Standardisation of design flows for coastal catchments in New Zealand

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Contents

Executive Summary

Introduction

As one of the outputs from the Transfund Research Project *Standardisation of Design Flows and Debris Control Intake Structures*, the purpose of this report is to provide further information for the bridge and culvert designer on hydrological approaches that are appropriate to the estimation of design flows in low-lying coastal catchments.

Currently, approaches can vary a great deal between practitioners. Even when the same procedures are used, design flows can differ substantially because selecting a single parameter, such as the runoff coefficient C used in the Rational Method, can be subjective. Ideally, for Transit New Zealand to set up standard designs for their flow structures and debris control intake structures for their state highways and other roads in New Zealand, a single approach should be used where standards are based as much as possible on research relevant to New Zealand. This will enable more relevant and consistent culvert and bridge design for waterways.

Study methods

Research was undertaken in 2001-2004 for the project based on rainfall-runoff analysis of two small catchments in low-lying coastal zones in New Zealand

Two study sites were used in two distinct coastal catchments undergoing rapid residential growth. One was the Mazengarb Catchment on the Kapiti Coast, near Wellington, and the second was a series of catchments around the Papamoa Drain near Tauranga, Bay of Plenty. In each case these catchments are dominated by a mixture of coastal dune and peat swamp soils, which have been highly modified as part of modern development earthworks practice. For each of these sites a series of sub-catchments were identified which represented a range of land uses.

Methods for calculating design flows

Our research and this report describes possible methods for the calculation of design flows in smaller urban coastal catchments. Currently these catchments would typically be assessed using the Rational Method, which is a simplistic equation for calculating peak flow using rainfall intensity, catchment area and a runoff coefficient as follows:

$$Q = 0.278\ C.I.A$$

where: Q = peak flow (m^3/s)
C = runoff coefficient
I = rainfall intensity for the duration equal to the time of concentration (mm/h)
A = catchment area (ha) (NZIE 1980)

A second method, the Regional Flood Frequency Formula (RFFF), was developed in New Zealand to combine gauged runoff data from throughout the North and South Islands as one regional model. Most of the catchments used for this regionalisation were medium to large-sized inland hill catchments, and as such coastal zones were typically not well represented. Other limitations include:

- Within the model, *"small catchments (A<10 km^2) have large prediction errors for the mean annual flood and q^{100}".*
- The regional approach also *"seriously underestimates Q for urban basins".*

For these reasons the RFFF is not recommended for use for small catchments in coastal zones or any urban catchments. Also a comparison of the research results with the RFFF results will lead to substantial variation.

Alternate calculation methods

Comparisons were drawn with unit hydrograph techniques. The development of regionalised Unit Hydrograph procedures would have some substantial benefit for the culvert and bridge designer. This benefit would be greater in those areas which lack long-term historical rainfall data, such as small coastal watersheds with increased residential development.

Development in 1999 of an Auckland-based regional model for the development of unit hydrographs has shown that the Rational approach is practical, achievable and useful.

However coastal rainfall–run-off research would have to be extended by bridge and culvert designers to provide enough information for the development of a regionalised Unit Hydrograph model in these areas. The research that has been completed to date has been particularly limited by a lack of extreme events.

Suggested amendments to Bridge Manual

The hydrological section of the Transit Bridge Manual (2002 version) should be rewritten (insertions are underlined italics) as follows:

> *The following two methods replace the methods outlined in section 3 of the Austroads Waterway Design Manual (1994) …*
>
> ***Rational Method***
>
> *The Rational Method is only applicable to small catchments, because of its inability to account for the effects of catchment storage in attenuating the flood hydrograph. The recommended maximum size of the catchment to which the method should be applied is 25 km^2 in urban catchments, and between 3 and 10 km^2 for rural catchments. The Rational Method is described in "Australian Rainfall and Runoff" (AIE 2001) and the "Handbook of Hydrology" (Maidment 1992).*
>
> *NZIE coefficient charts shall be used for the definition of 'C' within the Rational Method equation (see appendix X). It should be assumed that all design events have high antecedent conditions (i.e. addition of 0.1 to the calculated coefficient as outlined in the notes of this NZIE Chart).*

Regional Method

"Flood frequency in New Zealand" (McKerchar & Perarson 1989) is a regional method suitable for all rural catchments except those in which there is snowmelt, glaciers, lake storage or ponding. It should be used for rural catchments greater than 10 km^2. The Regional Method can also be used for rural catchments between 3 km^2 and 10 km^2, but should be checked against the Rational Method, particularly in coastal zones.

Regionalised unit hydrograph-based model

While these changes to the wording of the Bridge Manual will provide greater level of consistency, a regionalised unit hydrograph-based model would be the most flexible design tool for assessing culvert and bridge waterway requirements in the long term. This approach would also allow simple analysis of modern low-impact design-based stormwater solutions.

Such a model has already been developed and calibrated for the Auckland Region, and a similar project has also been recently been completed in Kapiti. Expanding these models to cover all major urban zones may be the most practical long-term solution.

Research and monitoring

Continued research within coastal urban catchments would help to add weight to the preliminary findings of the research project, which are that coastal runoff coefficients may be overestimated for large event storms.

A continuation of monitoring programmes in the existing study catchments would be of great value, with collection of storm data over a longer period of time likely to provide 'design storm' rainfall runoff data.

Abstract

This report provides further information for the bridge and culvert designer on hydrological approaches that are appropriate to the estimation of design flows in low-lying coastal catchments.

Currently, approaches can vary a great deal between practitioners. Even when the same procedures are used, design flows can differ substantially because selecting a single parameter, such as the runoff coefficient C used in the Rational Method, can be misleading. Ideally, to set up standard designs for flow structures and debris control intake structures for state highways and other roads in New Zealand, a single approach should be used where standards are based as much as possible on research relevant to New Zealand. This will enable more relevant and consistent culvert and bridge design for waterways.

Research was undertaken in 2001-2004 based on rainfall-runoff analysis of two small catchments in low-lying coastal zones of the North Island, New Zealand, where rapid urban development is occurring, i.e. Kapiti Coast near Wellington and Papamoa near Tauranga, Bay of Plenty. Results and recommendations are presented.

1. Introduction

This document has been developed as one of the outputs from the research project commissioned by Transfund New Zealand, entitled *Standardisation of Design Flows and Debris Control Intake Structures*. The purpose of this report is to provide further information for the designers of bridges and culverts for roads in New Zealand, on appropriate hydrological approaches to the estimation of design flows in low-lying, coastal catchments.

Currently (2004), approaches can vary a great deal between practitioners. Even when the same procedures are used, design flows can differ substantially due to the ambiguity in a single parameter selection, such as the runoff coefficient 'C' in the Rational Method.

Ideally, for Transit New Zealand (the road controlling authority for state highways) to set up standard designs for their flow structures for their state highways and other roads in New Zealand, a single parameter approach should be used where standards are based on research relevant to New Zealand. If this can be achieved Transit NZ will end up with more relevant and consistent culvert and bridge design for waterways.

Research undertaken in 2001-2004 for the project has been based on rainfall-runoff analysis of several small catchments in low-lying coastal zones in New Zealand where rapid urban development is occurring. These catchments represent zones that are considered to be least represented by previous work such as the Regional Flood Frequency Formula (RFFF, McKerchar & Pearson 1989).

The report is constructed as follows:

Chapters 1 & 2	introduce the report, providing the background to the study and the intended research outcomes.
Chapter 3	provides a brief summary of the research that was undertaken as part of the project.
Chapters 4 & 5	assess the results of the research against current best practice, both for the Rational Method, and for current Unit Hydrograph approaches.
Chapter 6	provides recommendations for changes to the existing Transit Bridge Manual (2002 version), and for further research opportunities for the future.

Concurrent to this research project, a report has been compiled combining New Zealand-based experience of debris control structures with international best practice. This document, entitled *Standardisation of Debris Control Structures*, has been developed to address culvert blockage, which is another key concern for the culvert or bridge engineer. (Contact Connell Wagner Ltd for further information.)

2. Background

2.1 Introduction

Transit NZ's current requirements for the estimation of design flows refer in general to the Austroads Waterway Design Manual (1994). This said, the Transit Bridge Manual (2002 version) provides its own levels of serviceability (Table 4.4 in this report) and supersedes the Austroad's flood estimation procedures with the following instruction:

> *The following two methods replace the methods outlined in section 3 of the Austroads Waterway Design Manual (1994).*
>
> ***Rational Method***
> *The Rational Method is only applicable to small catchments, because of its inability to account for the effects of catchment storage in attenuating the flood hydrograph. The recommended maximum size of the catchment to which the method should be applied is 25 km^2 in urban catchments, and between 3 and 10 km^2 for rural catchments. The Rational Method is described in "Australian Rainfall and Runoff" (AIE 2001) and the "Handbook of Hydrology" (Maidment 1992).*
>
> ***Regional Method (RFFF)***
> *"Flood Frequency in New Zealand" is a regional method suitable for all rural catchments except those in which there is snow-melt, glaciers, lake storage or ponding. It should be used for rural catchments greater than 10 km^2, and can be used for rural catchments between 3 km^2 and 10 km^2, but should be checked against the Rational Method.*
>
> ***For catchments other than those covered by the methods above***
> *For catchments other than those covered by the methods above, the determination of design floods should be the subject of detailed hydrological investigation.*

Our research and this report relate to the calculation of design flows in the smaller urban coastal catchments. Currently these catchments would typically be assessed using the Rational Method.

Using the above Transit NZ standards however, some cases may occur where the design engineer applies the RFFF (Regional Flood Frequency Formula) to small catchments that are predominantly rural. Because the RFFF and Rational methods may be used by practitioners and road engineers, both methods will be assessed against our results.

Ignoring the inherent limitations associated with any empirical assessment of actual events, there are general limitations for both approaches depending on the quality of the given input data.

2.2 The Rational Method

The Rational Method employs a simplistic equation to calculate peak flow using rainfall intensity, catchment area and a runoff coefficient as follows:

$$Q = 0.278.C.I.A$$

where: Q = peak flow (m^3/s)
C = runoff coefficient
I = rainfall intensity for the duration equal to the time of concentration (mm/h)
A = catchment area (ha)

Table 2.1 Runoff coefficients recommended by American Society of Civil Engineers and Water Pollution Control Federation (from Maidment 1992).

Description of Area:		**Runoff Coefficients**
Business	Downtown	0.70-0.95
	Neighbourhood	0.50-0.70
Residential	Single-family	0.30-0.50
	Multi-units, detached	0.40-0.60
	Multi-units, attached	0.60-0.75
	Suburban	0.25-0.40
	Apartment	0.50-0.70
Industrial	Light	0.50-0.80
	Heavy	0.60-0.90
Parks, Cemeteries		0.10-0.25
Playgrounds		0.20-0.35
Railroad yard		0.20-0.35
Unimproved		0.10-0.30
Character of surface:		
Pavement	Asphaltic and concrete	0.70-0.95
	Brick	0.70-0.85
Roofs		0.75-0.95
Lawns, sandy soil	Flat, 2%	0.05-0.10
	Average, 2-7%	0.10-0.15
	Steep, 7%	0.15-0.20
Lawns, heavy soil	Flat, 2%	0.13-0.17
	Average, 2 to 7%	0.18-0.22
	Steep, 7%	0.25-0.35

As I and A are clearly defined by the rainfall and catchment area data, the runoff coefficient (C) is the variable that is most open to interpretation for this equation.

As suggested in the Transit *Bridge Manual*, runoff coefficients can be derived from existing sources such as the *Handbook of Hydrology* (Maidment 1992), or *Australian Rainfall and Runoff* (AIE 2001). These texts are based on international data however, and in some instances provide only relatively coarse guidelines.

An example from the *Handbook of Hydrology* is given in Table 2.1. These coefficients have been derived from US-based data which will not always match New Zealand conditions. In addition to this, the wide range of possible values (in some cases greater than a 30% variation) provide uncertainty for the engineer.

2.3 Regional Flood Frequency Formula

The RFFF was developed to combine gauged runoff data from throughout the North and South Islands as one regional model.

The majority of catchments used for this regionalisation were medium to large-sized inland hill catchments. As such, coastal zones were typically not well represented. Other limitations raised by McKerchar & Pearson (1989) in their research include:

- Within the model "small catchments ($A < 10$ km^2) have large prediction errors for the mean annual flood and q^{100}".
- The regional approach also "seriously underestimates Q for urban basins".

For these reasons the RFFF is not recommended for use for small catchments in coastal zones or any urban catchments. As such, it is expected that a comparison of the research results with the RFFF results will show a substantial variation.

2.4 Research outcomes

With the current limitations of the Transit *Bridge Manual* 2002 methodology in mind, this research was expected on its completion to allow us to;

- Assess rainfall–runoff relationships in low-lying coastal regions under a range of land use parameters.
- From the research identify representative runoff coefficients as required for the Rational Method.
- Take the outputs from this research and test it against current Transit guidelines. This includes testing the outcomes against the RFFF method for these areas.
- Assess alternative catchment characteristics as required for US Soil Conservation Service (SCS) Unit Hydrograph modelling techniques. Unit Hydrograph techniques represent an alternative approach to peak flow estimation, which may have some long-term benefit within the Transit guidelines.
- Develop the outcomes of these comparisons into an updated standard for the Transit Bridge Manual as appropriate.

3. Research summary

Two study sites were identified for this project in two distinctly different coastal catchments undergoing rapid residential growth and urbanisation in the North Island. The first was the Mazengarb Catchment on the Kapiti Coast near Wellington, and the second was a series of catchments around the Papamoa Drain near Tauranga, Bay of Plenty. In each case these catchments are dominated by a mixture of coastal dune and peat swamp soils, that tend to be highly modified as part of modern development earthworks practice.

For each of these sites a series of sub-catchments were identified that represented a range of land uses. Site diagrams showing these sub-catchments are given in Figure 3.1, and the dominant land use for each of these sub-catchments is outlined in Table 3.1.

Table 3.1 Predominant land uses in the two study sub-catchments.

Catchment	Sub-catchment	Predominant Land Use	Sub-catchment Characteristics		
			Area (ha)	Impervious (%)	Average Channel Slope (m/m)
Mazengarb	Realm Drive	General residential	5.8	44	0.012
	Rosewood	General residential	1.4	46	0.023
	Nikau	Rural	354	7	0.006
	Ratanui	Rural residential	57.9	9	0.009
Papamoa	Evans Road	General residential	27.3	34	0.0008
	Beach Road	General residential	14.4	29	0.005
	Gravatt Road	General residential	185	32	0.0009
	Pacific Cove	Rural	45.3	3	0.001

Beginning in 2002 water levels were monitored in each of the sub-catchments first for 8 to 12 months to generate adequate flow data to enable a comparison of runoff. At the same time rainfall data was collected for both catchments.

The sub-catchments were small (all less than 3.5km^2), and ranged in land use as shown in Table 3.1. After an initial attempt to measure the Beach and Gravatt Road sites separately, the two sites were measured as one catchment throughout the study.

Once the raw data had been collected for each of these sites, the research turned towards deriving runoff parameters for each sub-catchment, for use in standard Rational Method calculations, and for more complex Unit Hydrograph-based procedures.

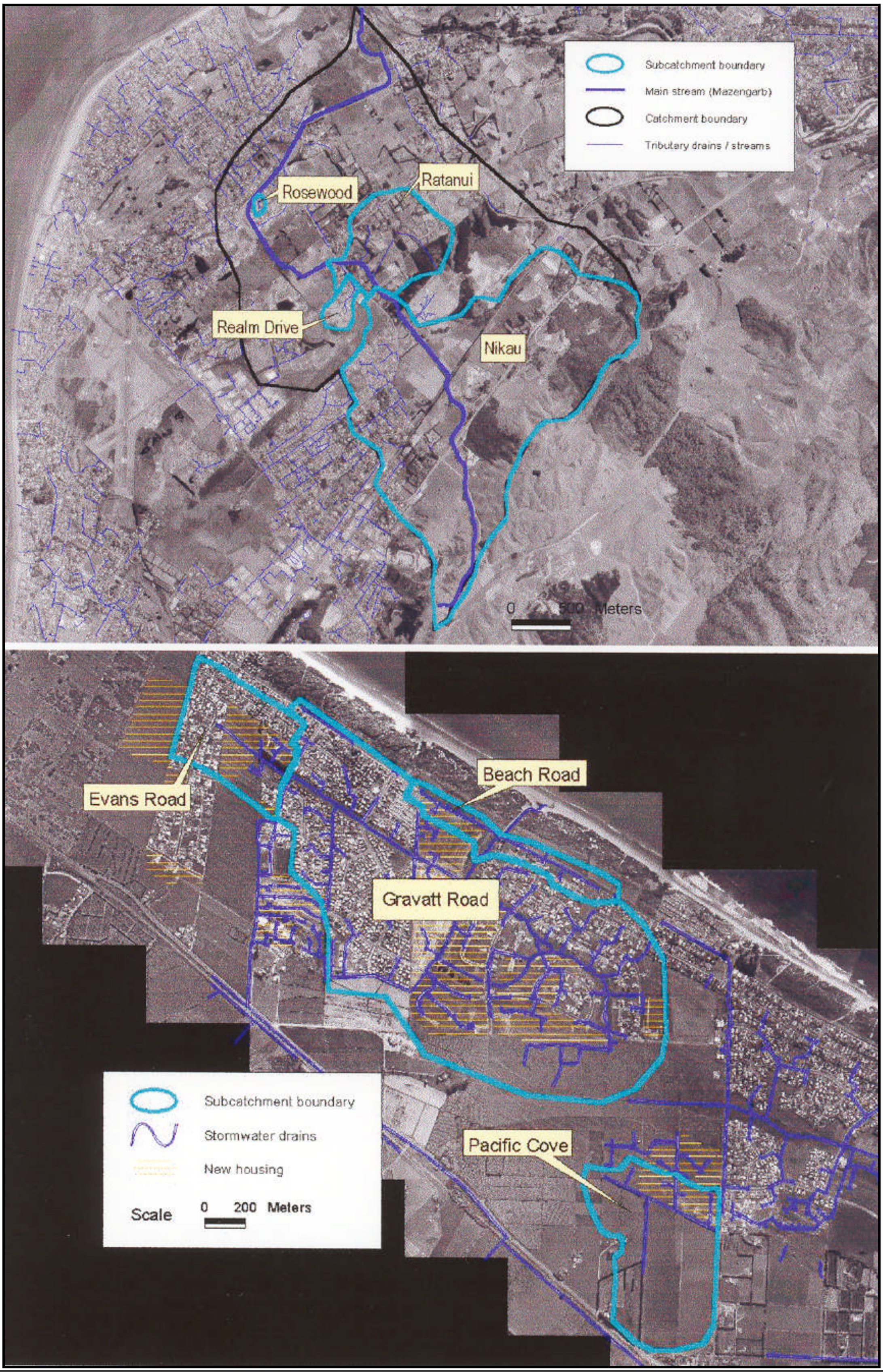

Figure 3.1 Study sub-catchments in the Mazengarb catchment, Kapiti Coast (above), and Papamoa catchment (below), near Tauranga, North Island, New Zealand.

4. Rational Method rainfall–runoff analysis

4.1 Previous work

There is a plethora of available information on different approaches to the application of the Rational Method runoff coefficient. In most cases such coefficient tables do not improve on general values such as those outlined in Table 2.1 (p.13). Some approaches do go further however, by attempting to incorporate catchment characteristics into the coefficient weighting.

Turner (1960) developed a chart (Table 4.1) that introduces rainfall intensity, relief, surface storage, and infiltration into the equation as well as the traditional land use function.

Table 4.1 Estimation of the Runoff Coefficient C for use with the Rational Method (Turner 1960).

Catchment Characteristics	Runoff-Producing Characteristics			
Rainfall Intensity	(0.15) 25-30 mm/hour	(0.10) 13-25 mm/hour	(0.05) 13 mm/hour	(0) Below 13 mm/hour
Relief	(0.10) Steep rugged country with average slopes above 20%	(0.05) Hilly with average slopes of 10-20%	(0) Rolling with average slopes of 5-10%	(0) Relatively flat with average slopes of 0-5%
Surface retention, stream and surface storage	(0.25) Negligible; few surface depressions, watercourses steep with thin film of overland flow	(0.15) Well defined system of small watercourses	(0.10) Considerable surface depressions; overland flow is significant; some farm ponds and swamps; some contour banks and furrows	(0.05) Poorly defined meandering stream course; large surface storage; water and soil conservation plan on 90% of catchment
Infiltration	(0.25) No effective soil cover; either solid rock or thin mantle of negligible infiltration capacity	(0.20) Slow water infiltration; e.g. solodic soils when surface sealed or saturated	(0.15) Loam soils or well structured clay soils, e.g. krasnozems	(0.10) Deep sands or well aggregated soil, e.g. chernozems
Cover	(0.30) No effective plant cover	(0.20) Sheet eroded native pasture; less than 10% of area under good native or improved pasture; clean cultivated crops	(0.15) Above 50% of area with improved cover; not more than 50% cultivation; open woodlands	(0.05) Above 90% of area with improved pastures; dry scherophyll-type forest

1. The procedure for estimate C is:
   (a) For each of the five listed catchment characteristics, select or interpolate a value representative of the catchment from the values in the brackets.
   (b) Sum the five values.
2. Reduce C by 10% to allow for interception in thick forest.

These charts were tested as part of a previous research project (Martell 1996) and were found to provide a good match for rural pasture, scrub and forest catchments in the Wellington Region. Davidson Ayson (1996) suggested that the Turner charts were developed for rural catchments and therefore have only limited applicability in urban catchments.

A comprehensive set of charts that incorporate urban runoff coefficients has been developed by the New Zealand Institute of Engineers (NZIE 1980) as shown in Table 4.2.

Table 4.2 Guideline and procedures for hydrological design of urban stormwater systems (NZIE 1980).

This publication was produced with the aim of achieving acceptance on a national basis and providing a better understanding by practitioners of the use of the Formula for Flood Flow Estimation. The working party which produced the document included representatives from Consulting Engineers, Municipalities, MWD (Water and Soil Division), University of Auckland (School of Engineering), and the Auckland Regional Water Board. It provides a guide for selection of runoff coefficients.

Natural Surface Types	***C***
Bare impermeable clay with no interception channels or runoff control	0.7
*Bare uncultivated soil of medium soakage	0.6
Heavy Clay soil types:	
Pasture and grass cover	0.4
Bush and scrub cover	0.35
Cultivated	0.3
Medium Soakage soil types:	
Pasture and grass cover	0.3
Bush and scrub cover	0.15
Cultivated	0.2
High soakage gravel, sandy and volcanic soil types:	
Pasture and grass cover	0.2
Bush and scrub cover	0.15
Cultivated	0.1
*Parks, playgrounds and reserves – mainly grassed	0.3
*Parks, playgrounds and reserves – predominantly bush	0.25
*Gardens, lawns, etc.	0.25
Pumice unconsolidated or similarly very permeable surfaces	0.1
Other Surface Types	***'C'***
Iron and non-absorbent roof surfaces	0.9
Asphalt and concrete paved surfaces	0.85
Near flat and slightly absorbent roof surfaces	0.8
Stone, brick and precast concrete paving panels – with sealed joints	0.8
Stone, brick and precast concrete paving panels – with open joints	0.6
Unsealed roads	0.5
Railway and unsealed yards and similar surfaces	0.35

*See Note 3 below:

These values apply for antecedent conditions that have left the surface wet but not necessarily saturated. If *extreme* conditions are to be checked (while not necessarily being the basis for design of a drainage system) then these values may need to be increased by 0.1, bearing in mind that less frequent, high intensity, storms can have less chance to infiltrate and hence require a higher coefficient.

Although lower runoff occurs in undeveloped shingle and sand country, it should be noted that development can easily reduce the ground's natural ability to absorb water. Also, small quantities of silt can reduce the permeability of sandy areas substantially. Furthermore, after periods of rain, ground water levels can be at the surface so that no further soakage can take place.

All values marked with an asterisk should be adjusted for soil types different from the 'average'. It is suggested that, for light and sandy permeable soils, C can be reduced by about 0.05. For heavy clay soils the value of C should be increased by about 0.05.

The above values assume an 'average' sloping terrain of 5%-10% (i.e. gently rolling). However, if the terrain is flatter or steeper this will have the effect of slowing down or speeding up overland flow and hence it will reduce or increase the value of C. It is thus recommended that, for all natural ground surfaces, slope adjustment should be made to the value of C, as set out below to allow for the slope.

Ground Slope	Adjustment to C
0 – 5%	-0.05
5-10%	0
10 – 20%	+0.05
20% or steeper	+0.10

Like the Turner charts the NZIE approach allows for extreme events (based on antecedent wetness as opposed to rainfall intensity), soil and slope type. Unlike the Turner charts, the NZIE guidelines were specifically designed for use on urban *and* rural catchments, which make them more flexible for the design hydrologist or engineer.

Importantly these charts were also developed in New Zealand, by a working group of consulting engineers, municipalities, the Auckland Regional Water Board, Ministry of Works, and the University of Auckland. In compiling the document every reasonable effort was made to *"circulate drafts and to obtain comment and assistance from groups and individuals actively involved in the field of urban stormwater design, including those setting standards for flood protection…."* (NZIE 1980).

As such the NZIE charts could be considered as a 'best practice' document for this country and it is of note that they are included, albeit in a slightly altered form, in the country's Building Industry Authority (1995) *New Zealand Building Code E1: Surface Water*.

4.2 Research project

As stated in the Acknowledgments, a research project was undertaken as a Masters thesis out of Victoria University of Wellington. This project assessed seven separate catchments for rainfall runoff responses. Four of the sub-catchments were on the Kapiti Coast near Wellington, and three at Papamoa Beach, near Tauranga. Both these regions are currently experiencing substantial growth, and therefore providing opportunities for both developed and undeveloped catchments to be assessed.

4.2.1 Research results

The results of the research showed that:

- A good correlation of results was achieved between median and maximum runoff coefficients for the coastal sites in Papamoa and Kapiti.
- A good correlation of results was achieved between increased impervious cover (i.e. increased urbanisation) and higher runoff coefficients.
- In most cases runoff coefficients increased relative to total rainfall, but not to rainfall intensity.
- A range of runoff coefficients were recorded at each site, and this highlighted the problems (i.e. choosing a single runoff coefficient when in reality it varies with rainfall depth) with the Rational Method approach (Watts 2002).

Median and maximum runoff coefficients from this research project are given in Table 4.3.

Table 4.3 Runoff Coefficients calculated for each sub-catchment.

Predominant Land Use	Sub-catchment	Catchment	Median Runoff Coefficient	Maximum Runoff Coefficient
General Residential	Realm Drive	Mazengarb	0.23	0.30
	Rosewood	Mazengarb	0.21	0.54
	Evans Road	Papamoa	0.21	0.27
	Beach Road	Papamoa	0.18	0.36
Rural Residential / Rural	Nikau	Mazengarb	0.05	0.11
	Ratanui	Mazengarb	0.06	0.14
	Pacific Cove	Papamoa	0.08	0.16

These results give median coefficient values from 0.18 to 0.23 for general residential catchments, and from 0.05 to 0.08 for rural and rural residential catchments. Maximum coefficients recorded were in the order of 0.30 to 0.54 for general residential, and 0.11 to 0.16 for rural and rural residential.

4.2.2 Rainfall frequency analysis

A strong correlation between rainfall depth and corresponding runoff coefficients was identified by the research project. Key design criteria used by Transit, in terms of event magnitude, have been defined with a minimum 10-year annual recurrence interval (ARI) as outlined in Table 4.4.

If probability analyses of the rainfall for each of these sites show substantially lower return period depths than the required design criteria, it could be argued that flows would be underestimated for Transit NZ’s purposes, which is to build bridges and culverts for roads.

Table 4.4 Level of serviceability to traffic using a road.

Vehicle Route Importance Category	Design Flood to be passed without interruption to traffic
Routes carrying more than 2500 vpd Routes carrying or crossing motorways or railways State Highways No. 1, 2, 3, 3A, 4, 5, 6, 8 & 8A	100 year ARI
Routes carrying between 250 and 2500 vpd State Highways if not in Category 1	50 year ARI
Routes carrying less than 250 vpd Non-permanent bridges	10 year ARI

ARI – Annual Recurrence Interval; vpd – vehicles per day

In order to understand the magnitude of the events recorded through the research period, rainfall frequency analysis of the collected data was undertaken for Paraparaumu and Papamoa. The analysis of the **rainfall** data that was collected in this research does not directly relate to design **runoff** probabilities. With a lack of any related flow record for these catchments, the assumption has been made that a direct relationship exists between the two.

Paraparaumu Rainfall Data

Table 4.5 shows the depth-duration-frequency data for the raingauge at Paraparaumu Aerodrome (2002 rainfall data, obtained from Greater Wellington Regional Council). This is the closest raingauge to the Mazengarb catchment having with a long record. To determine the return period of the events used in the runoff modelling (Watts 2002), the data from the Paraparaumu Aerodrome were used. Table 4.6 shows the maximum rainfall depth for each duration, and the date that the rainfall occurred.

Table 4.5 Depth-duration-frequency for rainfall at Paraparaumu Aerodrome (GWRC 2002).

Return Period	Average Annual Probability	Rainfall Depth (mm) for Selected Duration (hours)						
(years)	(%)	1 h	2 h	3 h	6 h	12 h	24 h	48 h
2	50	18	23	28	37	48	60	72
5	20	24	30	35	45	61	76	90
10	10	28	34	40	52	72	90	104
20	5	31	38	44	60	84	105	118
50	2	36	43	49	76	104	129	138
100	1	40	46	52	91	122	151	155

Table 4.6 Maximum rainfall depths for selected durations at Paraparaumu Aerodrome, 2001.

Duration (hours)	1 h	2 h	3 h	6 h	12 h	24 h	48 h
Maximum depth (mm)	13	21	28	37	51	60	79
Date	13/11/01	21/11/01	21/11/01	21/11/01	21/11/01	21/11/01	21/11/01
Return Period estimated from Table 4-5	<2Y	<2Y	2Y	2Y	2-5Y	2Y	2-5Y

Comparing the tables shows that for the 3- to 48-hour design storm durations the maximum rainfall depths observed were at least a 2-year return period, and for some, the durations represented between a 2- and 5-year return period. Although the data are not shown, all other rainfall events observed during the study period were less than the 2-year return period for all durations.

Papamoa Catchment

Depth-duration-frequency data for Papamoa was obtained using HIRDS version 2.0[1] (Table 4.7), as no long-term rainfall records exist for the catchment.

Table 4.8 shows the maximum rainfall depth for each duration, and the date that the rainfall occurred. The rainfall data used for the period were taken from Tauranga District Council's raingauge at Grant Place, Tauranga.

Table 4.7 Depth-duration-frequency data for Papamoa (obtained from HIRDS V2.0).

Return Period (years)	Average Annual Probability (%)	Rainfall Depth (mm) for Selected Duration (hours)						
		1 h	2 h	3 h	6 h	12 h	24 h	48 h
2	50	26	37	45	62	79	101	125
5	20	36	49	59	82	105	134	166
10	10	42	57	69	95	122	156	194
20	5	48	65	79	108	139	177	220
50	2	57	75	91	125	160	205	254
100	1	63	83	100	138	176	226	280

Table 4.8 Maximum rainfall depth (mm) for selected durations at Papamoa, 2001.

Duration (hours)	1 h	2 h	3 h	6 h	12 h	24 h	48 h
Maximum depth (mm)	20	36	39	44	56	59	88
Date	22/11/01	22/11/01	22/11/01	18/12/01	18/12/01	18/12/01	18/12/01
Return period estimated from Table 4.7	<2Y	<2Y	<2Y	<2Y	<2Y	<2Y	<2Y

Comparing the tables shows that, for all durations, the observed maximum rainfall depths represented a less than a two-year return period.

Summary

During the study period (June to December 2001), all rainfall events monitored in Papamoa represented a less than a 2-year return period for all durations (1 to 48 hours).

In Paraparaumu, the maximum rainfall depths observed (starting on 21 November 2001) were at least a 2-year return period for the 3- to 48-hour durations, with the 48-hour duration rainfall depth being between a 2- and 5-year return period rainfall. All other events were less than the 2-year return period rainfall depth for all durations (1 to 48 hours).

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1 HIRDS – High Intensity Rainfall Data system

4.3 Discussion

Using the charts developed by Turner (1960) and the NZIE (1980), a comparative analysis of runoff coefficients can be undertaken between these procedures and the coastal zone research results. An example of this analysis has been included in Appendix A. The results of the full analysis are covered in Table 4.9.

Table 4.9 Comparative Runoff Coefficients obtained using Turner and NZIE charts, and data from the two study catchments.

Predominant Land Use	Sub-catchment	Catchment	Turner's Coefficient	NZIE Coefficient	Maximum Research Coefficient
General Residential	Realm Drive	Mazengarb	0.60	0.51	0.30
	Rosewood	Mazengarb	0.60	0.51	0.54
	Evans Road	Papamoa	0.55	0.37	0.27
	Beach Road	Papamoa	0.45	0.34	0.36
Rural Residential / Rural	Nikau	Mazengarb	0.50	0.29	0.11
	Ratanui	Mazengarb	0.40	0.21	0.14
	Pacific Cove	Papamoa	0.50	0.32	0.16

Maximum recorded research coefficients have been used for this comparison as these reflect more closely the extreme rain events that standard coefficient tables (such as those of Turner and NZIE) are used for modelling.

As shown in Table 4.9 the results of the Turner charts appear to substantially over-estimate the runoff coefficient for events of this magnitude. There are some real concerns with the assessment of urban catchments using this system as none of the terminology allows for an urban content. This leads to substantial compromise for the 'surface storage', 'infiltration', and 'cover' components of the coefficient selection process. In most cases the Turner charts appear to estimate that runoff response is up to twice that measured in the field for similar rainfall intensities.

The results of the NZIE charts differ considerably from those of Turner. Table 4.9 shows clearly that the NZIE values relate more closely to maximum values recorded in the field. The NZIE charts appear to have much greater scope for variation in values. As such, they can make better allowance for the small, flat, coastal catchments that were assessed in this research.

The use of the NZIE charts was made considerably easier by the inclusion of specific urban coefficients. As seen in Appendix A, this allowed a weighted coefficient to be developed based on the percentage of urbanisation, which would explain the greater spread in values.

In the case of the NZIE charts the additional 0.10 has not been applied to the given values to allow for high antecedent conditions. This is because the size of the events that were used to measure against, i.e. generally 1-2 year storms, would not necessarily fall into this category. We would certainly put any event in the order of a 10-year ARI, or greater, in this extreme event category.

Even using the NZIE charts however, there is still a substantial disparity between the estimated and recorded C values for the rural and rural residential catchments. In catchments where a large proportion of the catchment is flat, functions such as infiltration and storage appear to govern, overriding other factors. For example, steeper portions of the catchment would have low infiltration (as occurs in the Nikau catchment). In our opinion this is most likely to relate to the impact of natural storage in these catchments.

In both catchments, the waterways include large areas of natural attenuation in such as drainage swales, ponds, etc. In addition, a single culvert constraint in such flat country can create a substantial amount of storage on the adjacent low-lying land. In both of the studied catchments this is known to commonly occur.

Additionally, the rural residential drainage is rarely piped, or otherwise connected, directly to a watercourse. This may mean that the slightly higher imperviousness of these catchments has little real impact on peak flows.

4.4 Conclusions

The measured runoff coefficients have shown that:

- Coefficients consistently increase relative to the developed proportion (which implies impervious area) of the catchment;
- Coefficients consistently increase with rainfall depth; and
- Coefficients are relatively consistent for each land use in both coastal zones.

These results relate to only short return-period events in the order of an annual storm however.

- The NZIE approach to assessing runoff coefficients is superior to other approaches that allow for the assessment of catchment characteristics, and also is based on New Zealand experience. For the size of events that Transit NZ will wish to consider in the design of any of its structures (i.e. 10-year ARI or greater), the addition of 0.10 for high antecedent wetness should be added to all calculated *C* values.
- Some consideration can be given to reducing the calculated coefficient value in flat, rural or rural residential, coastal catchments by up to 0.10, in order to allow for substantial natural storage volumes that are inherent in such areas.
- Such a measure is not recommended however as coefficients in the order of 0.30 to 0.40 are already quite low and to reduce these further may not provide appropriate levels of conservatism required for design.

4.5 Research limitations

Statistically analysing the magnitude of a runoff hydrograph is of limited value if hydrological records are short. This is a limitation for 'short timeframe' research projects such as this present one as it requires a subjective discussion to assess the results of 'extreme events' (say 10-year return period and above), to the largely annual storms that would be expected to be recorded within the project timeframe.

In the case of this research, some events measured were closer to or above a 2-year storm, but our conclusions can only be applied to shorter return period storms, thus providing little more than guidance for the assessment of larger events.

What is encouraging however is the results recorded from the two study areas in similar terrain showed consistency. This enables the researcher to assert that the maximum recorded coefficient values are in the *order of* a 1 to 2-year event for the coastal catchments investigated.

Other key limitations relate to scientific process, such as measurement errors, which are inherent in any data collection project. Again consistency of results would suggest that this was not a significant problem within the timeframe of this project.

5. Regional Flood Frequency Formula analysis

As discussed in Section 2.1.2 of this report, while the Regional Flood Frequency Formula is an option for use in smaller rural catchments in coastal areas, it is not expected to give comparable results to informed analysis using the Rational Method.

As an example we have analysed the results (Table 5.1) from two of the larger study sub-catchments in each of the two catchments, for flows based on the Regional Flood Frequency Formula (RFFF).

Table 5.1 Analysis of flows recorded from larger catchments in Mazengarb, Kapiti, and Papamoa.

Sub-catchment	**Location**	**Size** (km^2)	**$Q_{2.33}$ Design** (m^2/s)	**Actual Peak Flows** (m^2/s) **(Q_2 rain approx.)**
Nikau Valley	Mazengarb	3.54	4.2 m^3/s	1.4
Gravatt – Beach Road	Papamoa	2.0	2.6 m^3/s	0.5

For a number of reasons, it is difficult to statistically compare the results of the gauged data with the RFFF. The RFFF-design flow-return period is based on regional runoff analysis, while the return period for the actual flows is based on analysis of rainfall data. Also rainfall collected from the Papamoa dataset did not exceed a statistical 2-year storm at any time.

Nevertheless clearly a substantial difference exists between actual coastal runoff parameters and the RFFF method results.

The sample dataset of the RFFF lacks representative coastal catchments with long flow records. Therefore RFFF estimations are less reliable in coastal zones.

6. Unit Hydrograph rainfall-runoff analysis

6.1 Introduction

An alternative to the existing Transit NZ procedures are regionalised Unit Hydrograph approaches for calculating design flows. Detailed isohyet plans have been coupled with generic Unit Hydrograph software such as HEC-HMS to develop regional models in both Auckland (ARC 1999) and Kapiti (SKM 2003).

Unit Hydrograph procedures for the development of design flows are widely accepted for use both in urban catchments and in larger rural or forested catchments. The flexibility of this approach is highlighted in *Australian Rainfall and Runoff* (AIE 2001) which identified Unit Hydrograph methods as being suitable for a wide range of outcomes including:

- Routine design of minor to medium works on small to medium sized catchments.
- Medium to important works, generally on medium to large sized catchments.
- Extreme floods for major works (in this case the unit hydrograph would often be an input to a detailed hydraulic model).
- Diversion or construction floods with short average recurrence intervals.
- Deterministic estimates for flood forecasting and filling missing records.

To these applications we would add:

- Retention and detention structures including low impact design systems such as swales, soakpits and rain gardens.

While the parameters for unit hydrograph procedures are no easier to define for specific catchments than the rational coefficient, the outputs are clearly more valuable, with a wider range of functionality.

6.2 SCS Unit Hydrograph approach

Probably one of the most widely accepted approaches to Unit Hydrograph modelling is the US Soil Conservation Services (SCS) procedure. The basis of this system is discussed extensively in Hoggan (1989). As it is a comparatively complex approach, and can be coupled with a number of different hydrograph methods, we will not attempt to discuss the detailed process as part of this document.

In general terms, the equation is controlled by initial abstraction (measured as the amount of rain that falls at the beginning of an event with no discernible runoff), the time of concentration, rainfall, and storage losses which are controlled by a curve number (CN).

Within the equation the rainfall and time of concentration are catchment-defined, and the initial abstraction can be calculated by a default function. This leaves the CN as the defining function within the equation much the same as the coefficient number for the Rational Method. CNs have been developed by the Soil Conservation Service for a variety of different land uses and soil types, in both rural and urban catchments, as outlined in Appendix B.

The four hydrologic soil groups covered in these tables are defined by rates of infiltration (Hoggan 1997) as outlined below:

- **Group A** soils have low runoff potential and high infiltration rates even when thoroughly wetted. They consist chiefly of well to excessively drained deep sands or gravels, and have a high rate of water transmission (greater than 0.30 in./h [>8 mm/h]).
- **Group B** soils have moderate infiltration rates when thoroughly wetted and consist chiefly of moderately deep to deep, moderately well drained to well drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission (0.15–0.30 in./h [4–8 mm/h]).
- **Group C** soils have low infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes downward movement of water and soils with moderately fine to fine texture. These soils have a low rate of water transmission (0.05–0.15 in./h [1–4 mm/h]).
- **Group D** soils have high runoff potential. They have very low infiltration rates when thoroughly wetted and consist chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very low rate of water transmission (0.0–0.05 in./h [0–1 mm/h]).

The ability to use this system is further enhanced by proprietary software packages that are now available for using it. This includes a freeware version that can be downloaded from the SCS website.

6.3 Regionalisation of Unit Hydrograph procedures

Because the Unit Hydrograph method has a wide range of applications, as discussed in Section 6.1, applying this method using a validated regionalised approach would be valuable to Transit NZ.

6.3.1 TP108, a New Zealand-based Unit Hydrograph regionalisation

An example of a regionally based Unit Hydrograph procedure in New Zealand is *TP108 – Guidelines for Stormwater Runoff Modelling in the Auckland Region* (ARC 1999). This document was established by the Auckland Regional Council based on, and validated against, relatively steep Auckland catchments of up to 12 km^2 in size. Region-specific CNs were developed, and the model is applicable to both rural and urban catchments.

As part of the research required for this TP108, initial abstraction defaults calculated by the SCS method were often noted to overestimate considerably this function. It was concluded that initial abstraction was consistently measured to be in the order 0 to 5 mm for the catchments studied, and that, for modelling purposes, abstraction values of 5 mm could be used for rural catchments, while 0 mm should be used in urbanised catchments.

This approach to the assessment of design runoff events is now widely used throughout the Auckland Region.

6.3.2 Research results

Assessment of appropriate coastal CNs was undertaken as part of this research project. While the results of our research appear to be limited by insufficient major events, and in particular by a lack of extreme events, consistency was achieved between the study coastal zones for events of similar magnitude.

Interestingly, in agreement with TP108, initial abstraction of CN in the research catchments was significantly lower than the default setting in the SCS model. The results of our research showed initial abstractions values ranging from 0 to 3.5 mm, and for either of the two catchments with more than 40% impervious area, this initial abstraction never exceeded 1 mm.

These results match well with the experience of the Auckland research and suggest that, if this technique is to be used, initial abstraction should be specifically entered into the calculation as opposed to relying on the default.

6.4 Conclusions

- Clearly the development of regionalised Unit Hydrograph procedures would have some substantial benefit for the culvert and bridge designer. This benefit would be greater in those areas that are not well represented by the RFFF.
- Development in 1999 of an Auckland-based regional model for the development of Unit Hydrographs has shown that the Unit Hydrograph approach is practical, achievable, and useful.
- Coastal rainfall–runoff research would have to be extended to provide adequate information for the development of a regionalised Unit Hydrograph model in these areas. The research that has been completed to date appears to be particularly limited by a lack of extreme events.
- The completed research has confirmed the findings of TP108 in that default initial abstraction within the SCS model does not relate well to small rural and/or urban catchments in New Zealand.

7. Recommendations

The following recommendations are made from this research.

7.1 Amendments to Bridge Manual

The hydrological section of the Transit Bridge Manual should be rewritten (new material is underlined italics) as follows:

> *The following two methods replace the methods outlined in section 3 of the Austroads Waterway Design Manual (1994).*
>
> ***Rational Method***
> *The Rational Method is only applicable to small catchments, because of its inability to account for the effects of catchment storage in attenuating the flood hydrograph. The recommended maximum size of the catchment to which the method should be applied is 25 km^2 in urban catchments, and between 3 and 10 km^2 for rural catchments. The Rational Method is described in "Australian Rainfall and Runoff"* [AIE 2001] *and the "Handbook of Hydrology"* [Maidment 1992]*.*
>
> *NZIE coefficient charts shall be used for the definition of 'C' within the Rational Method equation (see appendix X). It should be assumed that all events have high antecedent conditions (i.e. addition of 0.1 to the calculated coefficient as outlined in the notes of this NZIE chart).*
>
> ***Regional Method***
> *Flood Frequency in New Zealand"* [McKerchar & Pearson 1989] *is a regional method suitable for all rural catchments except those in which there is snow-melt, glaciers, lake storage or ponding. It should be used for rural catchments greater than 10 km^2. The Regional method can also be used for rural catchments between 3 km^2 and 10 km^2, but should be checked against the Rational Method, particularly in/for coastal zones.*

7.2 A Regionalised Unit Hydrograph-based Model

While these changes to the wording of the Transit *Bridge Manual* (2002 version) will provide a greater level of consistency, a regionalised Unit Hydrograph-based model would be the most flexible design tool for assessing designs for culverts and bridges for waterway requirements in the long term. This approach would also allow for the simple analysis of numerous modern low-impact design-based stormwater solutions.

Such a model has already been developed and calibrated for the Auckland Region, and a similar project (SKM 2003) has also been completed in Kapiti. Expanding these models to cover all major urban zones may be the most practical long-term solution.

7.3 Research and monitoring

Continued research within coastal urban catchments would help to add weight to the preliminary findings of the research project that coastal runoff coefficients may be overestimated in large event storms. A continuation of monitoring programmes in the existing study catchments would be of great value, with collection of storm data over a longer period of time likely to provide 'design storm' rainfall runoff data.

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Appendix A Marked example of comparative coefficient calculations

Using the charts developed by Turner (1960) and the NZIE (1980), a comparative analysis of runoff coefficients can be undertaken between these procedures and the coastal zone research results.

Mazengarb catchment, Paraparaumu

General Residential:

Both the Realm Drive and the Rosewood sub-catchments in the Mazengarb catchment are based fully on dune sand. In both cases sand will have been compacted in the development process to provide sound building platforms. These subdivisions are typically very flat although Realm Drive is a rare exception. Despite compaction, the soils are usually moderately to well drained. Taking the highest hourly rainfall recorded in the Paraparaumu area during the duration of the project, using Turner's charts (see Table 4.1) would give a runoff coefficient as follows:

Component	Coefficient
Rainfall intensity @ 13 mm/h	0.05
Rolling to flat terrain	0
Surface storage retention: average in previous areas and negligible on roads, etc.	0.15
Infiltration: again a mixed response as above	0.20
Cover: difficult to assess using Turner charts	Say 0.20
	0.60

The NZIE charts (see Table 4.2) if applied to the same area would give the following results:

NZIE Approach		Weighted Average
65%	High soakage gardens, etc. at 0.2	0.13
45%	Impervious surfaces at 0.85	0.38
		0.51

For an extreme event storm, 0.10 could be added to this weighted average. As no large events were recorded, i.e. nothing above Q10, this requirement has been avoided.

Appendix B SCS curve numbers

Table B-1 Runoff curve numbers (CN) for urban areas[2] (SCS 1986).

Cover Description	Average % impervious area[3]	Curve numbers for hydrologic soil group			
Cover type and hydrologic condition		**A**	**B**	**C**	**D**
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, gold courses, cemeteries etc.)[4]					
Poor condition (grass cover <50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover >75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding R-o-W)		98	98	98	98
Streets and roads:					
Paved; curbs and storm sewers (excluding right-of-way)		98	98	98	98
Paved; open ditches (including right-of-way		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way		72	82	87	89
Western desert urban areas:					
Natural desert landscaping (pervious areas only)[5]		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)		96	96	96	96
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:					
1/8 acre or less (town houses)	85	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
Developing urban areas					
Newly graded areas (pervious areas only, no vegetation)[6]		77	86	91	94
Idle lands (CNs are determined using cover types similar to those in Table 2-2c)					

[2] Average runoff condition, and Ia = 0.2S.

[3] The average % impervious area shown was used to develop the composite CNs. Other assumptions are as follows: Impervious areas are directly connected to the drainage system, impervious areas have a CN of 98, and pervious areas are considered equivalent to open space in good hydrologic condition. CNs for other combinations of conditions may be computed using Figure 2-3 or 2-4 in manual.

[4] CNs shown are equivalent to those of pasture. Composite CNs may be computed for other combinations of open space cover type.

[5] Composite CNs for natural desert landscaping should be computed using Figures 2-3 or 2-4 in manual based on the impervious area percentage (CN = 98) and the pervious area CN. The pervious area CNs are assumed equivalent to desert shrub in poor hydrologic condition.

[6] Composite CNs to use for the design of temporary measures during grading and construction should be computed using Figures 2-3 and 2-4 in manual, based on the degree of development (impervious area percentage) and the CNs for the newly graded pervious areas.

Table B-2 Runoff curve numbers (CN) for cultivated agricultural lands in the US[7] (SCS 1986).

Cover Description			CN for hydrologic soil group			
Cover type	**Treatment**[8]	**Hydrologic condition**[9]	**A**	**B**	**C**	**D**
Fallow	Bare soil		77	86	91	94
	Crop residue cover (CR)	Poor	76	85	90	93
		Good	74	83	88	90
Row crops	Straight row (SR)	Poor	72	81	88	91
		Good	67	78	85	89
	SR + CR	Poor	71	80	87	90
		Good	64	75	82	85
	Contoured (C)	Poor	70	79	84	88
		Good	65	75	82	86
	C + CR	Poor	69	78	83	87
		Good	64	74	81	85
	Contoured & terraced (C&T)	Poor	66	74	80	82
		Good	62	71	78	81
	C&T + CR	Poor	65	73	79	81
		Good	61	70	77	80
Small grain	SR	Poor	65	76	84	88
		Good	63	75	83	87
	SR + CR	Poor	64	75	83	86
		Good	60	72	80	84
	C	Poor	63	74	82	85
		Good	61	73	81	84
	C + CR	Poor	62	73	81	84
		Good	60	72	80	83
	C&T	Poor	61	72	79	82
		Good	59	70	78	81
	C&T + CR	Poor	60	71	78	81
		Good	58	69	77	80
Close-seeded, or	SR	Poor	66	77	85	89
Broadcast		Good	58	72	81	85
Legumes, or	C	Poor	64	75	83	85
Rotation Meadow		Good	55	69	78	83
	C&T	Poor	63	73	80	83
		Good	51	67	76	80

C Contoured CR Crop residue cover C&T Contoured & terraced SR Straight row

7 Average runoff condition, and Ia = 0.2S.

8 *Crop residue cover* applies only if residue is on at least 5% of the surface throughout the year.

9 Hydrologic condition is based on combination of factors that affect infiltration and runoff, including (a) density and canopy of vegetative areas, (b) amount of year-round cover, (c) amount of grass or close-seeded legumes in rotations, (d) % residue cover on the land surface (good ≥ 20%), and (e) degree of surface roughness.
Poor: Factors impair infiltration and tend to increase runoff.
Good: Factors encourage average and better than average infiltration and tend to decrease runoff.

Table B-3 Runoff curve numbers (CN) for other agricultural lands in the US[10] (SCS 1986).

Cover Description		Curve numbers for hydrologic soil group			
Cover Type	**Hydrologic Condition**	**A**	**B**	**C**	**D**
Pasture, grassland, or range-continuous forage for Grazing[11]	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Meadow-continuous grass, protected from grazing and generally mowed for hay		30	58	71	78
Brush-brush-weed-grass mixture with brush the major element[12]	Poor	48	67	77	83
	Fair	35	56	70	77
	Good	[13]30	48	65	73
Woods-grass combination (orchard or tree farm)[14]	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods[15]	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	[4]30	55	70	77
Farmsteads-buildings, lanes, driveways, and surrounding lot		59	74	82	86

10 Average runoff condition, and Ia = 0.2S.

11 *Poor:* 0% ground cover or heavily grazed with no mulch.
Fair: 50 to 75% ground cover and not heavily grazed.
Good: >75% ground cover and lightly or only occasionally grazed.

12 *Poor:* 50% ground cover.
Fair: 50 to 75% ground cover.
Good: >75% ground cover.

13 Actual CN is less than 20; use CN = 30 for runoff computations.

14 CNs shown were computed for areas with 50% woods and 50% grass (pasture) cover. Other combinations of conditions may be computed from the CNs for woods and pasture.

15 *Poor:* Forest litter, small trees, and brush are destroyed by heavy grazing or regular burning.
Fair: Woods are graced but not burned, and some forest litter covers the soil.
Good: Woods are protected from grazing, and litter and brush adequately cover the soil.