow values and one significantly low flow value are partnered with a regular flow value with a similar catchment area in order to determine the cause of this large variation.

Table 5: TM61 Outlying Flow Characteristics

Catchment Flow	High (A)	Regular (B)	High (C)	Regular (D)	Low (E)	Regular (F)
Area (km^2)	**1.39**	**1.28**	**2.46**	**2.61**	**1.51**	**1.54**
Direct Path (m)	1413	1561	1896	3735	2268	2461
River Path (m)	1726	1741	1956	3685	2301	3062
Average Slope	0.2452	0.2111	0.2005	0.1138	0.0469	0.0796
W_{IC}	0.95	0.73	1.05	1	0.7	0.9
W_S	67	62	67	69	41	58
W	63.65	45.26	70.35	69	28.7	52.2
C	1900	900	2000	1950	360	1050
AEP	0.05	0.05	0.05	0.05	0.05	0.05
T_C (min)	10.41	11.11	12.39	25.09	24.56	24.97
Design Rainfall (mm)	9.62	9.73	8.67	11.7	14.3	13.1
Standard Rainfall (mm)	37	39	40	52.5	52	52.5
R	0.26	0.25	0.22	0.22	0.28	0.25
K	0.70	0.53	0.68	0.19	0.29	0.25
Shape Factor (S)	1.14	1.03	1.14	0.57	0.77	0.7
TM61 Q (m^3/s)	**10.02**	**3.87**	**13.49**	**7.07**	**1.44**	**3.52**

The first two catchments (A and B) in the table above have similar areas, shape factors and rainfall factors. Therefore the cause of the large difference in flow rates is due to the C factor. This is a result of the higher W_{IC} used to represent the ground cover for the catchment because the river path and average slope for both catchments are similar which would lead to a similar W_S value being obtained.

The second two catchments (C and D) in the table above have similar areas, C and R factors. The river length for the higher flowing catchment is shorter but the average slope is steeper when comparing characteristics with the regular flowing catchment, leading to a similar W_S value being obtained. Coupled with having similar W_{IC} values, these characteristics lead to a similar C factor value for both catchments. Therefore the cause of the large difference in flow rates is due to the shape factor which is twice as high as the regular flowing catchment. This value is influenced by the area and direct path length of the catchment.

The third two catchments (E and F) in the table above have similar areas, R factors and S factors. The difference in river lengths along with average slopes and ground cover coefficients leads to the low flowing catchment having a smaller C factor value, which is almost three times smaller than the regular flowing catchment.

6.4 Rational Method

The coefficient range for the Rational Method ranged from 0.15 to 0.5 as all catchments were "Forested Areas with Steep Slopes" or "Steep Grassed Areas". The absence of urban catchments was the reason for land-cover coefficients not being any larger.

The input variable that had the largest regression value between the flow rates was the area for the Rational Method. The R^2 value of 0.66 is larger than the R^2 value for the TM61 Method. This is due to the reduced number of input variables that the Rational Method has. Therefore less aspects of the catchment are taken into consideration for the calculations which allows for the remaining inputs to make a larger contribution to the final flow value. Figure 32 shows the relationship between flow rate and area. The equation for this data series is:

$$\text{Rational Method } Q = 3.37*\text{Area} + 1.34$$

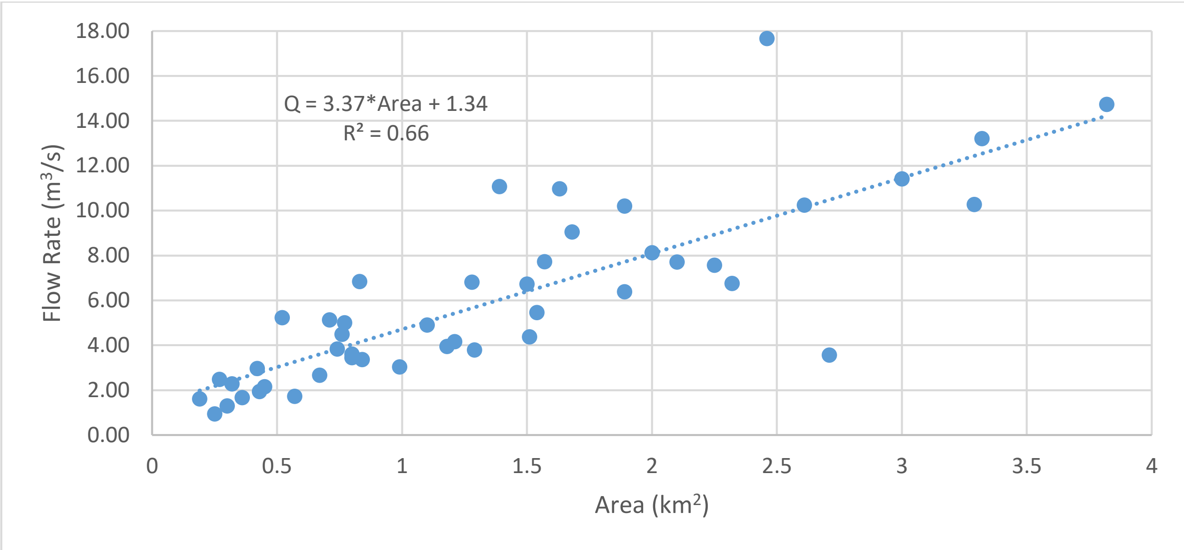

Figure 32: Rational Method Flow Rate and Area Relationship

Table six below shows the catchment characteristics and flows from three data plots in Figure 32. One significantly high flow value and one significantly low flow value are partnered with a regular flow value with a similar catchment area in order to determine the cause of this large variation.

Table 6: Rational Method Outlying Flow Characteristics

Catchment Flow	High	Low	Regular
C	0.5	0.15	0.5
Rainfall Intensity (mm)	52	31.7	28.4
Area (ha)	**246**	**271**	**261**
Rational Q (m^3/s)	**17.67**	**3.56**	**10.24**

The high flow catchment has the same ground cover coefficient and similar area to the regular catchment. Rainfall intensity is 83% larger and is the cause of the large Rational Method flow for this data plot. The rainfall intensity of the regular catchment is the smallest recorded out of the entire study which is why there is such a large contrast.

The low flow catchment has a similar rainfall intensity and area to the regular flow catchment. The cause of the significantly low flow is due to the 0.15 value used for the ground cover coefficient, which is the smallest value used in the study. The catchment would have therefore been fully forested and have shallow slopes. This ground cover coefficient is the middle value for the "Wooded Areas with Level Ground" and the lowest value for "Forested Areas with Steep Slopes" which is a suitable estimate.

6.5 Sensitivity Analysis

Twenty three of the 50 catchments that had a W_{IC} coefficient of 0.7 had the coefficients changed to 1.1 which represents mainly bare surfaces in order to simulate the catchment characteristics following harvesting. Figure 33 below shows the comparison of before and after harvesting flow rates for each selected catchment. It can be seen that every catchment had an increase in flow which is expected as all other variables are held constant. The average increase in flow from all catchments is 249% with a standard deviation of 23.4% which means that if the culvert was permanent then much larger diameters will be required.

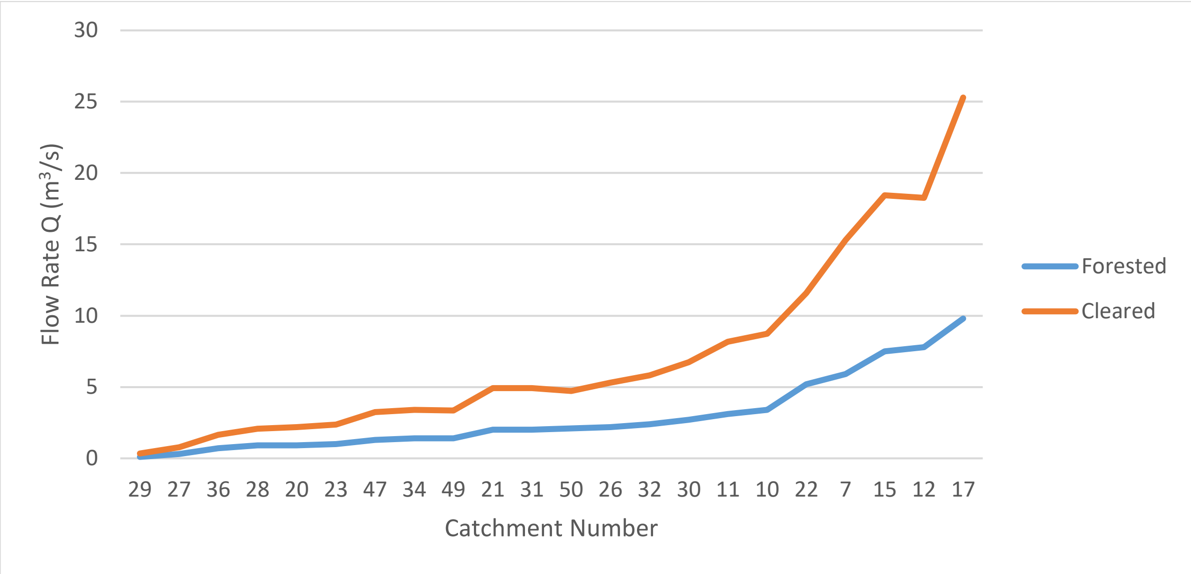

Figure 33: TM61 Flow Comparison when Changing W_{IC} from 0.7 to 1.1

Undergoing this same process using the Rational Method is more complicated as deriving an appropriate coefficient for simulating a post-harvest catchment is more difficult due to the less descriptive guidelines of the method. Therefore this simulation has not been done using the Rational Method as uncertainties would be too significant.

6.6 Industry Survey

Ten surveys were completed with professionals within the forestry industry that design culverts. The results are presented below in an order corresponding to the answers that were obtained through the survey. Table seven below shows the region these professionals worked within.

Table 7: Survey Responses per Region

Region	Frequency
Nelson	2
Hawkes Bay/Napier	2
Wanganui	1
Waikato	1
Auckland	1
Northland	2
Marlborough	1

Figure 34 below shows the positions within the companies that the surveyed individuals held. The majority of foresters surveyed were harvesting planners/supervisors with the next most frequent position being forestry engineers and foresters, with one person being an environmental and procurement manager.

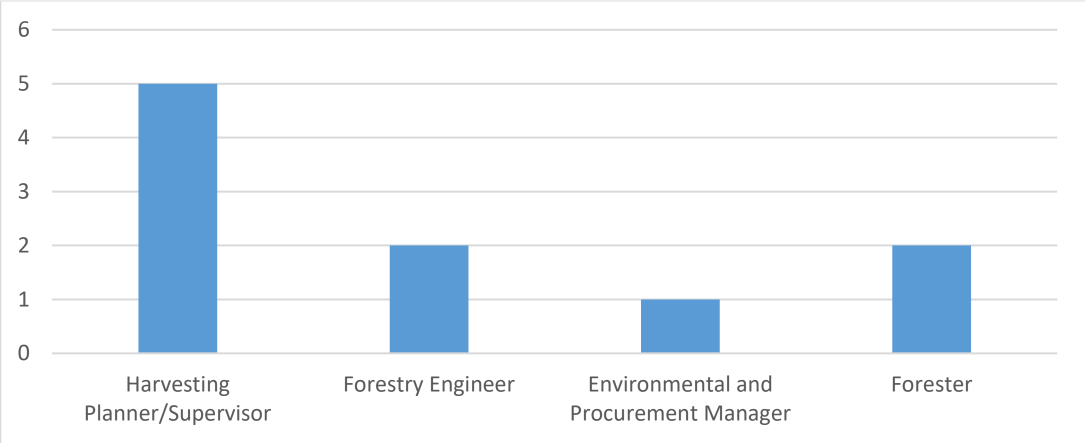

Figure 34: Phone Survey Company Position

6.6.1 Preferred Methods

It can be seen in Figure 35 below that the most frequently used empirical method is the Rational Method with only one of the survey responses saying that they do not use this method.

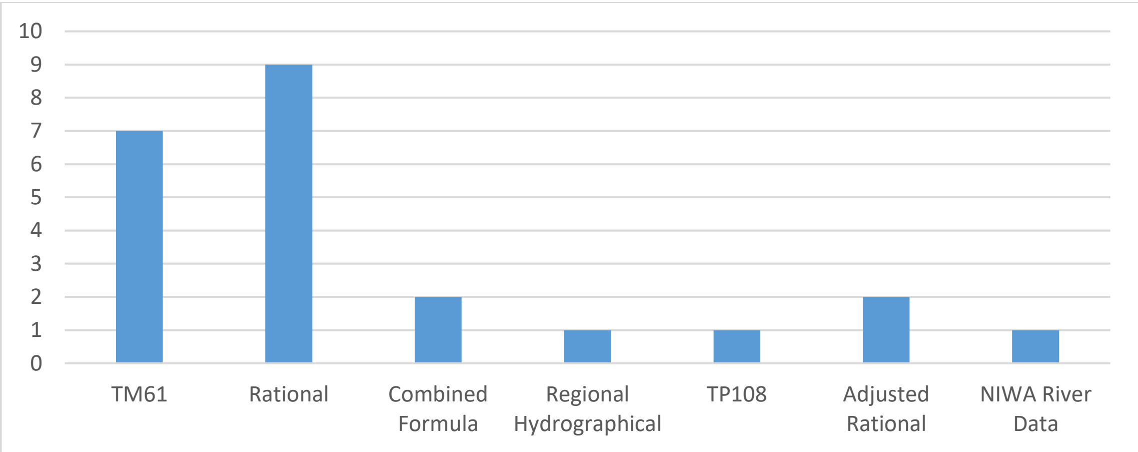

Figure 35: Flood Flow Method Preferences

Many of the survey responses stated that they use multiple methods for determining flood flow rates so that they are still complying with NES guidelines. Table eight below shows the methods used by each person surveyed.

Table 8: Flood Flow Preferred Method per Person

Survey Number	Response
Survey 1	TM61, Rational
Survey 2	TM61, Rational
Survey 3	TM61, Rational, Regional Hydrographical, Adjusted Rational
Survey 4	TM61, Rational, Combined Formula
Survey 5	TM61, Rational, TP108
Survey 6	TM61, Rational
Survey 7	Combined Formula
Survey 8	Rational
Survey 9	TM61, Rational, Adjusted Rational
Survey 10	Rational, NIWA River Data

Respondents were asked to state their reasoning for why they preferred their chosen method. The main contributing factor for these preferences was the size of the catchments that they are usually dealing with. There was however some inconsistency with the catchment size limit that made the surveyed person change from one method to another.

Respondents stated that the Rational Method was used for smaller catchments and the TM61 was used for the larger catchments. The area limit for the Rational Method varied between 15 hectares to 300 hectares from all of the respondents.

In the literature review, the Gordon Keller citation stated that the Rational Method is suitable in catchments smaller the 120 hectares while the NZ Forest Owners Association stated that it is suitable for catchments with an area between $1km^2$ to $25km^2$. These two recommendations are widely varying and do not align with any of the responses from the survey. This could be one of the main reasons for highly variable flow rates as there is no established limit for the use of these methods even when the literature states that these methods are suited to certain catchment sizes.

6.6.2 Headwall and Wing Design

The surveys revealed that headwalls and wings are very rarely incorporated in the design of forestry culverts with two of the people responding saying they did use headwalls and wings while the other eight said that they did not.

The individual respondents saying that they did incorporate headwalls and wings into their design said that they were only for significant culverts without referring to the reason why these culverts were deemed significant. One respondent stated that the headwalls were always constructed from timber instead of concrete as it was a cheaper alternative and easier to install.

The large amount of respondents who said they did not design wings or headwalls, stated that they use riprap armouring as a substitute. The reasoning behind this preference varied between individuals which are listed below:

- Riprap armouring is a much cheaper substitute because the rock material is usually at a closer proximity which costs less to extract and transport compared to the purchasing and transportation of culvert wings and headwalls.
- Many of the woodlots that the people did the flow analysis for were deemed to be too small for wings and headwalls to be considered for construction. There were a range of catchment

area limits specified by some of the respondents which could lead to an inconsistency in culvert construction. Only one respondent specified the parameters for not needing any armouring or headwalls/wings and this was when the pipe diameter was less than one meter. Riprap armouring was installed if the flow rate was greater than $2m^3/s$.

- One individual stated that by simply extending the pipe further beyond the embankment, there was no need for installing headwalls or wings.

6.6.3 Flow Adjustments and Culvert Materials

Each respondent was asked if they made any adjustments to their flow calculations when considering the suitable material to be used by the culvert. There were two responses which did not state whether or not they made adjustments while all other responses said that they did not make any adjustments.

The selection of materials used for the culvert also varied highly between the designers which are shown in Table nine below. The three culvert types that were mentioned by the people surveyed are represented by the columns in Table nine with the reasoning for the selection of this material. There is some overlap between the literature and survey responses for the reasoning behind the culvert material choice such as the service life, cost and ease of construction. Only one of the survey respondents mentioned the importance of allowing safe passage for fish travel through the culvert which is emphasized in the NES and NZFOA as a contributing factor. The size of the catchments that the surveyed culvert designers worked on is not specified which also may have a large influence on the culvert material.

Table 9: Culvert Material Preference Response

	Plastic	Metal	Concrete
1	Permenant (easier installation)	-	Temporary culverts (not damaged when removed)
2	EUROFLO, Farmboss (>375mm)	Helcor (recently decomissioned)	Irreguarly (Box Culvert)
3	-	-	-
4	-	-	-
5	Farmboss	-	Adjusts with Mannings for roughness
6	Small culverts (limit not specified)	Helcor (except in erosive soils)	Large, Concrete over flow base
7	Smaller diameters (concrete lined)	-	Large backfills (higher bearing capacity)
8	Slow river velocity	-	Fast river velocity
9	Always	-	-
10	-	-	Always (reusable, robust)

6.6.4 Culvert Sizing from Flow Calculations

From the survey eight people responded saying they use a chart for calculating the required culvert size from the determined flood flow, while two responded saying they did not. Both of the people surveyed who responded saying “No” to using charts stated that they used spreadsheets for determining flow rate which automatically calculated the required culvert size.

These charts were obtained from various sources such as the New Zealand Forest Road Engineering Manual. The chart that features in this manual is sourced from Concrete Pipe Association of Australia 1986. The use of this chart could lead to inconsistencies in performance as multiple people surveyed within the forestry industry size their culverts which are composed out of varying materials, however this chart is specifically designed for concrete pipes. It is worth noting that none of the people surveyed made flow adjustments depending on the material they had chosen. These two factors could lead to small inconsistencies. Another person responded saying that they did not know the origin of the chart which they use for sizing culverts.

One of the people surveyed said that they use the same 325mm pipe for cross-drains on roads and a 450mm culvert as a default pipe, which is an NES minimum requirement for crossings if the catchment is small enough. The catchments area threshold for this pipe size was not specified.

Another person surveyed said that they determine the appropriate culvert size using a chart but then use the culvert guidelines from the Ministry for Environment to determine multiple barrel culverts with the equivalent capacity. This was done in order to avoid requiring a resource consent to use pipes with a diameter exceeding 1800mm and therefore reducing construction costs.

6.6.5 Problems Encountered During Design Process

Table 10 below shows how many times each particular response was stated during the survey. Some of the responses to this question raised multiple issues raised as the people surveyed could not decide which problem was most serious.

Table 10: Culvert Design Problems Encountered

Problem	Responses
Coefficient Derivation	3
Sizing Before and After Harvest	2
Information Available	1
Selecting Flow Rate	1
Lack of Expertise	1
NES Restrictions	1
Infrastructure Comparison	1
Time of Concentration	1
Crossing Type Selection	1

It can be seen that the most frequently encountered problem when sizing culverts is the selection of the appropriate ground cover coefficient. The next most common problem for the people surveyed was the decision of whether to design the culvert for the catchment following harvesting or keeping the design to a pre-harvest land cover. This issue is also associated with the most common problem as the ground cover coefficient will be the values that represents the woodlot pre and post-harvest.

The other problems mentioned were:

- The lack of information that could be obtained from third party woodlots is evident when the council investigates the area following a problem occurring.
- Deciding which out of the calculated flow rates should be used for the sizing of the culvert. This person had some preferences towards the final decision such as the smaller flow rate would be used if it allowed for the bypass of resource consents.
- An individual stated that they find that they lack the confidence and knowledge when sizing culverts as they are not engineers. This individual also stressed that the NES does not allow room for discretion and therefore believes that over-engineering is the only option to avoid being taken to court for non-compliance.
- Whether comparing flow calculations to neighbouring catchments which have previously been calculated was an appropriate approach and what verifies making that decision.

- Deriving the Time of Concentration (T_c) is difficult to complete if the catchment has not been inspected as the individual does these calculations from a desk. There is also the minimum T_c of 10 minutes that must be used on the NIWA HIRDS website which can be too large for smaller woodlots. The result of this is that further interpolating must be done in order to achieve the appropriate value which may be less accurate.
- There is difficulty determining which crossing type was the most suitable after completing the flow rate calculations.

6.7 Problems Encountered

6.7.1 Coefficient Selection

For both flow calculation methods, a coefficient has to be selected to represent the ground cover characteristics of the catchment. There are tables provided for each method that describe the ground cover type and which coefficient should be used, however the descriptions are vague, particularly for the rational method where a category can be "Forested Areas with Steep Slopes" with no mention of what slope incline is considered "steep".

Throughout the entire data gathering stage of the report a coefficient classification method was maintained so that the ground cover coefficients for the TM61 and Rational Method were kept consistent. Even when maintaining this regime, there were still highly contrasting results between these two methods which raised the question whether a suitable coefficient had been chosen. Figure 37 below shows the relationship between the "C" factors for both methods which does not follow a linear trend. This variance could also be attributed to the river length variable which is considered in the TM61 but not with the Rational Method when determining these C values.

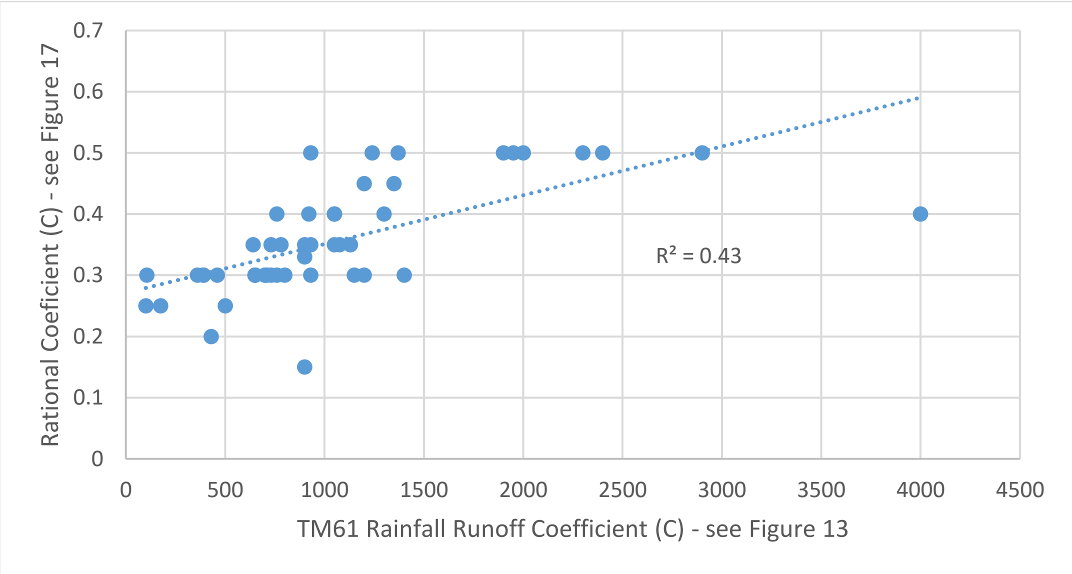

Figure 36: Coefficient Contrast Between Methods

6.7.2 Slope Averaging Method and Time of Concentration

The Equal-Area Method was used for calculating the average slope through each catchment. There are other methods for calculating the average slope such as the Taylor-Schwarz and the Modified Taylor-Schwarz which are all likely to give differing average slope values and therefore have an effect on the flood flow rate.

The Ramser-Kirpich Equation was used as the only formula when defining the Catchment Time of Concentration (T_c) even though there are also the Bransby-Williams and U.S. Soil Conservation Service equations available. It would also be likely that these equations would define different T_c values and affect the final flood flow rates.

6.7.3 Large Area Data Collection

The majority of catchments analysed were smaller than two square kilometres. This was because of the catchment sizes which were mentioned by many of the people who took part in the phone surveys. Therefore, a large emphasis was placed on these catchment sizes as these seemed to be the generic woodlot size, meaning that the findings from this study may be unsuitable when analysing large catchments.

6.7.4 Time of Concentration Limit Reached

There were many instances when the calculated Time of Concentration was less than ten minutes. This became a problem because the rainfall depths and intensities in the tables on the NIWA HIRDS website have a minimum time of ten minutes. Because of this, the values used for rainfall depths/intensities below ten were kept the same as the value at ten. The other option for this problem was to extrapolate beyond the ten minute limit which could be difficult as neither of the trends are linear.

For Times of Concentration that fell between two of the times shown on the table, simply converting the values from tabular to graphical format allowed for the values to be interpolated.

6.7.5 Surveys Taken in Canterbury and West Coast

The entirety of the catchments selected for analysis were from either the Canterbury or West Coast regions. The reason for these two regions being selected was that they had highly contrasting rainfall indexes which would allow for the analysis of the rainfall coefficients to apply to a larger range of values. The majority of the catchments were selected in Canterbury which had lower rainfall indexes compared to the West Coast. The absence of catchments analysed in other regions that may have contrasting geographical features could lead to the results being more specified to catchments within these two provinces which have certain slope formations.

7 Discussion

There is a correlation between the results from the catchment analysis and the relevant literature, with the main observation being that the Rational Method was found to estimate higher flood flows. There was however little literature found which was specifically related to these methods being applied in forestry operations with no mention of particular scenarios which could generate inaccuracies.

It was found that area had the strongest relationship with the flow rate and that the most common cause of significantly variable flow rates was the coefficient value for both empirical methods. The three equations derived from plotting these empirical methods against each other and against area are as follows:

$$\text{Rational Method} = 1.07*(\text{TM61}) + 1.71$$

$$\text{TM61 } Q = 2.86*\text{Area} + 0.05$$

$$\text{Rational Method } Q = 3.37*\text{Area} + 1.34$$

There was correlation between the catchment analysis and the surveys. The most common response when asked which part of the culvert design process is the most difficult was the selection of ground cover coefficients which I personally also found the most difficult, especially for the Rational Method.

The additional findings from this analysis was that TM61 flow rate increased by an average of 249% when the W_{IC} coefficient is changed from 0.7 to 1.1, which simulates the effects of clear-felling a fully forested catchment. This same simulation is more difficult when using the Rational Method because of the higher amount of discretion required from the designer when selecting the appropriate ground cover coefficient.

By using the Adjusted Rational Method which features more specific guidelines and allocates values for specific slope gradients into the coefficient derivation, a more accurate simulation of flows before and after harvesting can be obtained. This method will also result in a more linear relationship when making comparisons to the TM61 ground cover coefficients and therefore the two flow rates will become more similar and consistent.

The limitations of this study are largely due to the number of catchments analysed along with the number of surveys conducted. If a larger number of culverts were analysed then the findings could be presented with higher confidence levels. Increasing the number of surveys conducted will also generate results with a higher level of confidence. This is because the preferences of a larger number of culvert designers will be provided and more conclusive statements can be made.

Another limitation of this study is the generalisation of the responses from the survey so that they could be presented in a visual format. The result of this is that the detail of each response has been reduced or altered to a category that is similar to other responses in order to make a conclusion of what the preferences of culvert designers are. This occurred for the company positions that the people surveyed said they held, along with the problems encountered during the culvert design.

8 Conclusion

Culvert sizing operations in the New Zealand forest industry are highly variable yet still very important in order to achieving a cost effective and environmentally sustainable operation. An analysis of current methods for determining flood flows was undertaken whilst information was gathered through surveys to determine the preferences and problems encountered by culvert designers within the forestry industry.

The catchment analysis found the Rational Method to be estimating higher flows compared to the TM61 method. Area and flow rate had the strongest relationship out of all input variables for both empirical methods. The most common cause of outlying variables from figures plotting flow methods against the area was the ground cover coefficient. Flow rates of fully covered catchments increased by an average of 245% when completely harvested.

Surveying of culvert designers revealed that the Rational Method was the most used empirical method with headwalls and wings being rarely implemented in the culvert design. Flow calculations are not adjusted depending on the culvert material and sizing of culverts from flow rates is commonly done using charts. The most difficult aspect of the design process for most people is selecting the appropriate coefficients for the catchment.

The main limitations of this study are the number of catchments that were analysed along with the number of people surveyed. Predicting the suitable flow rate for a singular catchment cannot be done by using the findings from this study, however it reveals abnormalities in commonly used empirical methods and culvert designs that should be taken into consideration by the designer.

9 Acknowledgments

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11 Appendices

11.1 Survey Responses

11.1.1 Question One

Have used both TM61 and Rational Method. Has found in the past that both methods tended to be excessive. Also found that any area greater than 300 ha is too large for these calculations to be used (rational method is less affected than TM61). The Ministry for Environments has a different method for calculating culvert sizes

Uses both the TM61 and rational methods.

Uses the TM61 method, Rational method, adjusted Rational Method and regional hydrological Method (91 McKerchar flood estimation – a revised design procedure) Said that the rational method largely overestimates the flow in catchments smaller than 20 hectares which they usually deal with.

TM61 and Rational Method. They use a formula which incorporates both the TM61 and Rational methods. This came from heavy disputes within the district between the company and the regional council. The result of this was that they were given a formatted spreadsheet of rainfall data and variables, which takes 50% of TM61 and Rational method as one is known to overestimate and the other is known to underestimate. The spreadsheet is supplied by the Environmental Auditing Team Waikato and this became the standard operating procedure.

Try to use TM61 but has not had prolonged use with it. Uses rational method along with TP108 which is an Auckland council stormwater guideline for flood flow analysis.

Generally uses TM61 for most catchments but found that it doesn't work for areas under 15 hectares and therefore uses rational for smaller areas.

Uses spreadsheet which is combination of TM61 and Rational, reference guide with risk index (for extreme options with catchments).

Mostly rational method as catchment sizes are smaller and beneath the TM61 threshold (not specified).

Uses TM61, Rational, Modified Rational. The flow rate to be used for sizing the culvert is selected by assessing the flows and identifying which flows are outliers as they are somewhat obvious. Uses the Rational Method for smaller catchments (~100ha) as they are better designed for these sizes/TM61 not.

Uses Rational Method and NIWA River Data.

11.1.2 Question Two

Does not use headwalls or wing in culvert designs.

For most culverts, headwalls and wings are not used as they are considered too expensive. As a substitute when they are available, limestone boulders or concrete slabs can be used as they do not add to the costs of the culvert establishment. It is much cheaper to extend the pipe beyond the embankment, costing slightly more pipe rather than headwalls and wings.

Only when they are necessary because they are expensive, any culverts that are less than one meter means that there will not be any headwalls or wings. Instead they use riprap armouring as it is a cheaper alternative that is still effective for anything more than 2 cubic metres per second.

Depends what they are doing, for bigger culverts council expect something as they design drawings of what they expect. There are many instances where there are adequate resources available which can be used as substitutes. These include hard rocks which can be used as headwalls and wings as they are strong and are not washed away as easily as slash and lighter objects. This is very useful when slash blocks the culvert and the flow starts going over the crossing rather than through the culvert as the rocks do not join the flow. When the soil has bad strength properties and there are inadequate resources such as strong rock, often they will use logs to construct headwalls for additional protection.

Uses riprap armouring and rocks if available, depends on the resources available and cost effectiveness.

Does not purposefully design headwalls but in the past has used riprap armouring to offset larger flows. Mentioned that the NES has a requirement for headwall protection which they try and work around without over engineering.

Have not used headwalls or wings in the past. The largest culvert that they have installed is three battery culverts with a diameter of 1.2 metres but didn't seem to think that headwalls or wings were necessary.

Uses armouring instead of headwalls but largely depends on operator and how they place the rocks. Also depends on availability of rock at the site.

Does not design concrete headwalls or wings to increase flow capacity but uses local materials, usually rocks to armour the bank and prevent erosion.

Does design wing-walls using timber panels (usually 6*2) instead of concrete because of the cheaper price and ease of instalment.

11.1.3 Question Three

When installing permanent culverts, material of choice is plastic as they are cheaper. When installing temporary culverts, material of choice is concrete as they are strong and will not be disfigured during removal process.

Use multiple pipe types, these including:

- Large plastic pipes (EUROFLO Pipes).
- For smaller 375mm road culverts, 450mm Farmboss plastic pipes are used.
- Did use to use helcor steel pipes for larger crossings with +900mm diameter pipes but manufacturing has halted since last year.
- There is also occasional use of concrete box culverts, which are not included as a culvert type on the chart for sizing.

Does not adjust flow calculations if certain material is being used.

No, the flow is unadjusted regardless of what material is being used.

Tries to use farmboc (ribbed PE pipe used in agriculture) as they are lighter than concrete. If using concrete culverts adjusts for flow with mannings (roughness coefficient). Does not make adjustments regarding the stormwater flow and material used.

Does not make flow adjustment depending on material. Said that material of choice was dependant largely on soil characteristics. Examples of this are that they did not use helcor pipes in catchments that had erosive soils as these pipes were made out of metal. There were also cases where the presence of pumice caused the chipping of pipes. Mentioned that a countermeasure that has been used recently by other engineers is pouring concrete over the base of the pipe to prevent this degradation. This will however reduce the cross-sectional area of the pipe. Helcor pipes are not being made any more so usually uses concrete for large culverts and plastic for smaller culverts.

Does not adjust flow calculations. Has a preference of plastics as it is cheaper and easier to handle but uses concrete for larger backfills as they can withstand a larger bearing load. Talked about having a concrete layer around the plastics to improve strength and still not costing as much as concrete culvert.

Does not make flow adjustments, tends to just do the calculation and slightly mark up the size of the culvert. Choice of material depends on the flow intensity of the river. Slow moving rivers with gentle water flows have plastic culverts (quite often having a silt riverbed), whereas faster creeks with moving rocks are concrete.

Doesn’t adjust flow calculations as they only ever used polyethylene, ribbed pipes.

Does not adjust flow calculations with corresponding material. Prefers to use concrete culverts because they are more robust and easier to retrieve and reuse.

11.1.4 Question Four

Uses chart to calculate culvert sizes from flood flow values from TM61 and Rational Method. Then uses Ministry for Environment to calculate alternate culvert configurations with multiple culverts. This way it is still a permitted activity and the culvert does not exceed 1800mm which requires a resource consent from the council and costs extra.

Uses the chart for sizing culvert from flood flow calculations.

Uses the chart after sizing culverts using TM61 and Rational.

Calculates the culvert size required using the spreadsheet attached.

Typically uses conversion chart. Uses cross culvert with a diameter of 325mm on roads as it is a requirement, Uses the minimum NES size 450mm for crossing if catchments small enough (size not specified).

Uses chart to determine culvert size.

Culvert size determined by spreadsheet used, therefore no need for the chart.

Uses chart for calculating culvert size from flow.

Uses chart which originally came from OPUS (Civil Engineering Firm) who usually would use this chart for urban catchments but stressed that there is no problem using chart for both urban and woodlot culverts.

Does use a chart for determining culvert size from flow rate calculated but does not know the origin of where the chart came from. Said that they found the chart in the office.

11.1.5 Question Five

There are other requirements such as 20% of the culvert cross-section having to be submerged to allow passage for fish to spawn. This leads to some of the culvert area being wasted during large storm events as it is already occupied by the general water flow. To avert this problem, multiple smaller culverts can be used to withhold the equivalent flow.

This allows one culvert to be installed lower to accommodate for the fish while the other culvert can be used to combat large storm events. By doing this, the cost of the culverts is also reduced as the price increases rapidly with the increase in diameter and culverts are a necessity which means that they can be sold at a premium price. It is also better to overestimate the size of the culvert to reduce the chance of serious environmental damage.

Most difficult step in the process is gathering the information that is considered accurate enough. This includes finding an appropriate value for the land use coefficient that represents the whole catchment, even when there are multiple land coverages.

The calculation of the culvert sizes using the chart as the materials.

Applying the concentration during the flow calculation process. Referring to the correct selection of values for inputs within the TM61 Method.

Has some difficulty when determining the sizing of the culverts before and after they have been harvested as the ground cover has greatly changed. Needs to understand which environment to design culvert for whether it is remaining there following harvesting.

Used the Talbots Method before the NES was introduced which calculated culvert cross section required. This method does not consider the land characteristics or rainfall intensities or depths which makes the results very basic and most likely very conservative which will lead an unnecessarily large culvert being used.

Found that using a singular value for the C and W_{IC} values using the TM61 was difficult. This comes from the uniqueness of each catchment and the variability that occurs within the catchment. The main point that was raised was that at the top of the catchment the steepness is much greater whereas towards the end of the catchment the steepness is lesser. The soil characteristics through the catchment are also going to change because of this (along with the saturation of the soil being variable). However, an appropriate single value needs to be an input for the calculation to be made. There is no real solution to this as every catchment has different features.

Trying to push the amount of discretion when considering the state of the catchment, (can get away with pipe sizes if various adjustments are made). The largest struggle is with dealing with the third party on private woodlots as you are working with a lower, 20m resolution and larger contour lines. The lack of resources means that the input values are less accurate and therefore a less accurate flow value is used for the sizing of culverts. Corporate forests are much easier to deal with as there is a larger amount of resources available and a more accurate value can therefore be obtained. For the private forests, when there is a problem with the culverts and the council shows up asking to review the calculations, the lack of detail is evident.

Getting consistency on flow rate between methods and deciding which value is deemed the appropriate value. Value consideration also depends on whether resource consent is required for the size of the culvert. Smaller flow calculation will be used if they can bypass resource consent as it costs more and requires council approval.

Mentioned that they are not an engineer and has a lack of knowledge and confidence compared to engineers regarding culvert sizing.

Mentioned that frustration is caused during culvert calculations as the size of the culvert is completely dependent on the flow of water and not the speed and impact. Along with this is the lack of geological consideration taken into account.

Talked about how the NES doesn't have room for much discretion and because of this, tends to over-engineer culverts because of lack of confidence in this domain and doesn't want to be taken to court.

The nature of the spreadsheet inputs, which is centred around settling on coefficients that are accurate enough to represent the entirety of the catchment.

There was also concern raised about if the culvert would withstand flows after the woodlot had been harvested as the ground coefficient would change. Stated that if it's a huge difference you use bareland coefficient for the initial culvert but if difference is insignificant then you can keep the designed culvert for a forested area.

The final concern was that through the use of battery culverts, there is no consideration of the additional friction from the battery.

Being confident about flow calculations. Judges calculations on other infrastructure nearby, from other companies. Looks for signs of overtopping if the culvert has been in that position for a long amount of time. Then does the calculations by himself to see if flow was adequate, considering it has already been done by someone else. Also the only person to express their concern about springs contributing to the river which isn't considered by either method.

Said that the culvert designing process is always done on at their desk which makes assessment of the catchment more difficult. Mentioned that the time of concentration is the hardest to obtain as inspection is not undergone. Also said that because they usually deal with small woodlots, often finds that the time of concentration is lower than 10 minutes which is not displayed on the NIWA HIRDS website and there must interpolate further to obtain value.

Stated that determining the crossing type was the most difficult aspect of the design. More specifically which type of culvert is the most suitable for the crossing i.e. pipe or box culvert or bridge construction which would seek proper engineering consultation.

11.2 Catchment Locations

Location	No.	Southing	Easting	Location	No.	Southing	Easting
Akaroa	1	43 38 18	172 56 49	Glasnevin	26	43 7 51.48	172 48 39.5
Hickory Bay	2	43 46 40.34	173 5 58.05	Macdonald Downs	27	43 3 37.64	172 34 3.09
Hickory Bay	3	43 46 57.76	173 4 27.29	Macdonald Downs	28	43 3 16.14	172 33 19.95
Hickory Bay	4	43 47 2.22	173 3 55.82	Mount Culverden	29	42 39 22.20	172 47 39.92
Hickory Bay	5	43 47 32.43	173 03 39.03	Middle Valley	30	44 4 16.65	171 1 47.43
Halswell	6	43 36 7.51	172 36 28.01	Pleasant Valley	31	44 6 4.53	171 6 32.14
Cashmere	7	43 35 19.65	172 37 45.63	Waihaorunga	32	44 42 9.88	170 51 29.82
Coopers Creek	8	43 15 45.58	172 5 36.53	Waimate	33	44 45 28.32	170 59 24.23
Oxford	9	43 14 52.93	172 11 27.79	Broomfield	34	43 9 8.85	172 33 4.79
Glentui	10	43 13 25.3	172 14 29.77	Weka Pass	35	42 59 49.65	172 45 27.89
Pleasant Valley	11	44 02 19.01	171 04 8.12	Cheviot	36	42 51 33.28	173 17 25.23
Peel Forest	12	43 41 44.49	172 46 28.51	Spotswood	37	42 45 12.9	173 22 0.77
Conway Flat	13	42 39 16.19	173 24 45.59	Teviotdale	38	43 3 25.23	173 0 49
Stag and Spey	14	42 29 23.53	173 21 6.17	Teviotdale	39	43 1 28.35	173 1 28.23
Peketa	15	42 26 56.21	173 29 36.99	Teviotdale	40	42 59 53.77	173 5 14.37
Hundalee	16	42 35 19.26	173 24 10.57	Greta Valley	41	42 56 14.69	173 0 29.47
Hundalee	17	42 34 31.18	173 22 48.13	Scargill	42	42 54 11.62	172 57 33.41
Spotswood	18	42 41 15.15	173 12 06.85	Lowry Hills Range	43	42 51 42.6	173 0 42.94
Hawkswood	19	42 41 20.53	173 21 8.73	Okuku Range	44	43 6 6.14	172 25 59.42
Marsden	20	42 34 37.13	171 12 39.31	Okuku Range	45	43 4 41.72	172 26 18.06
South Beach	21	42 30 32.1	171 15 21.44	Okuku Range	46	43 5 47.41	172 27 13.8
Paroa	22	42 30 31.16	171 13 38.91	Okuku Range	47	43 4 32.62	172 28 11.39
Dunganville	23	42 33 0.68	171 19 35.91	Okuku Range	48	43 7 1.98	172 29 27.05
Peketa	24	42 25 2.88	173 35 8.58	Okuku Range	49	43 8 17.28	172 26 16.33
Glasnevin	25	43 6 23.64	172 47 49.87	Okuku Range	50	43 8 15.15	172 27 30.92

11.3 Raw Data

*Highlighted boxes contain values that were too small for interpolation.

Area (km^2)	Direct Path (m)	River Path (m)	Average Slope	W_{IC}	W_S	W	C	T_C (min)	Design Rainfall (mm)	Standard Rainfall (mm)	R	K	Shape Factor	TM61 Q (m^3/s)	C	Rainfall Intensity (mm/hr)	Rational Q (m^3/s)
2.61	3735	3685	0.11	1	69	69	1950	25.1	11.7	52.5	0.22	0.19	0.57	7.1	0.5	28.4	10.2
9.71	6302	7070	0.09	1.05	80	84	2900	45.1	19.1	67.5	0.28	0.24	0.71	44.4	0.5	26.7	35.7
6.82	4270	4567	0.12	1.05	75	78.8	2400	29.0	15.4	55	0.28	0.37	0.875	34.5	0.5	30.7	28.9
5.1	3560	3778	0.14	1.05	71	74.6	2300	23.6	12.3	52	0.24	0.40	0.9	23.1	0.5	36.8	25.9
2.46	1896	1956	0.20	1.05	67	70.4	2000	12.4	8.7	40	0.22	0.68	1.14	13.5	0.5	52.0	17.7
3.82	3158	3186	0.12	0.8	65	52	1075	21.9	10.6	50	0.21	0.38	0.87	7.5	0.35	39.9	14.7
2.71	2542	3073	0.12	0.7	65	45.5	900	21.1	10.6	50	0.21	0.42	0.93	5.2	0.15	31.7	3.6
8.29	4627	5983	0.25	0.7	100	70	4000	26.8	16.4	53	0.31	0.39	0.89	74.8	0.4	40.3	36.9
0.52	1322	1698	0.23	0.85	68	57.8	1350	10.6	13.5	39	0.35	0.30	0.79	3.1	0.45	80.8	5.2
0.77	1369	1427	0.30	0.7	69	48.3	920	8.4	12.0	37	0.32	0.41	0.92	3.1	0.4	58.8	5.0
0.71	1105	1191	0.28	0.7	62	43.4	760	7.4	10.9	36	0.30	0.58	1.09	2.7	0.4	65.4	5.1
2	2502	2651	0.21	0.7	75	52.5	1200	15.5	15.0	43	0.35	0.32	0.8	7.8	0.3	49.0	8.1
2.1	2417	2627	0.15	0.9	60	54	1400	17.5	14.8	46	0.32	0.36	0.85	9.28	0.3	44.3	7.7
0.99	1434	1579	0.07	0.75	44	33	430	15.4	13.2	43	0.31	0.48	0.99	1.8	0.2	55.5	3.0
1.68	1652	2137	0.33	0.7	80	56	1300	10.9	9.7	38	0.26	0.62	1.1	7.5	0.4	48.7	9.0
1.89	1900	2400	0.17	0.8	65	52	1050	15.5	13.1	45	0.29	0.52	1.03	7.1	0.35	55.9	10.2
3	2448	2830	0.15	0.7	69	48.3	930	18.4	15.3	46	0.33	0.50	1	9.8	0.3	45.9	11.4
1.39	1413	1726	0.25	0.95	67	63.7	1900	10.4	9.6	37	0.26	0.70	1.14	10.0	0.5	57.7	11.1
0.19	832	883	0.31	1	57	57	1370	5.7	10.2	37	0.28	0.27	0.74	1.1	0.5	61.3	1.6
0.42	1683	1781	0.09	0.7	50	35	500	15.5	24.1	45	0.53	0.15	0.44	0.9	0.25	102.0	3.0
0.32	1123	1500	0.17	0.7	57	39.9	650	10.8	19.8	39	0.51	0.25	0.7	1.4	0.3	86.0	2.3
0.83	1803	1946	0.16	0.7	60	42	710	13.3	23.5	41	0.57	0.26	0.7	3.4	0.3	99.5	6.8
0.27	766	833	0.14	0.7	44	30.8	390	7.3	15.8	36	0.44	0.46	0.98	0.9	0.3	111.0	2.5
0.43	866	902	0.06	0.8	15	12	100	10.9	10.9	39	0.28	0.57	1.09	0.2	0.25	65.1	1.9
0.57	1162	1591	0.10	0.95	22	20.9	175	13.7	10.3	41	0.25	0.42	0.92	0.4	0.25	43.8	1.7

Area (km²)	Direct Path (m)	River Path (m)	Average Slope	W_{IC}	W_S	W	C	T_C (min)	Design Rainfall (mm)	Standard Rainfall (mm)	R	K	Shape Factor	TM61 Q (m³/s)	C	Rainfall Intensity (mm/hr)	Rational Q (m³/s)
1.29	2201	2308	0.14	0.7	57	39.9	700	16.0	10.2	43	0.24	0.27	0.74	2.1	0.3	35.4	3.8
0.25	926	1148	0.12	0.7	44	30.8	390	10.0	7.6	36	0.21	0.29	0.77	0.3	0.3	45.4	0.9
0.36	1011	1148	0.14	0.7	48	33.6	460	9.5	9.3	36	0.26	0.35	0.86	0.7	0.3	55.7	1.7
0.3	890	932	0.21	0.7	24	16.8	105	6.9	8.6	36	0.24	0.38	0.87	0.1	0.3	51.9	1.3
1.5	1820	2122	0.15	0.7	60	42	730	14.9	12.7	42	0.30	0.45	0.57	2.4	0.3	54.2	6.7
0.8	1220	1443	0.20	0.7	57	39.9	650	9.9	9.1	36	0.25	0.54	1.04	2.0	0.3	54.3	3.6
1.1	1509	1802	0.16	0.7	57	39.9	650	12.6	9.0	40	0.22	0.48	0.99	2.2	0.3	53.8	4.9
1.21	1891	2405	0.07	0.85	50	42.5	780	21.7	11.9	50	0.24	0.34	0.86	2.6	0.35	35.6	4.2
2.25	2915	3536	0.16	0.7	75	52.5	1150	21.2	13.5	50	0.27	0.26	0.74	5.87	0.3	40.6	7.6
3.32	2647	2917	0.10	0.85	60	51	1050	22.4	12.0	51	0.24	0.47	0.98	8.3	0.4	36.0	13.2
1.51	2268	2301	0.05	0.7	41	28.7	360	24.6	14.3	52	0.28	0.29	0.77	1.44	0.3	35.0	4.4
0.84	1385	1973	0.11	0.8	53	42.4	730	15.7	11.9	45	0.26	0.44	0.57	1.3	0.35	41.4	3.4
1.18	1884	2500	0.11	0.8	57	45.6	900	19.2	11.5	49	0.23	0.33	0.86	2.9	0.35	34.6	3.9
1.89	2238	2617	0.11	0.8	60	48	930	19.2	11.6	49	0.24	0.38	0.87	4.3	0.35	34.9	6.4
0.45	1264	1388	0.12	0.8	49	39.2	640	11.6	8.2	38	0.22	0.28	0.77	0.8	0.35	49.4	2.1
2.32	1577	2077	0.08	0.85	51	43.4	760	18.2	11.7	46	0.25	0.93	1.3	14.1	0.3	35.1	6.7
1.54	2461	3062	0.08	0.9	58	52.2	1050	25.0	13.1	52.5	0.25	0.25	0.7	3.5	0.4	32.1	5.5
1.57	1900	2060	0.08	1	48	48	930	18.8	11.9	48	0.25	0.43	0.57	2.6	0.5	35.6	7.7
1.63	1718	1916	0.13	1	55	55	1240	14.5	11.4	42	0.27	0.55	1.04	7.0	0.5	48.7	11.0
3.29	3418	3871	0.10	0.8	66	52.8	1130	27.7	16.1	54	0.30	0.28	0.77	8.8	0.35	32.3	10.3
0.76	1418	1584	0.25	0.8	68	54.4	1200	9.7	9.6	36	0.27	0.38	0.87	3.2	0.45	47.5	4.5
0.67	1860	2044	0.13	0.7	57	39.9	650	15.2	11.3	45	0.25	0.19	0.57	1.0	0.3	48.1	2.7
1.28	1561	1741	0.21	0.73	62	45.3	900	11.1	9.7	39	0.25	0.53	1.03	3.9	0.33	58.4	6.8
0.74	1288	1488	0.21	0.7	59	41.3	700	9.9	10.4	36	0.29	0.45	0.58	1.3	0.3	62.4	3.8
0.8	1706	1999	0.14	0.7	63	44.1	800	14.4	12.2	42	0.29	0.27	0.74	2.0	0.3	51.9	3.4