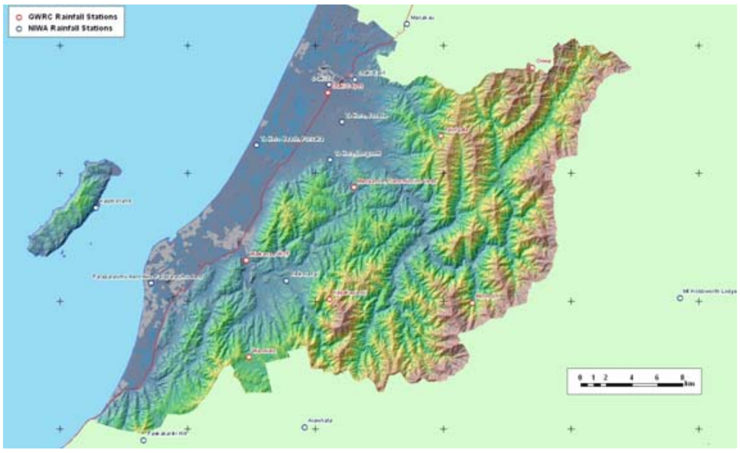
Appendix 1 - Updated Isohyet Based Calculation of Design Peakflows



UPDATED ISOHYET BASED CALCULATION OF DESIGN PEAKFLOWS

Final

1) 11 October 2011

Updated Isohyet Based Calculation of Design Peakflows

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11 October 2011

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Introduction

As part of Kāpiti Coast District Council's subdivisional and development requirements, Sinclair Knight Merz have been engaged by the Council to prepare a standard for the calculation of stormwater design flows on the Kāpiti Coast.

This report is an update of the 2003 Sinclair Knight Merz report titled "*Isohyet Based Calculation of Design Peakflows"*. While the methodology remains unchanged this update includes the revised isohyets plans that were developed in the report "*Update of Kāpiti Coast Hydrometric Analysis*, 2008, SKM".

These plans incorporate the predicted impacts of climate change into the Kāpiti Coast hydrometric analysis. The predicted 2090 mid-range temperature scenario was used to estimate the climate change rainfall growth factor to 2090. This growth factor was used to produce a second set of isohyet maps. In 2008 the predicted effects of climate change on the Kāpiti Coast District are an increase in rainfall by between 8 and 16% over the 2 to 100 year ARI events.

Table 1-1. Growth factor for Paraparaumu Airport rainfall based on NIWA's 2090 mid-range temperature climate change scenario.

Average Recurrence Interval (years)	2	5	10	20	50	100
2090 Climate Change Growth Factor	1.08	*1.10*	1.12	1.14	1.16	1.16

Note: The 5 year result was not included in the NIWA report, so has been interpolated from the data.

In this report the unit hydrograph based approach is modelled on the US Soil Conservation Service software HEC-1. This approach has been internationally recognised and is widely used throughout the world. Haestad's HEC-1 and HEC-HMS are unsupported 'freeware' versions available through the US Army Corps of Engineers website. Support is available to subscribers through the Bentley software provider.

These guidelines provide examples on how to produce design hydrographs using both of the aforementioned versions of the software.

Unit hydrograph modelling is widely used for the development of floodplain management plans, and has been used for this purpose in Kāpiti since the early 1990's. This method of developing runoff design flows is also being widely used throughout New Zealand and is the basis of the Auckland Regional Councils rainfall-runoff guidelines 'TP-108'.

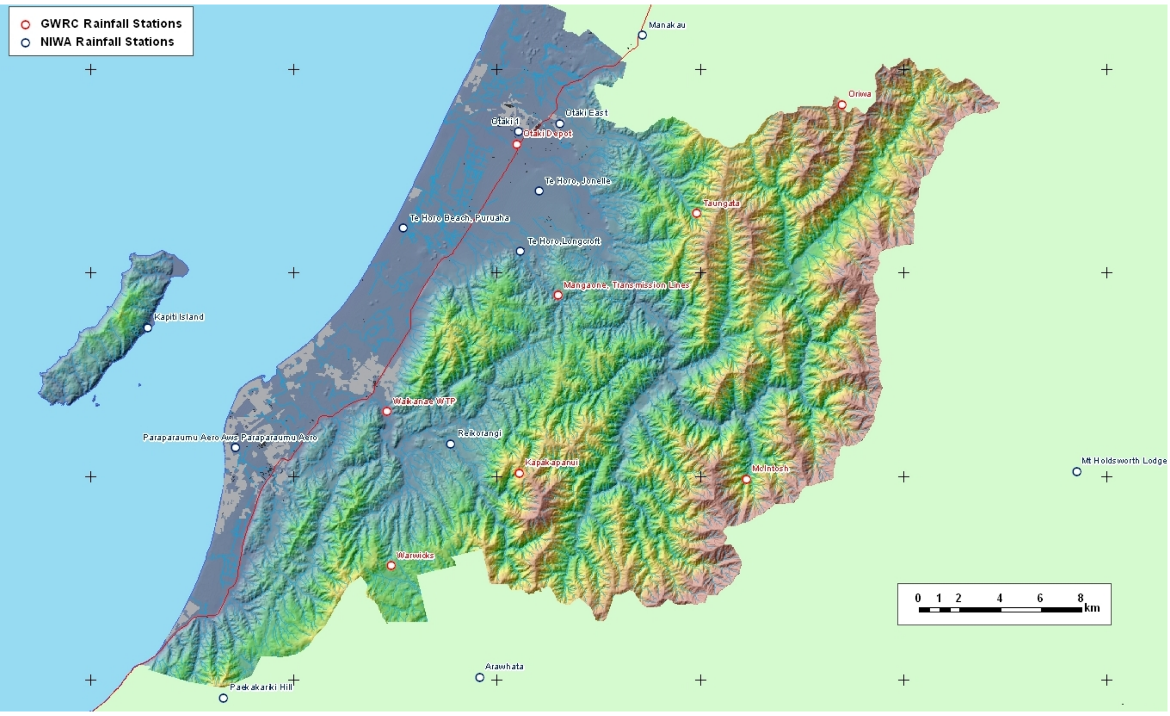
Background

24 Hour Rainfall Isohyet Plans

The intention of this report is to provide a system of assessing design storm runoff for peak flows and storage volumes to allow for consistent design of low impact structures. Design storm isohyets have been developed for the 2, 5, 10, 20, 50 and 100 year annual recurrence interval events as well as for the 2, 5, 10, 20, 50 and 100 year annual recurrence interval events assuming the 2090 mid scenario climate change predictions.

Annual maxima daily rainfall totals were extracted for 22 stations in the Kāpiti Coast region. This represents a combined total of 549 years of data. The stations that were used in the analysis are shown in Figure 2-1 below. The South Waiotauru site was excluded from the 2008 update due to consistently lower rainfall depths than other surrounding sites. Further investigation would have to be undertaken on this site before it was to be included within the study.

Figure 0-1 : Annual Maxima Rainfall Station



The methodology employed in this study for determining the frequency distribution of annual maximum storm rainfalls for the Kāpiti region involves a regional frequency analysis technique using the method of L-Moments. The approach involves identification of the most appropriate distribution for the region, followed by estimation of the regional parameters for that distribution.

The parameter estimates are used to calculate the rainfall quantiles for each locality (station) within the region.

Further discussion of this analysis is covered by the document "*Update of Kāpiti Coast Hydrometric Analysis*, 2008, SKM". A generalised logistic distribution was adopted for the Regional Analysis.

Rainfall recurrence isohyet maps have been generated for the 2, 5, 10, 20, 50 and 100 year ARI rainfall depths and for the predicted impacts of climate change, using kriging geostatistical techniques. The respective maps are appended at the rear of this report as Appendix A.

Clark Unit Hydrograph using the SCS Curve Numbers

The unit hydrograph method of flood estimation was first proposed by Sherman and has since found wide application for both design and estimation of actual floods where a hydrograph and reasonable accuracy are required (Maidment, 1992).

Unit Hydrographs are defined by the runoff resulting from uniform units of rainfall depth over an entire catchment. The difference between rainfall volumes and runoff volumes in the unit hydrograph model is expressed as losses to the system, which can relate to a variety of forms such as evapo-transpiration, and storage within vegetation, the soil, and undrained depressions.

The key components for the development of a unit hydrograph model are therefore rainfall depth relationships, rainfall losses, and catchment characteristics. Each of these items have been separately discussed through the remainder of this chapter, and are covered considerably more comprehensively in Hoggan (1996).

Rainfall Depth Relationships

A 24 hour balanced storm has been proposed for general use. A long balanced storm of this nature is commonly used for floodplain management based work and allows for storage volumes to be more accurately assessed for low impact design storage based solutions.

The balanced storm approach 'nests' high intensity rainfall events within the 24 hour storm profile. This allows for peak estimates of flow to be accurate for small catchments while also providing an appropriate assessment of larger storage volume issues.

A symmetrical distribution has been applied in this case so that the peak rainfall intensities will fall across the midpoint of the storm.

24 hour rainfall depths for any catchment can be estimated for the 2, 5, 10, 20, 50 and 100 year annual recurrence interval (ARI) events and for the predicted impacts of climate change using the

24 hour isohyets maps attached as Appendix A. For larger catchments weighted averages can be calculated, or the catchment can be split up and modelled as a series of sub-catchments.

Once 24 hour rainfall depths have been defined, these have to be converted into some form that allows a balanced storm to be developed in Graphical HEC, or HEC-HMS. For both of these software packages a normalised depth-duration-frequency relationship can be multiplied by the 24 hour total depths to provide duration-depth data. The normalised rainfall depth-duration relationship is shown in table 2-1.

Table 0-1 : Normalised Depth-Duration Relationship for 24-hour Rainfall

Duration	Normalised Rainfall Depth (I/I_{24})
5 Mins	0.08
15 Mins	0.14
1 Hour	0.26
2 Hour	0.38
3 Hour	0.46
6 Hour	0.60
12 Hour	0.81
24 Hour	1

Computed duration depths can be entered directly into Graphical HEC or HEC-HMS as a balanced storm as will be explained in chapter 3 and 4.

The normalised rainfall depth relationship has been developed using the Paraparaumu Aerodrome rainfall record. This provides the longest record of continuous (as opposed to daily read) data in the region with 48 years record.

Rainfall-Runoff Losses

One of the advantages of the SCS method of unit hydrograph modelling is that it provides a system for the delineation of rainfall losses over the period of the storm based on a catchments soil, and land-use characteristics. These curves, unlike linear losses across a storm, allow for antecedent storage to impact the shape of the storm profile. This reflects reality where greater rainfall losses would be expected through the earlier portions of the storm.

The SCS loss method is defined by the following equations; (Hoggan, 1996).

$$Q = \frac{(P - I_a)^2}{P - I_a + S}$$

$$S = \frac{1000}{CN} - 10$$

Where[1];

Q = accumulated Runoff (mm)

P = accumulated Rainfall (mm)

I_a = initial Abstraction

S = potential maximum retention after runoff begins (mm)

CN = curve number, percent of runoff

Initial Abstraction

Initial abstraction is approximated by the empirical equation $I_a = 0.2S$ as the default parameter of the SCS model. Initial abstraction has been found to be less than this in studies completed within the Kāpiti Coast however. Work completed for a Masters thesis confirmed that for storms in the order of an annual flood, I_a values fluctuated between 0 and 4mm (Watts, 2002). This corroborates the results of TP108 (Beca Carter, 1999), which suggests initial abstraction values of 5mm for pervious areas and 0mm for impervious.

Our suggestion is that for fully urbanised catchments I_a values of 0mm be used, and small rural catchments 5mm is used. No data is available for larger catchments, but this is one area where further work could be done with available data.

Delineation of Curve Numbers

Curve numbers (CN's) define the volume of storage losses for any modelled rainfall event. These values can be delineated from a standard set of runoff curve tables that were developed by the US Soil Conservation Service. These tables, (Appendix B), allow for a variety of differing land uses, including urban land, for a range of differing soil types.

As these tables allow for the analysis of a wide variety of land uses and soil types previous work completed in the Kāpiti Coast District has identified base CN values that encompass most of the soil types typically found in the region. A summary table of typical CN values (based on Connell Wagner, 2001) is as follows;

1) [1] TP-108, ARC 1999

Soil Type		Curve Number
1.	**Loose Dune Sands**	
	Assumed soil type A.	45
2.	**Gravel Silt Loams**	
	Pasture	69
	Urban Gardens*	61
	Bush	48
	Assumes soil type B. In some cases testing will show gravel soils to have higher infiltration capacities than this in which case soil type A should be assumed.	
3.	**Residential Inland Dune sands**	
	Assumes soil type B and accounts for construction compactions.	61
4.	**Greywacke Argillite Steepland Soils**	
	Pasture	79
	Urban*	74
	Bush	65

* Excludes connected impervious areas as covered in section 2.2.3.

This table is intended as guidance and should not substitute formal ground investigation in cases of uncertain soil conditions.

Catchment Characteristics

A variety of catchment characteristics need to be defined for the development of the Clarke's unit hydrograph. These include

An assessment of soils for development of the Curve Numbers covered above.

An assessment of Connected Impervious Areas.

The nature of catchment Storage.

Calculating the Time of Concentration

Soils Categories

CN tables, as covered in Appendix B, identify the substantial impact of soils properties on total runoff volumes. Soils are assessed under four categories (TP108, 1999) as follows:

Group A soils have low runoff potential and high infiltration rates even when thoroughly wetted. They consist chiefly of deep, well to excessively drained sands or gravels and have a high rate of water transmission (greater than 8mm/h).

Loose dune sands would typically fall within the Group A soil category, and well drained gravels would also fall within this category.

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 (4-8mm/h).

Inland compacted sands, less well drained gravel loams and valley based gravel loams would typically fall within this soil group.

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 (1-4mm/h).

Most of the steepland argillite, greywacke and loess based soils would fall into this category.

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 and 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 (0-1mm/h). Existing peat bogs may fall into this category.

Connected Impervious Areas

Connected impervious areas are recorded as a percentage of the residential zone that is impervious, and directly connected via formal drainage systems to the receiving waterway. A previous assessment of current land-use (Connell Wagner, 2001), gave Connected impervious values of;

Residential A – older lots 800m2 average	38% CIA
Residential B – newer lots 600m2 average	55% CIA
Residential C – retirement villages	65% CIA
Industrial	72% CIA
Commercial	85% CIA
Road Designation	36% CIA
Town Centre (Paraparaumu)	50% CIA
Educational	72% CIA
Hospital	72% CIA
Open Space/Rural Zone	0% CIA

Storage Values

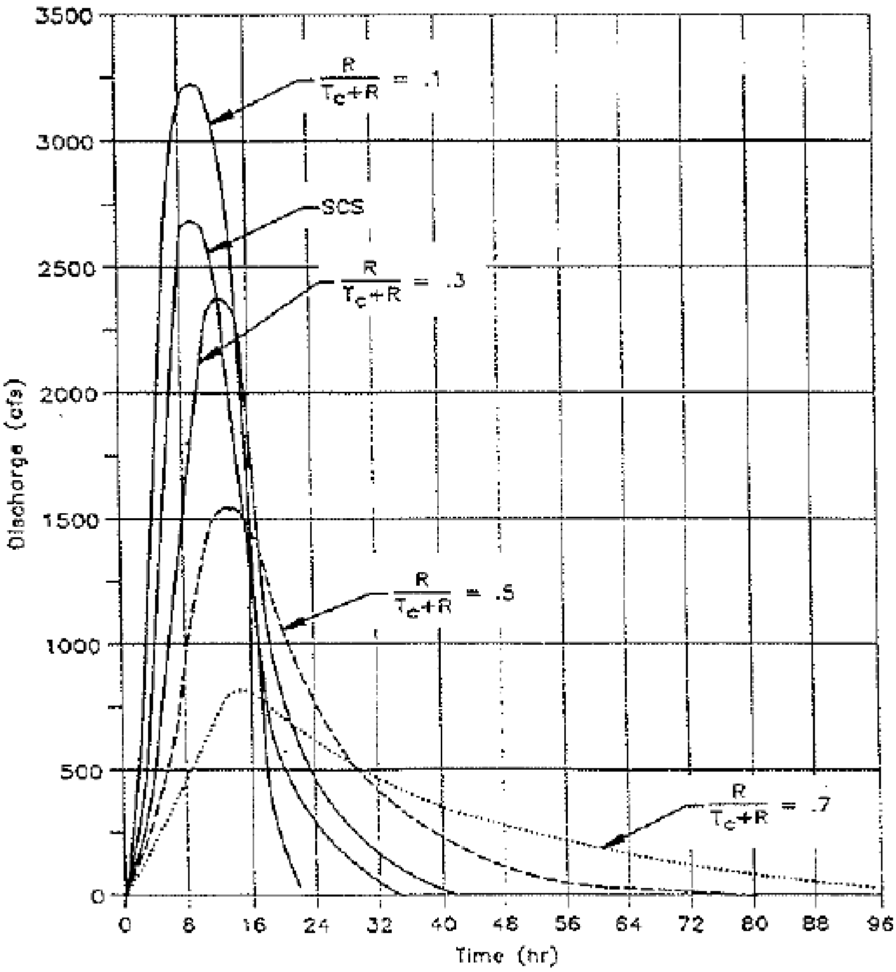
Storage volumes for any one event are defined by the given CN. The shape of the volume outflow in the Clarke's unit hydrograph is determined by the storage coefficient R. The value R is interdependent of the concentration time and can be given as;

R = Tc*Ratio/(1-Ratio) Where the ratio represents the shape of a given hydrograph as shown in figure 2-2.

In this situation the concentration time becomes the control of R given a set ratio of runoff. This is seen as a distinct advantage as although some work has been undertaken in an attempt to quantify R in the Kāpiti Region, (Watts, 2001, Connell Wagner, 1999), this work has not been conclusive, and has provided a wide variety of results.

Using the runoff ratio approach, ratios can be set for differing landuse types to control the runoff hydrograph shape. These can be applied for any given time of concentration to provide a value for R that can be entered into the hydrograph equation.

Figure 0-2 : Storage/Concentration Time Ratio Curves (Hoggan, 1996)



From previous work undertaken by Connell Wagner, (2001), appropriate ratios for R have been defined as;

0.25 for highly developed industrial commercial catchments;

0.30 for most residential catchments;

0.35 for high storage residential catchments;

0.45 for rural steepland catchments.

0.60 for rural flatland catchments.

A more detailed discussion of the calculation of storage coefficients, and indeed all of the above SCS parameters, is covered in Hoggan, 1996. This is an excellent background text for the engineering hydrologist.

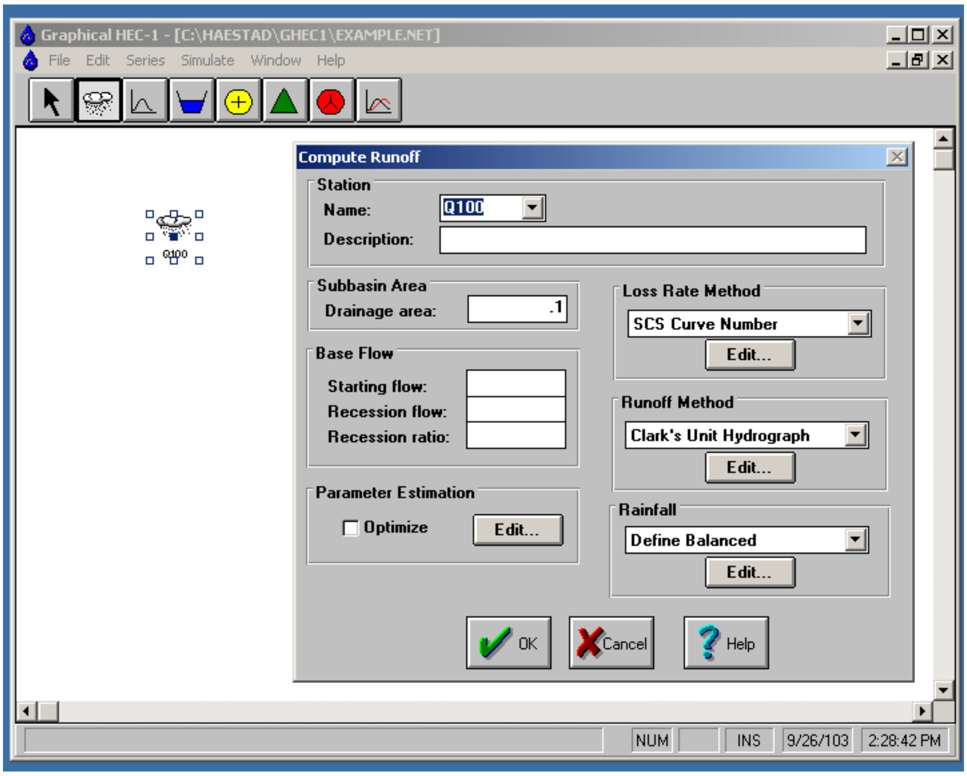
Concentration Times

Times of concentration should be calculated in accordance with the requirements for subdivision and development. An example calculation of concentration times is covered in section 6.4 of this report.

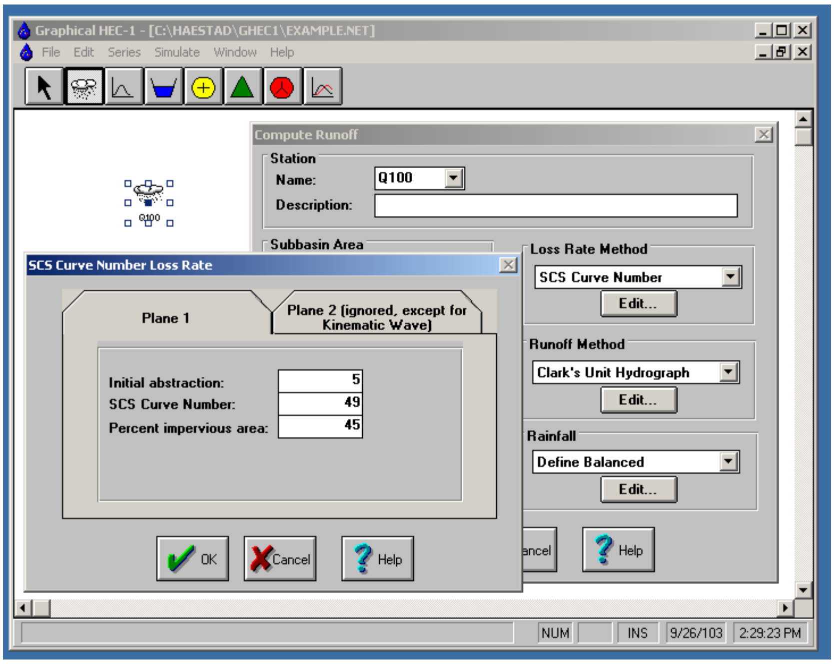
Haestad's Graphical Hec-1

Haestad's are an American software company that have taken the proprietary HEC 'freeware' and developed a windows front end that is both easy to use, and backed up by full software support currently provided by Bentley.

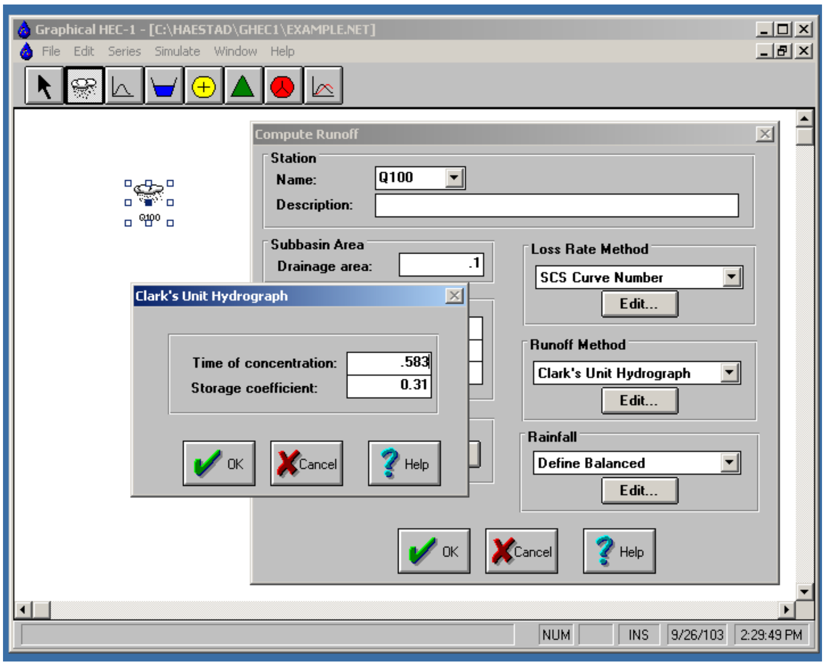
To develop an SCS hydrograph using the information from the previous chapter, the design engineer or hydrologist will need to follow the following steps.



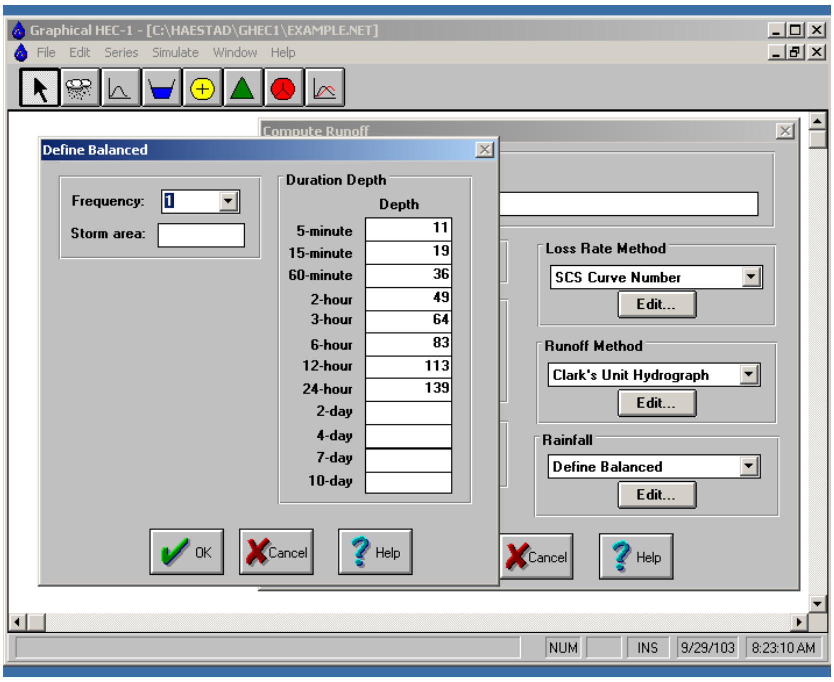
Step 1 – Select the storm item to open a new basin model and enter catchment size under drainage area.



Step 2 – Select the SCS curve number item under the loss rate method and enter the initial abstraction, Curve Number (CN), and Percent impervious area (CIA) in the boxes as shown. These items should be worked through as discussed in the previous chapter.

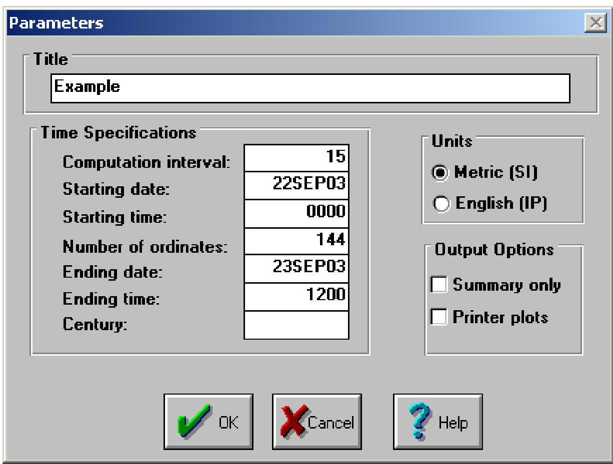


Step 3 – Calculate the time of concentration and enter the time, (in hours), and the assessed storage coefficient under the Clarkes Unit Hydrograph runoff method.



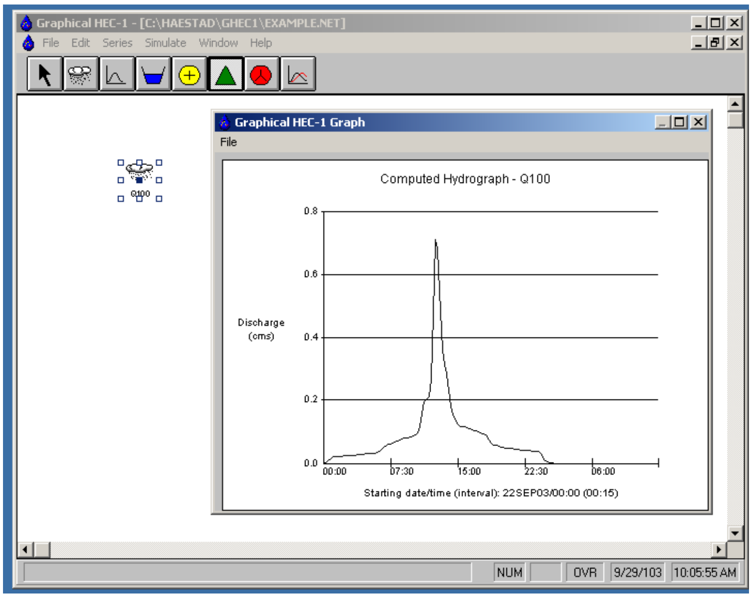
Step 4 – Add in the balanced rain event under 'Define Balanced' in the rainfall portion of the model. These values would be calculated as per sections 2.2.1.

This is all the data that is required to run the model. Typically the model would be run for the full 24 hour storm but in some special circumstances it could be run for shorter periods of time. The hydrograph can be reduced to a twelve hour storm simply by leaving the 24 hour rainfall depth out of the rainfall duration depth series. The model will automatically adjust to a twelve hour storm.



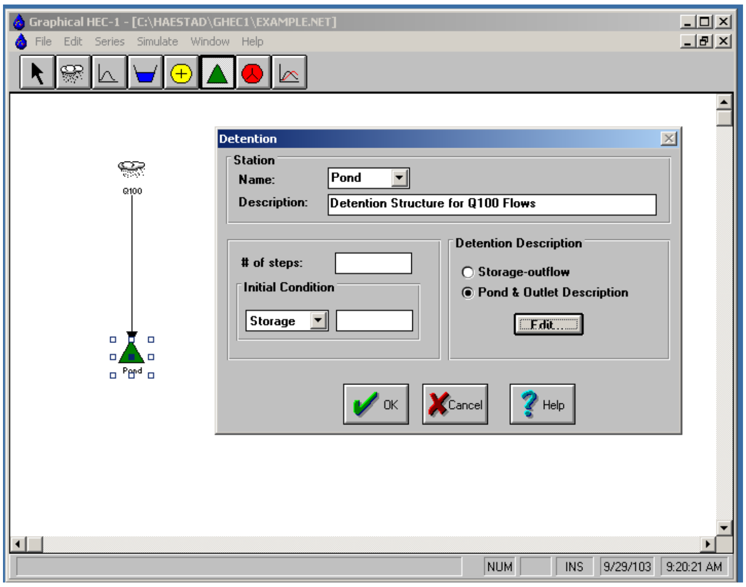
SINCLAIR KNIGHT MERZ

Step 5 – From the *simulation* menu the model parameters need to be entered to allow the programme to be run. Typically for a 24 hour storm the model is run for 36 hours as shown above to allow for the full hydrograph to be represented. In situations where detention is being modelled this may need to be further extended to allow for slow drawdown from detention structures. The final results of the analysis can be represented in tabular form or graphically as shown below.



Storage Structures

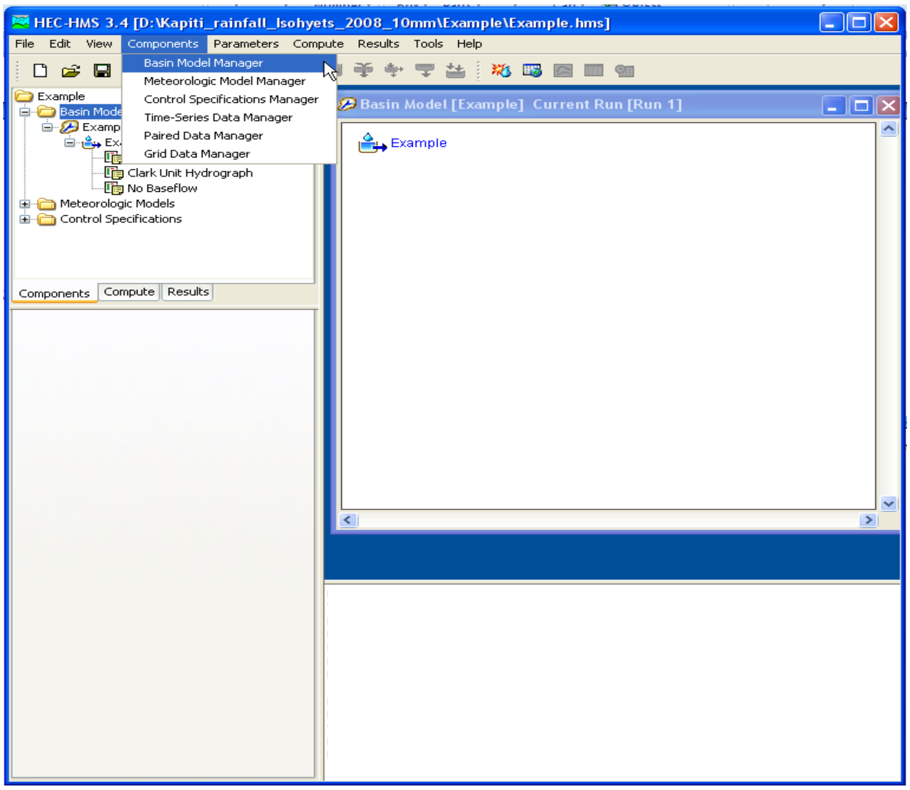
Storage ponds and other structures can be easily modelled within the HEC system by running the newly calculated unit hydrograph through a stage-storage-discharge relationship. Pond and outlet relationships are defined from first principles and entered into the detention basin. The hydrograph is attached to the basin, and the model run as before.



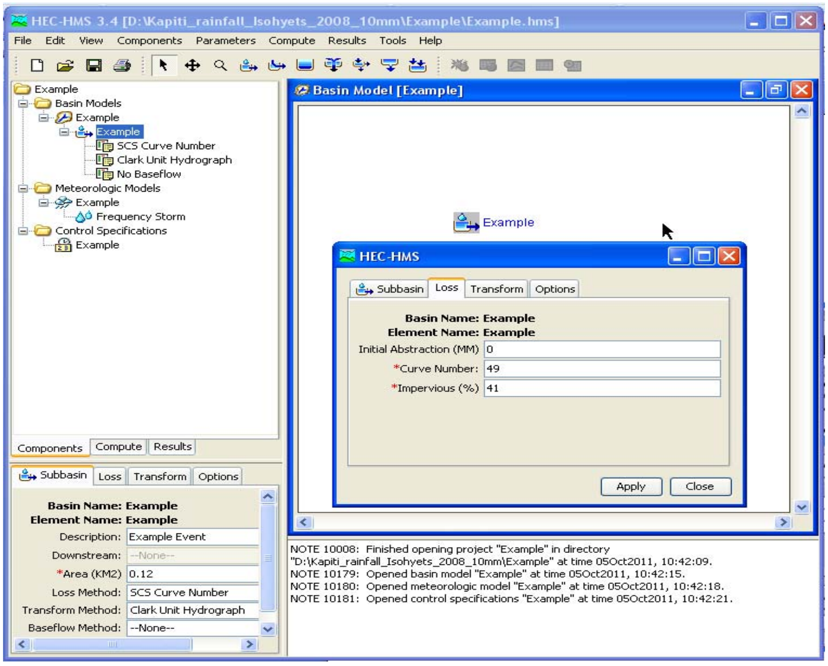
US Army Corps of Engineers HEC-HMS

The freeware version of the unit hydrograph modelling software is available off the internet as HEC-HMS. Also available for download with this software are full software user manuals. To compute a unit hydrograph the following steps need to be completed.

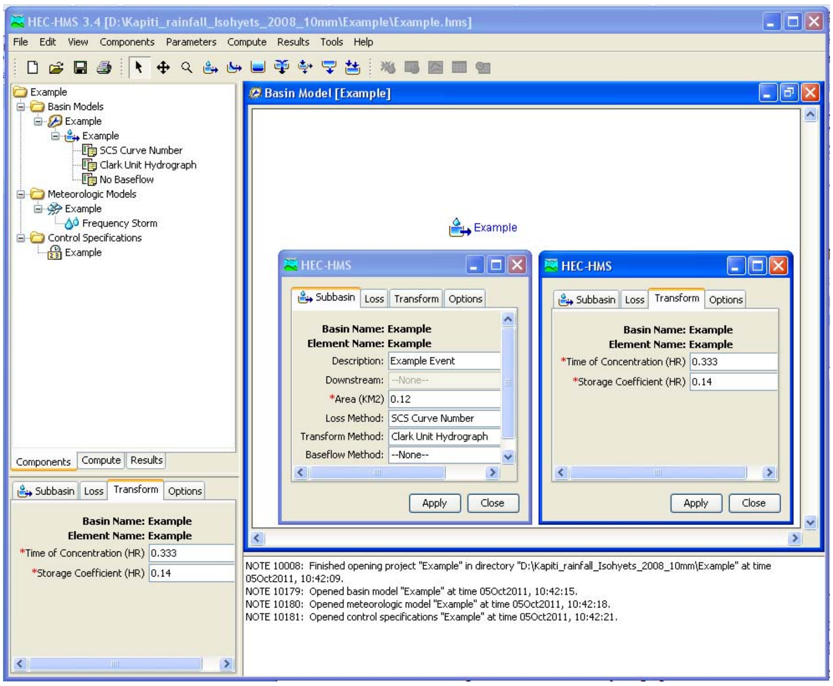
For each hydrological 'project' there are three separate 'model' components. These are the basin model, the meteorological model, and the control specifications. Each of these components can be created under the *component* menu in the project screen.



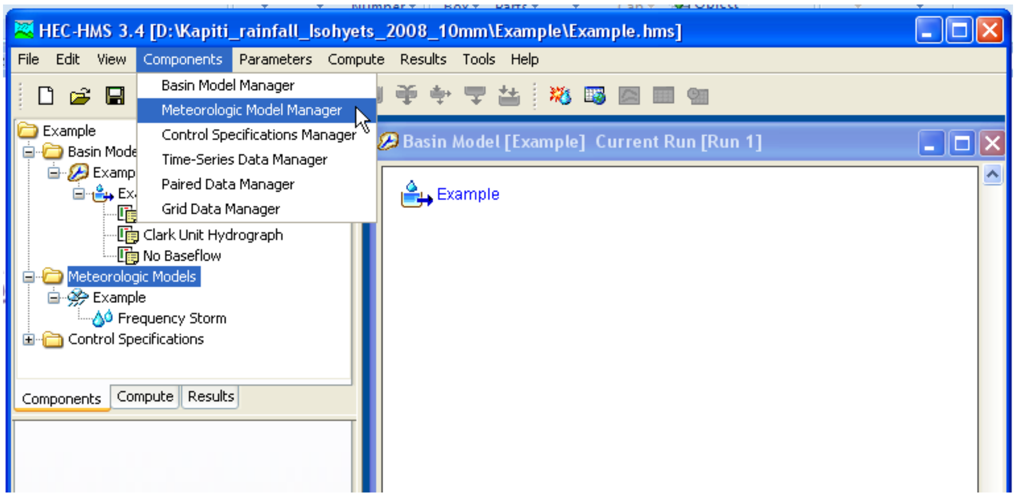
Step 1 – Create a new basin model manager and open a sub-basin element using the sub-basin creation tool. This icon is displayed on the toolbar. Once this element has been created the catchment characteristics can be entered into the model.



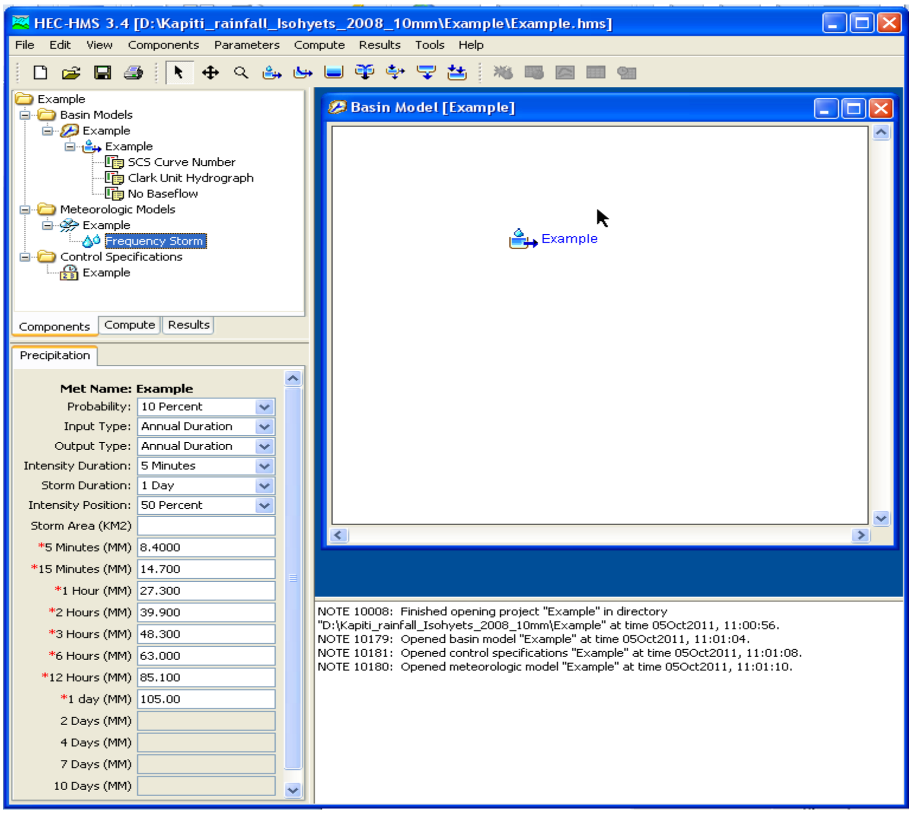
Step 2 – Select the loss rate method as the SCS Curve Number, and enter the initial abstraction, loss rate, and connected impervious area data into the model as outlined in chapter 2.



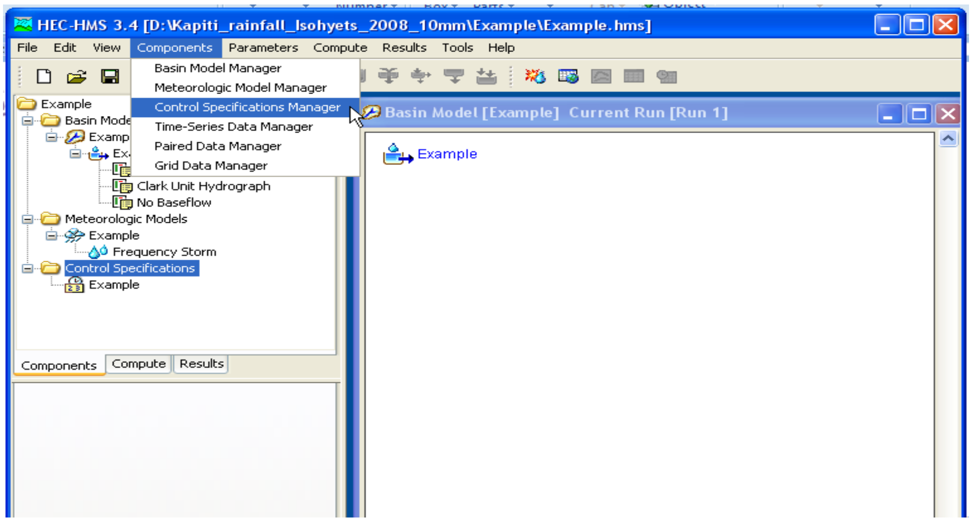
Step 3 – Select the unit hydrograph method as the 'Clark' unit hydrograph and enter time of concentration and storage ratio into the model. Baseflow should be set to 'none' unless some good data is available and the baseflow is going to be significant comparative to the peakflow and total storage volumes.



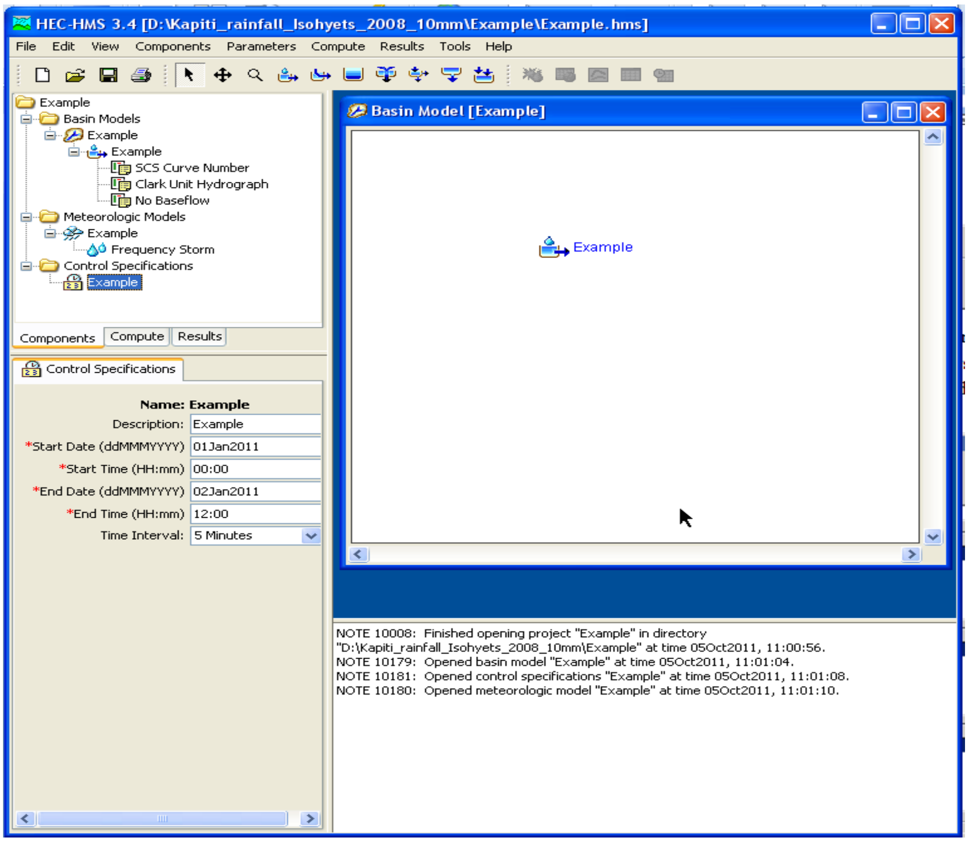
Step 4 – A meteorological model needs to be created under the *component* menu of the project. Once this is defined it can be opened to allow entry of design rainfall information as shown below.



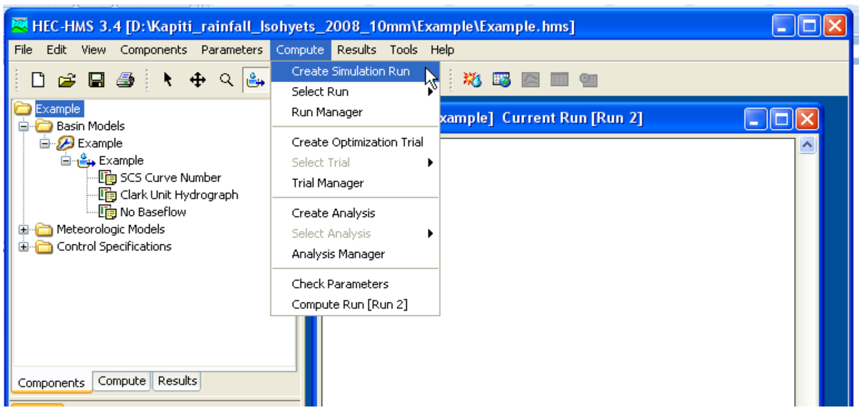
Step 5 – Selecting the 'frequency storm' method from the menu, the balanced rainfall data can be entered into the meteorological model.



Step 6 – A control specification needs to be created under the *components* menu of the project. Once this is defined it can be opened to allow entry of information as shown below

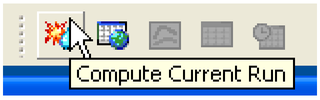


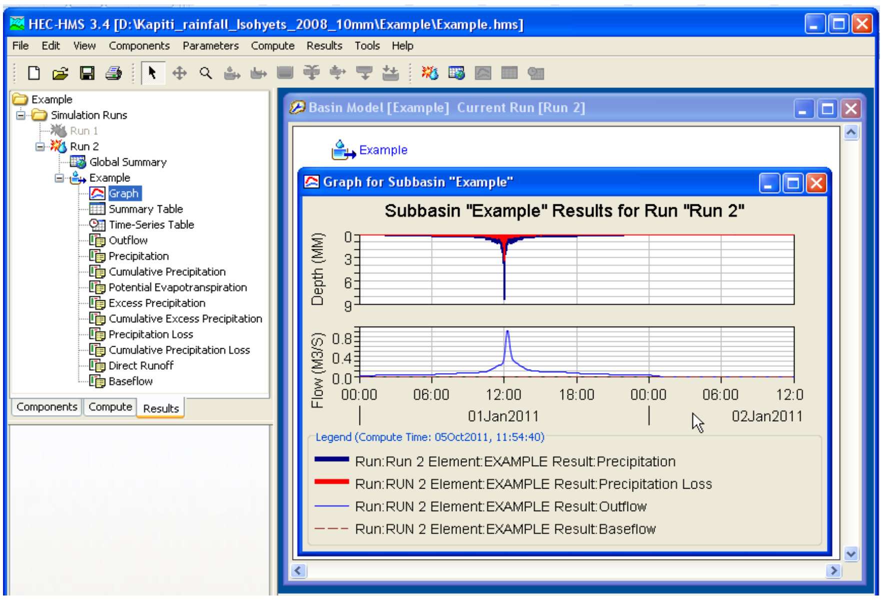
Step 7 - The control specifications are essentially the project time and date running parameters. Again the models should be run for 36 hours as in the previous chapter.



Step 8 – Once the control specifications have been set, the project model run is set up by selecting *Create Run Simulation* under the *Compute* menu. Here the run is given a name and the Basin Model, Metrologic Data and Control Specifications are selected.

The model is run by selecting *Compute Run* under the *Compute* menu or using the icon on the toolbar.





Results can be viewed by selecting the Results Tab. From here the results can be viewed as graphs as well as time series and general tabular data.

Storage Structures

Storage structures in HEC-HMS are developed as a detention structure within the basin model. Again, pond and outlet relationships are defined from first principles and entered into the detention basin. The stage storage and discharge relationship will be based on specific outlet conditions that would be engineered for each specific situation.

Model Limitations.

Rainfall Isohyet Plans

Statistically the frequency analysis undertaken on the available rain gauge sites is sound. Development of the regional isohyets brings these records together in a broad way however, and will tend to ignore small local differences. It should also be noted that most of the upper catchment gauges (Taungata, Oriwa, McIntosh and Kapakapanui) have the shortest rainfall records and may therefore be subject to change in the longer term when a more substantial record is available.

Calibration of Empirical Assumptions

Calibration of empirical assumptions for the development of extreme event storms, covered in this report, is limited. Previous work undertaken by Watts (2002), while providing good data on Initial Abstraction, lacked the large storm events required to meaningfully assess general losses (CN's) and storage functions (R). Some work optimising Hec-1 for the large event storms was undertaken following the storms of October 1998, which were recorded at the Coastlands weir, but a lack of other large events at this gauging station is again a limitation to these results.

The data that has been analysed has typically been from catchments of less than 7 km^2. The isohyet based approach to analysing catchment runoff should not typically be applied to catchments with a greater area than this prior to further calibration work being completed.

For the designer it is important to recognise that due to this a lack of existing hydrometric data the approach encompassed in this report is essentially an uncalibrated empirical process and should be treated as such.

Further Work

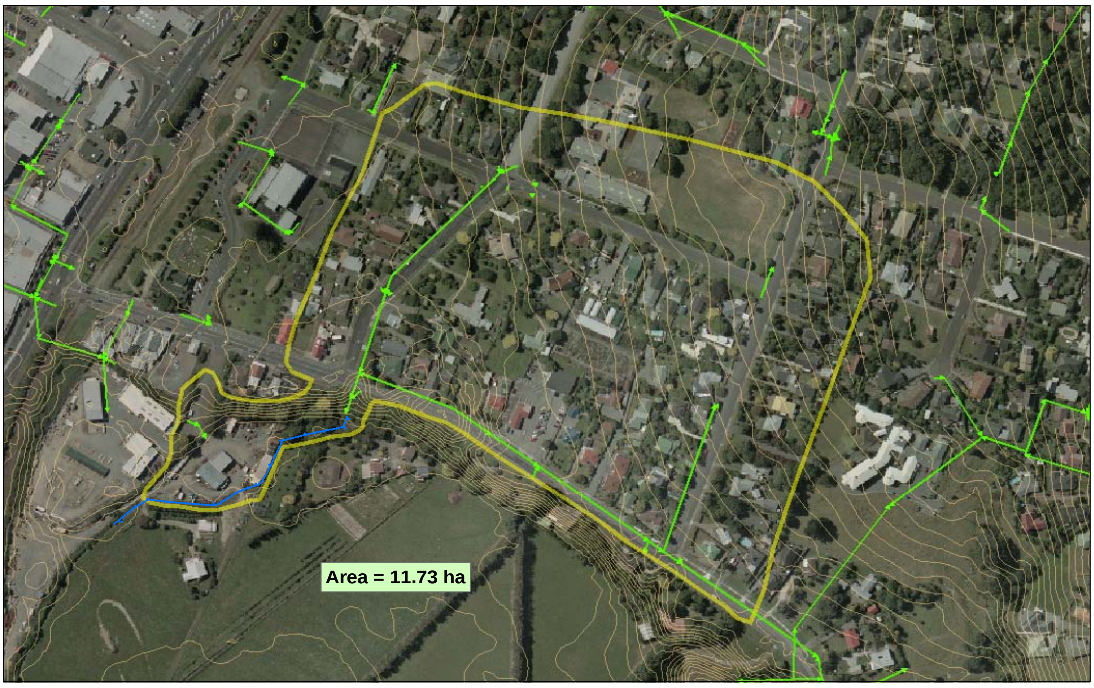
- Some additional local rain gauges through urbanising areas may, in the long term, add useful detail to the rainfall isohyet plans.
- Further analysis of I_a could be developed from the data for the Waikanae and Ōtaki Rivers. This would give some feel for large catchment initial abstraction values.
- New data collected at the Wharemauku, Mazengarb, Mangaone and Waitahu flow gauges could be analysed for frequency, and then used to calibrate for storage runoff ratios and general catchment losses.
- Gauging of additional smaller urban streams, such as the Muaupoko and Wainui, would add to the existing knowledge base and allow for more conclusive analysis in the long term.

Worked Example

Introduction

The following example has been developed to assist the engineer in applying this standard. The example is based on a small residential/commercial catchment in Waikanae that discharges via an open channel to the Waikanae River. The area was defined as being 11.73 hectares and is drained via a formal stormwater piped network as shown below in Figure 6-1.

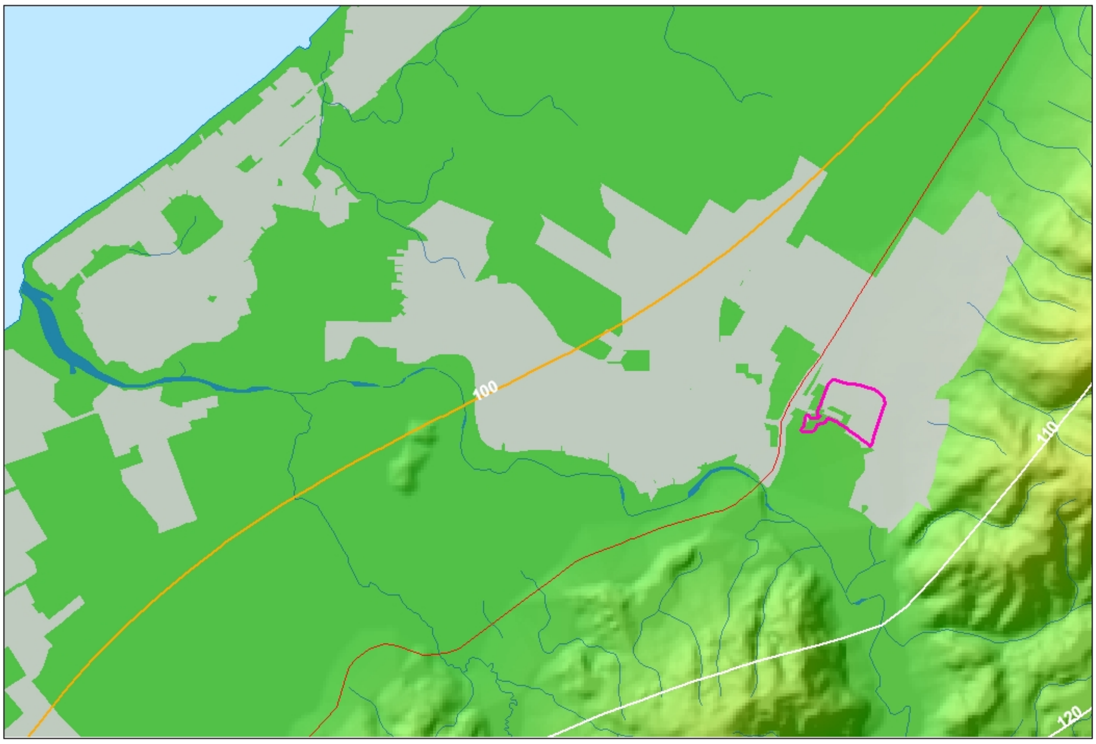
Figure 6-1. Site Plan of Example Catchment.



Rainfall

Rainfall depths are taken from the 10 year isohyets plan for the catchment area identified. Figure 6-2 locates the catchment on the isohyets plan.

Figure 6-2. Catchment Location on the 10 Year Isohyet Plan.



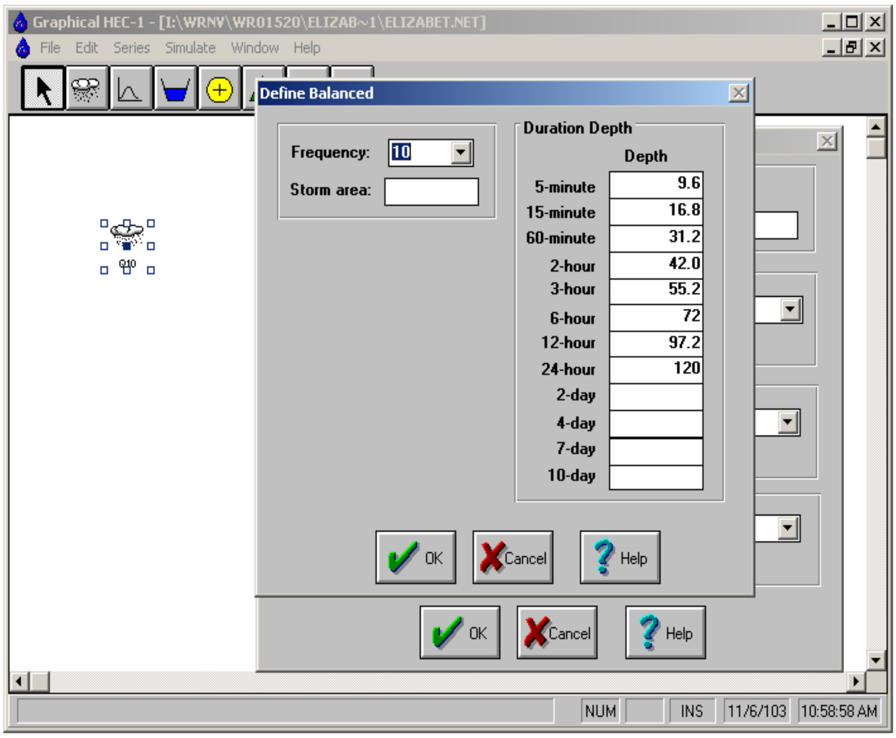
Average rainfall depths for this catchment are estimated at 105mm off the plan. This total depth is then applied to the normalised depth-duration relationship, (section 2.2.1), as shown in table 6-1.

Table 6-1: Normalised Depth-Duration Relationship for 24-hour Rainfall

Duration	Normalised Rainfall Depth (I/I_{24})	Normalised 10 Year Rainfall
5 Mins	0.08	**8.4**
15 Mins	0.14	**14.7**
1 Hour	0.26	**27.3**
2 Hour	0.38	**39.9**
3 Hour	0.46	**48.3**
6 Hour	0.60	**63.0**
12 Hour	0.81	**85.1**
24 Hour	1	**105**

These normalised 10 year rainfall depths can then be entered, with the catchment area, into the Hydrological model as outlined in chapter 3 and 4 and shown in Figure 6-3 using Graphical Hec.

Figure 6-3. Rainfall depths applied for the 10 Year Example



Catchment Characteristics

Initial Abstraction

Initial abstraction in a fully urbanised catchment would be set at **0mm** as outlined in section 2.2.2.1.

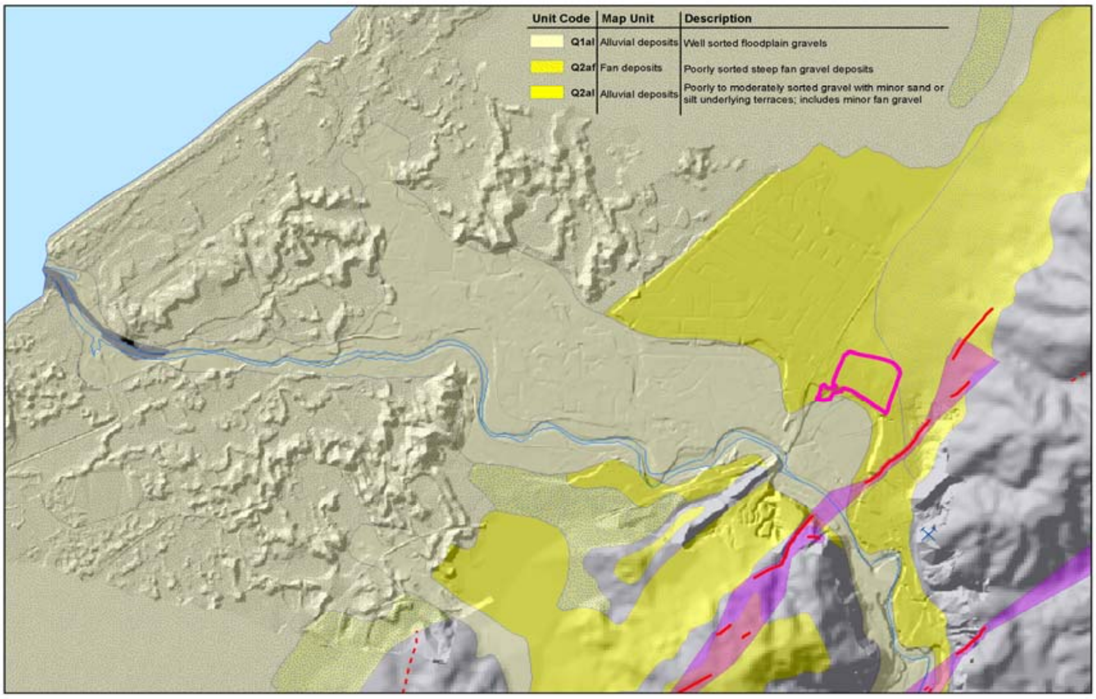
Curve Numbers (CN) and Connected Impervious area.

Defining soils parameters can be taken from Soil Bureau Land-Use Inventory Maps in all but urban areas. These maps are difficult to source however and may need to be supplemented by larger geological plans which also cover urban areas.

In either case site an initial site walkover should confirm the nature of the soils with ground investigation if necessary.

For the example case we have used the larger geology maps for the urban based area (figure 6-4). The geology shows a mixture of alluvial and outwash gravels that are well to moderately well drained.

Figure 6-4. Geology of the Given Catchment Area



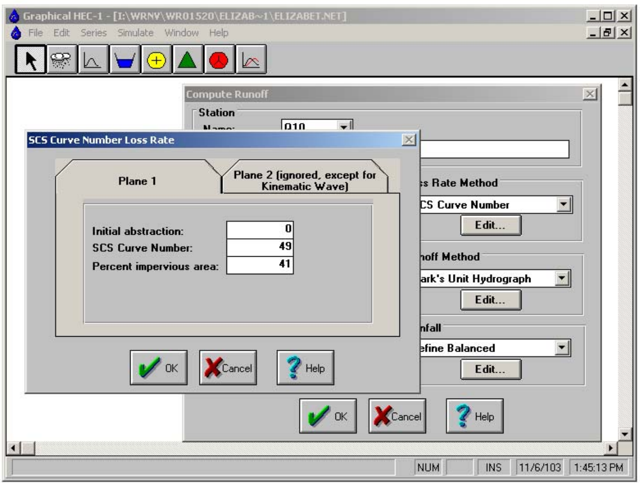
These alluvial soils are well drained and there is no record of flooding in this catchment on Councils flood incidence records. In addition previous soakage testing in this area have shown high soakage rates. From Appendix B it has been assumed that these soils would fall into category A, and that the general ground cover (lawns gardens etc) would be in fair (average) condition. This gives a **CN of 49.**

To this value the impervious portion of the catchment needs to be added. This has been estimated as 38% under section 2.2.3.2 for the Residential portion of the catchment (92%), and 72% for the remaining industrial area. This gives a weighted connected impervious area of;

Industrial @ 72%*.08	5.8
Residential @ 38%*.92	35.0
Estimated Total Impervious Area	**41%**

These loss rate characteristics are entered into the model under the loss rate method as discussed in chapter 3 and shown in figure 6-5.

Figure 6-5. Loss Rate Factors Applied for the 10 Year Example.



Time *of Concentration*

Calculation of the time of concentration under Kāpiti District Councils new sub-divisional and development requirements is as follows.

The first step in the calculation of rainfall intensity is to determine the "time of concentration" for the catchment, or the time taken for water to travel from the remotest part of the catchment to the head of the section of the drain or culvert in question.

Tc = time of flow to design point = (overland flow + open channel flow + kerb and channel flow + pipe flow), where:

a) Time of overland flow for most urban drainage systems can be obtained from "Chart for Overland Flow" Appendix C.

If the natural surface is longer than 1000 metres the Empirical Bransby-Williams formula shall be used:

$$tc = \frac{FL}{A^{0.1}\ S^{0.2}}$$

where

tc = time of concentration in minutes

F = 59.5 when area in square metres

	=	92.7 when area in hectares
L	=	main channel length (km)
A	=	catchment area
S	=	main channel slope (m/km)

b) Time of channel flow can be obtained using Mannings formula.

c) Time of kerb and channel flow can be obtained using Mannings formula for n 0.018 as an average value.

d) Time of pipe flow (the example assumes a 300mm diameter) can be obtained by from the "Chart for Pipe Flow" Appendix C.

Time of concentration shall not be taken less than 10 minutes in all areas:

The outcome for the Time of Concentration calculations for the example catchment would therefore be;

Overland Flow is 20m @ 3% grade (Refer Appendix C)	10.5min
Gutter Flow is 150m @ 4.8% grade (Refer Appendix C)	2.0min
Pipe Flow is 600m @ 2% grade @ 1.8m/s (Refer Appendix C)	5.5min
Concentration time in Minutes.	**Say 20min**.

Storage Value (R)

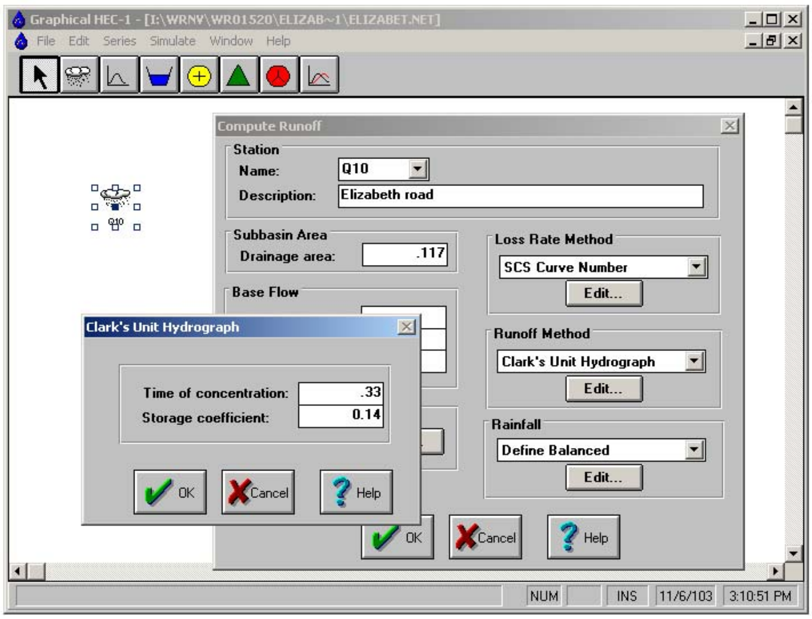
From section 2.2.2.3 the ratio for R has been defined as 0.30 for standard residential catchments. To determine R from this ratio the function R = Tc*Ratio/(1-Ratio) is applied.

In this case this would give an R value of

R = 0.33*.30/(1-.30) = **0.14**

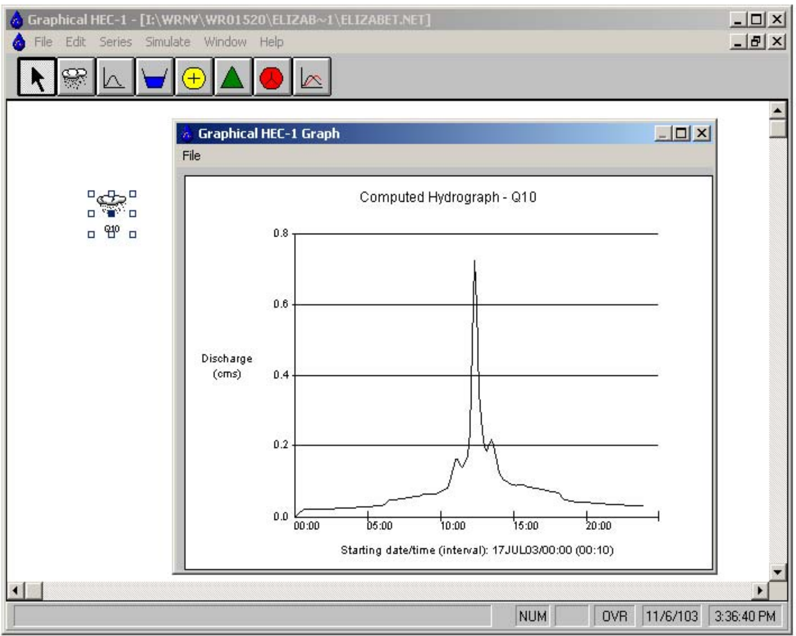
The time of concentration and R values are the final parameters to be entered into the hydraulic model as given in figure 6-6.

Figure 6-6. Concentration Times and Storage Values Applied for the 10 Year Example



This is the last of the parameters required for the calculation of the unit hydrograph which can now be computed to provide the output hydrograph. This output is given below as figure 6-7.

Figure 6-7. Output Hydrograph from 10 Year Example.

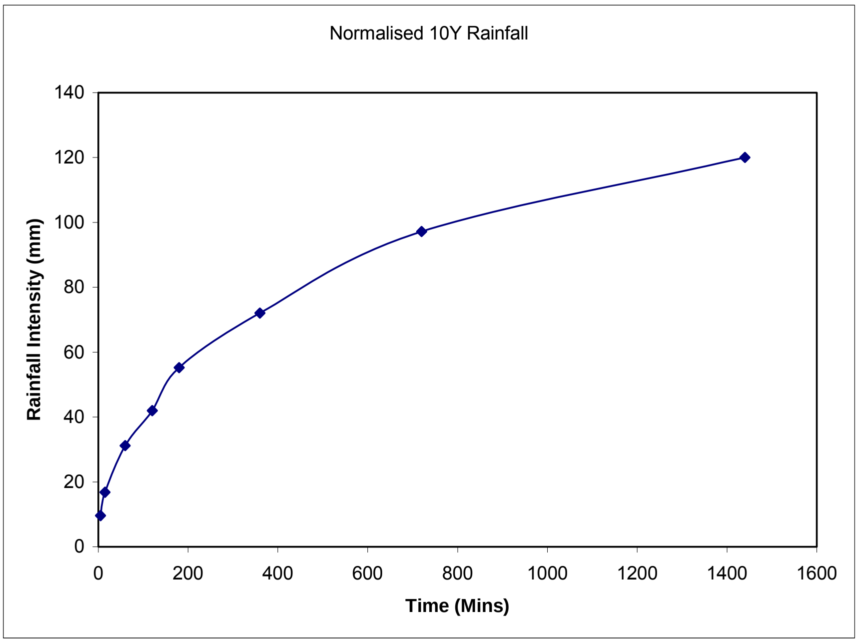


Rational Formula

The Rational Formula has been traditionally used to estimate catchment peak flows in urban areas. It is not the intention of the updated sub-divisional and development requirements to exclude the use of the rational formula for this purpose. It will typically not be useful for calculating volume based solutions however and will not be encouraged for use in this area of design.

The isohyets plans that have been developed can be used to provide all the rainfall intensity data required under this method. This can be achieved by plotting the normalised rainfall results from table 6-1 against time as shown below in figure 6-8.

Figure 6-8. 10 Year Rainfall Intensity Curve for the Example Catchment



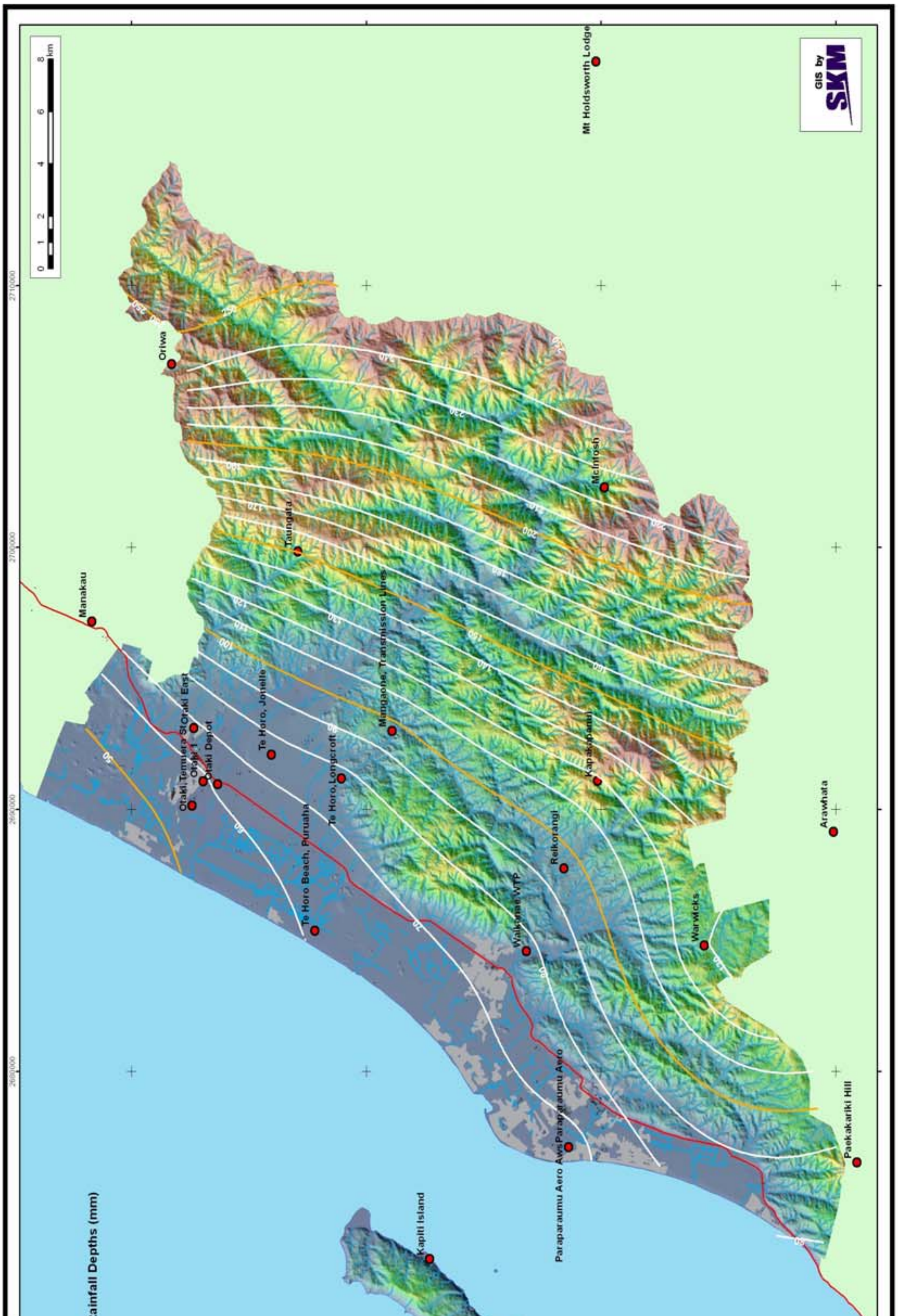
Importantly it should be remembered that intensity under the rational formula is measured in hours so ensure that intensities for shorter or longer periods are factored up or down respectively.

References

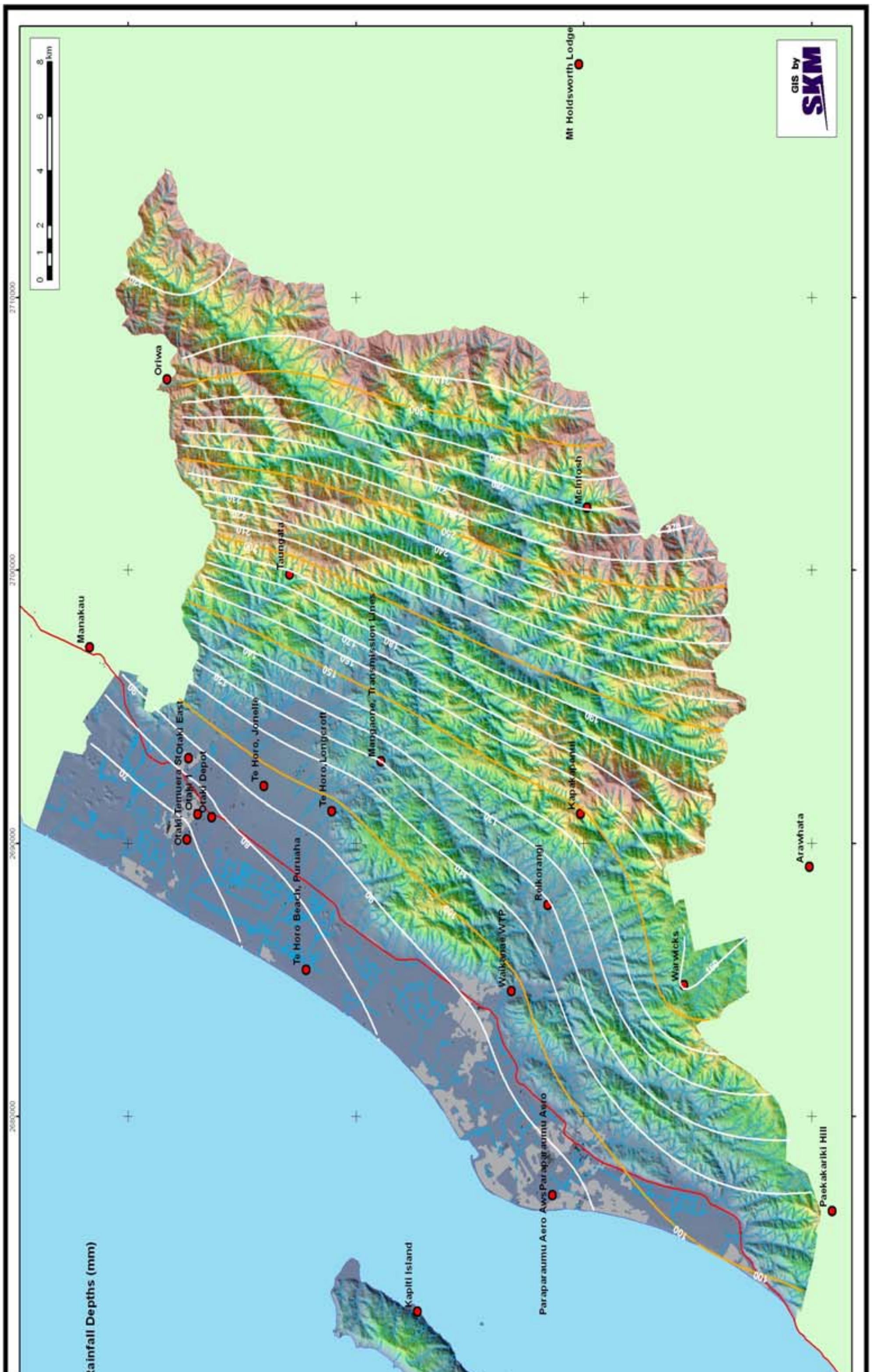
Maidment, D (ed.), 1992	Handbook of Hydrology, McGraw Hill.
Watts, L, 2002	Hydrologic Response and Runoff Model Parameters in the New Zealand Coastal Zone. Unpublished Masters Thesis, Victoria University of Wellington
Auckland Regional Council, 1999	Guidelines for Stormwater Runoff Modelling in the Auckland Region. Technical Publication N° 108, Auckland Regional Council
Hoggan, D, 1996	Computer Assisted Floodplain Hydrology and Hydraulics, Second Edition. Department of Civil and Environmental Engineering, Utah State University, McGraw-Hill.
Connell Wagner, 1999	Wharemauku Stream Hydrometric Analysis of October 20-21st Storm, Connell Wagner Ltd
Connell Wagner, 2001	Wharemauku Stream Stormwater Runoff and Floodplain Assessment.
USACE, 2000	Hydrologic Modelling System HEC-HMC Technical Reference Manual – US Army Corps of Engineers, Hydrologic Engineering Centre
SKM, 2008	Update of Kāpiti Coast Hydrometric Analysis

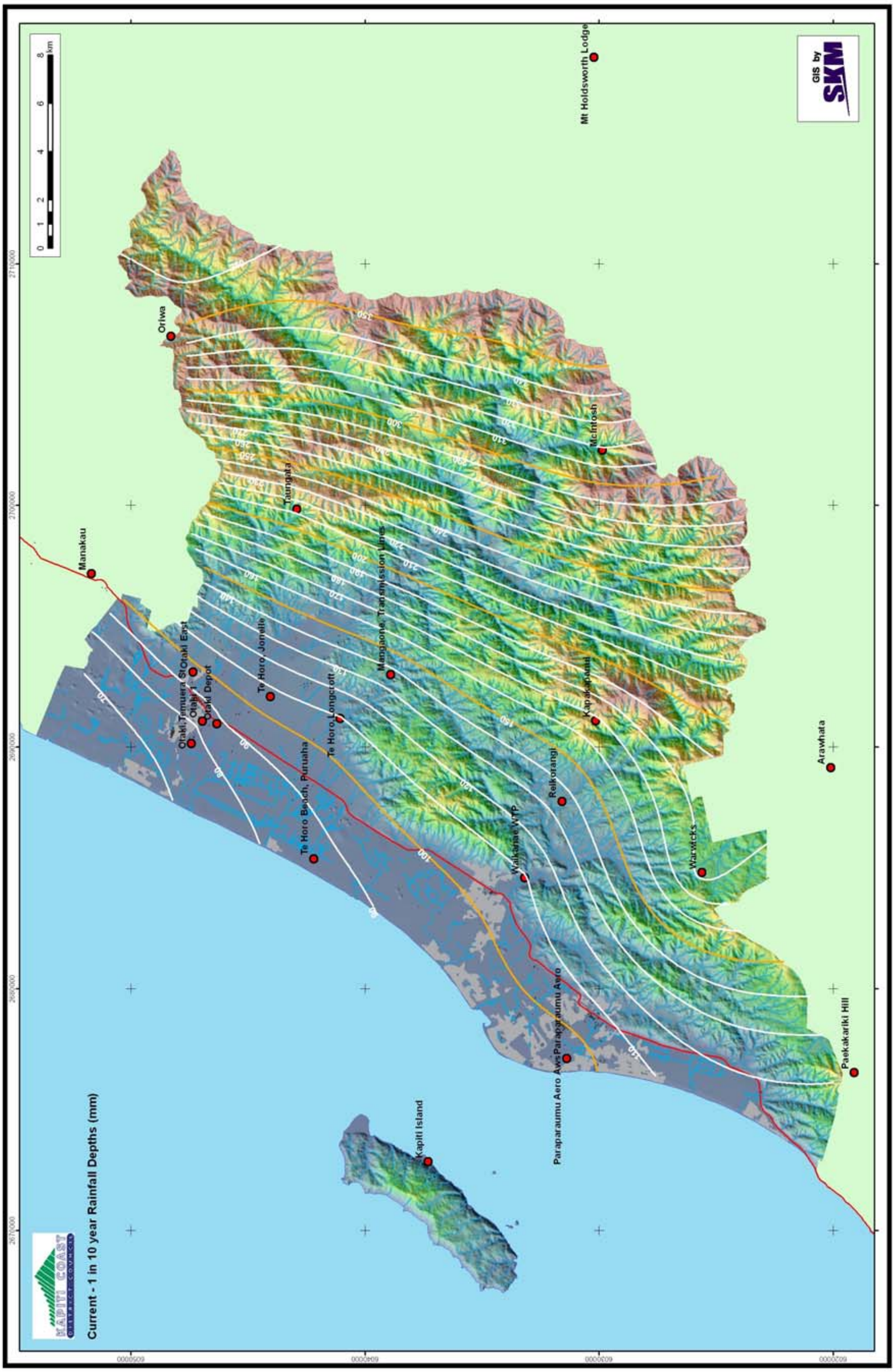
Appendix A Rainfall Recurrence Isohyet Maps

Current Rainfall Recurrence Isohyet Maps

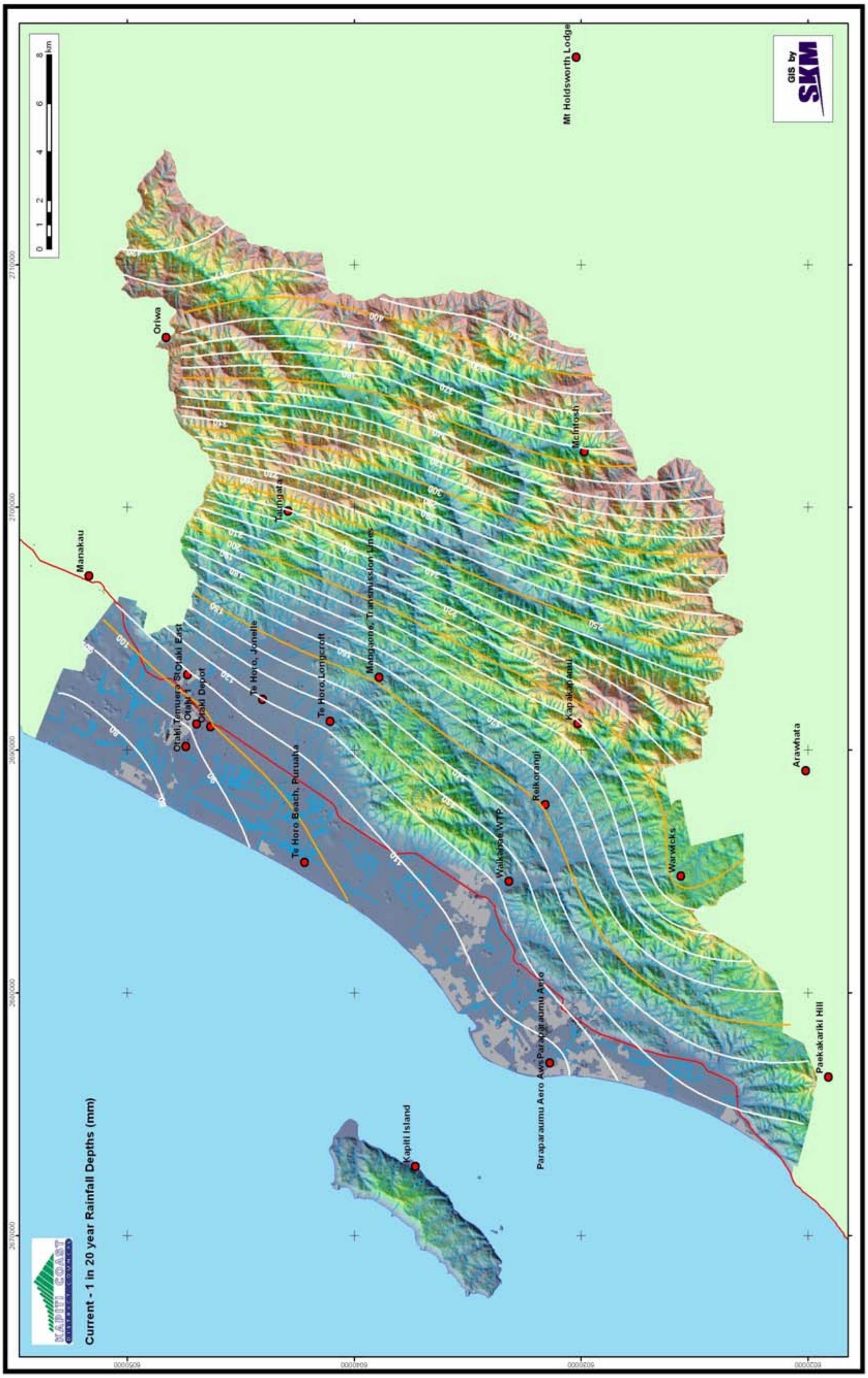

Current - 1 in 2 year Rainfall Depths (mm)
KAPITI COAST
GIS by SKM
km
Kapiti Island
Paraparaumu Aero Aws
Paraparaumu Aero
Paekakariki Hill
Te Horo Beach, Puruaha
Waikanae WTP
Warwicks
Reikorangi
Arawhata
Otaki Depot
Otaki Temuera St
Otaki East
Te Horo, Longcroft
Te Horo, Jonelle
Mangaone, Transmission Lines
Kapakapanui
Manakau
Taungata
McIntosh
Oriwa
Mt Holdsworth Lodge

SINCLAIR KNIGHT MERZ
SKM

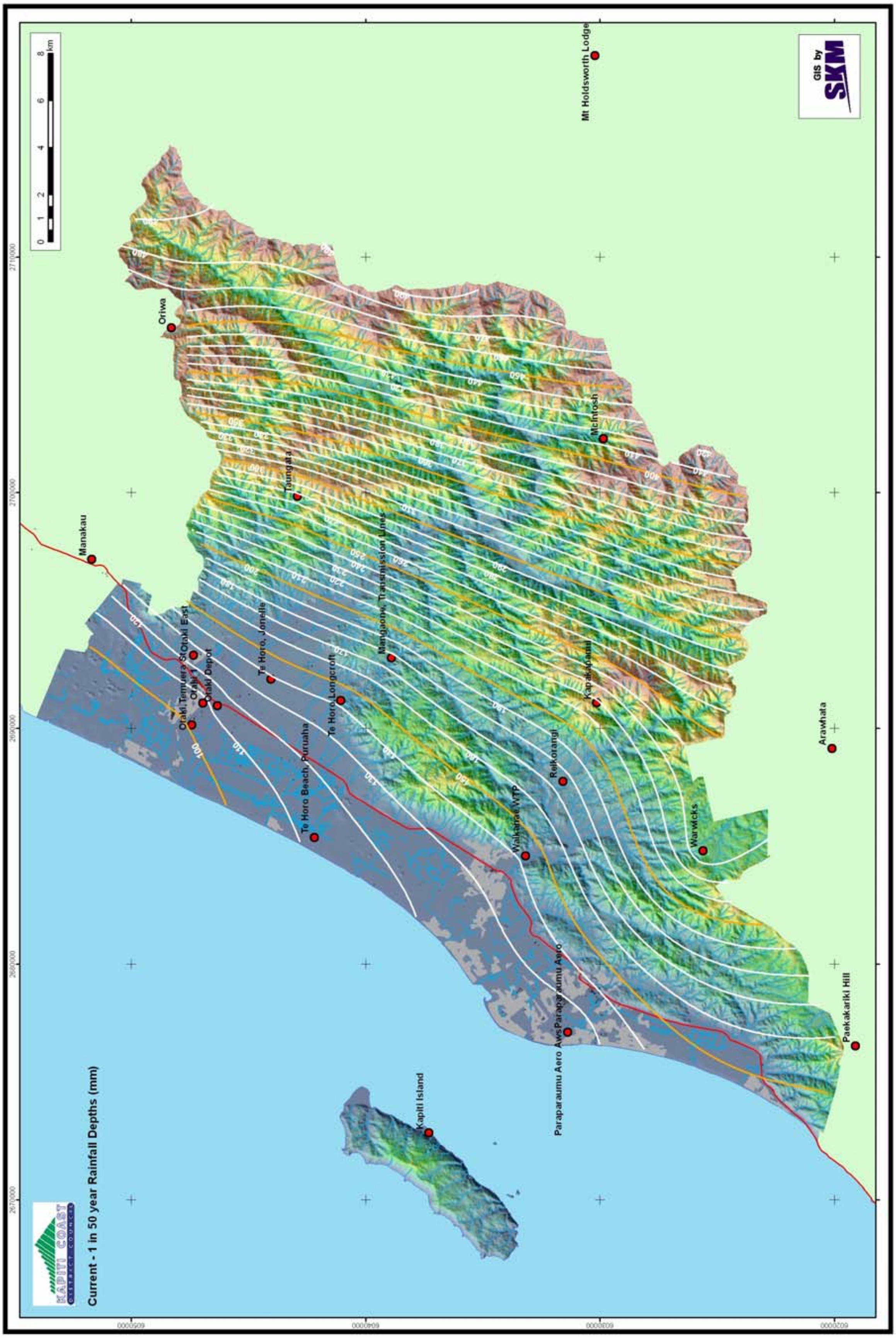


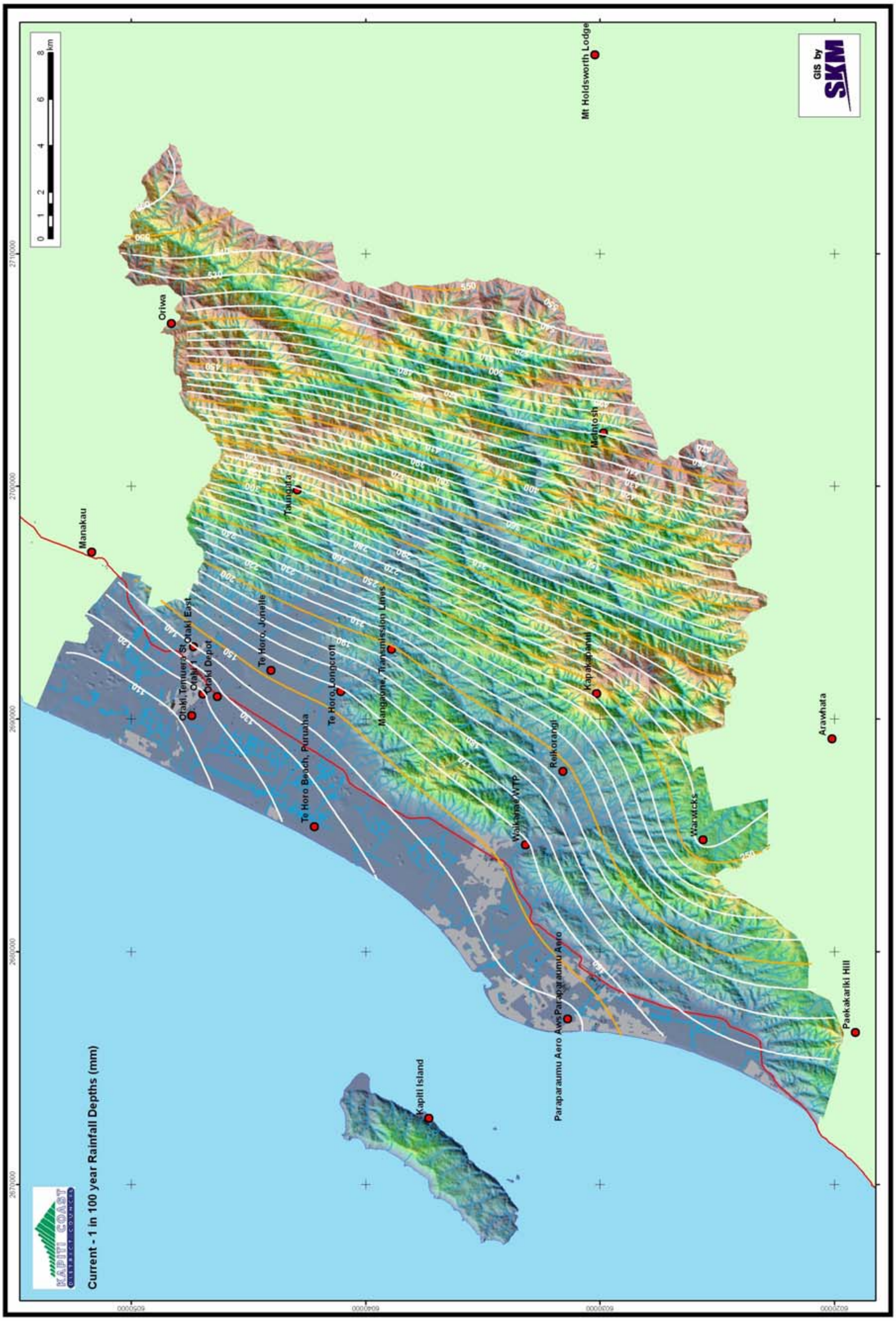


Current - 1 in 10 year Rainfall Depths (mm)
Manakau
Oriwa
Mt Holdsworth Lodge
Taungata
McIntosh
Otaki East
Otaki Depot
Te Horo, Jonelle
Mangaone, Transmission Lines
Te Horo, Longcroft
Te Horo Beach, Puruaha
Kapakapanui
Arawhata
Reikorangi
Waikanae WTP
Warwicks
Paraparaumu Aero
Paekakariki Hill
Kapiti Island
GIS by SKM

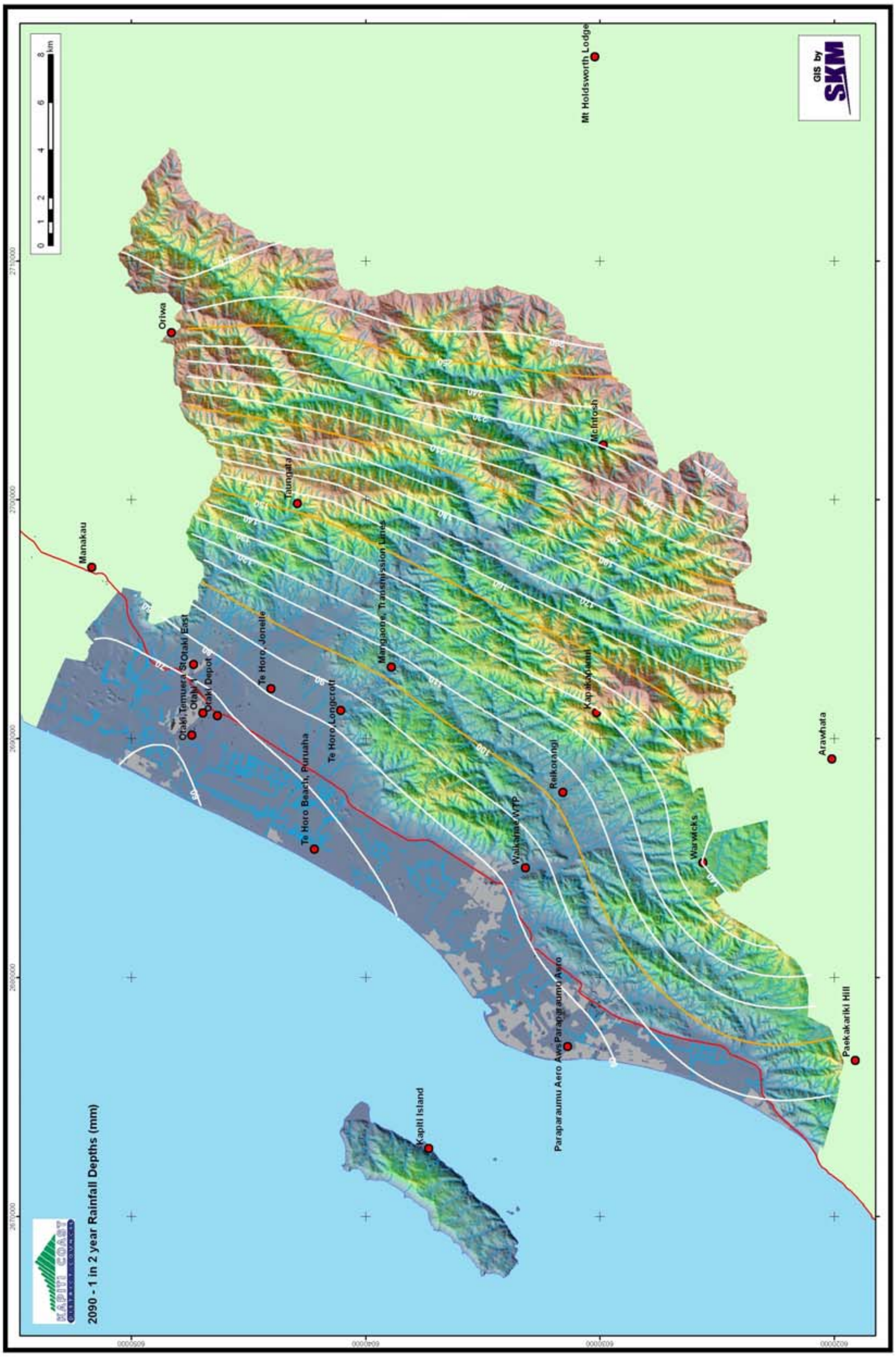


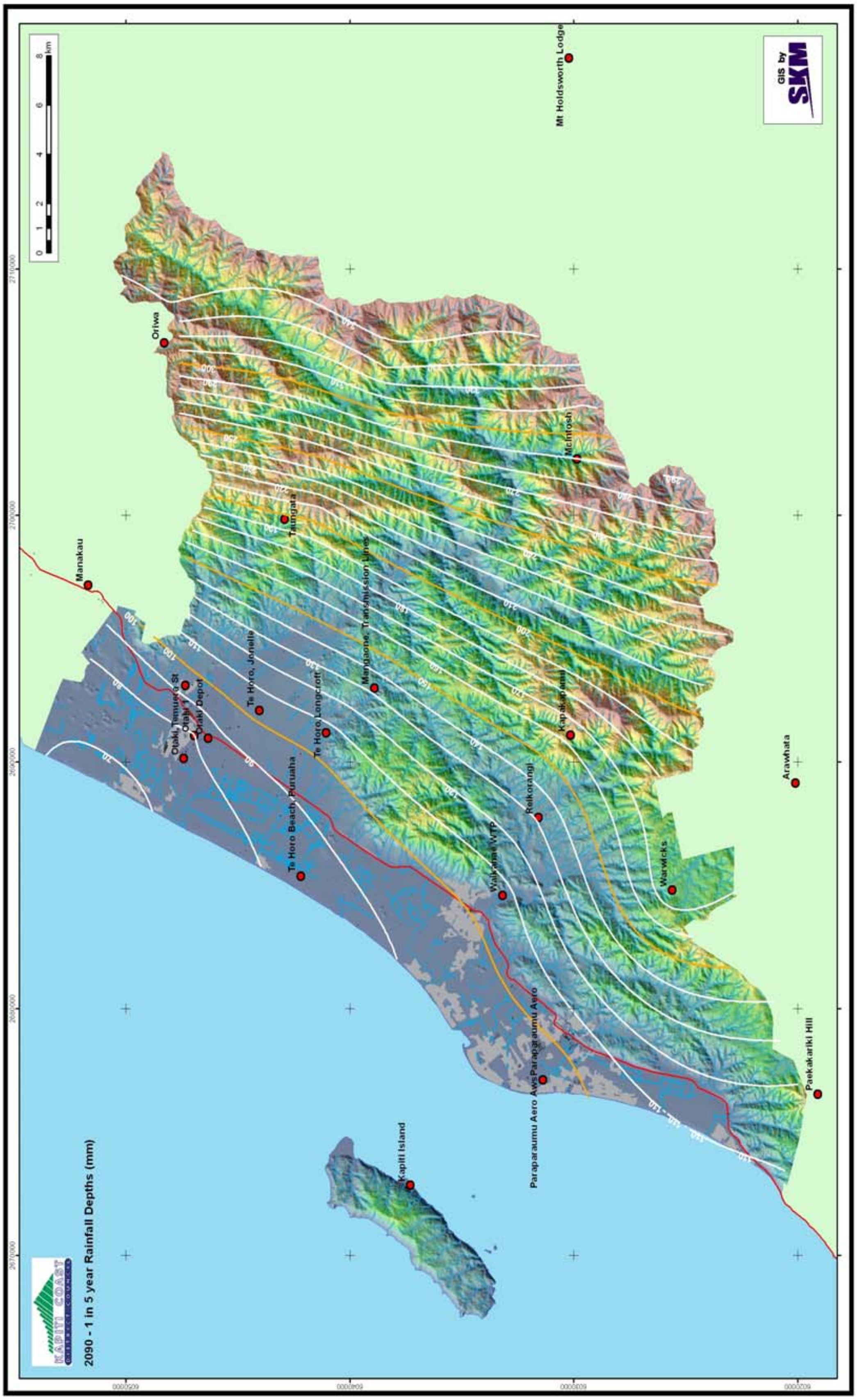
Current - 1 in 20 year Rainfall Depths (mm)
KAPITI COAST
Manakau
Oriwa
Taungata
McIntosh
Mt Holdsworth Lodge
Otaki Temuera St
Otaki East
Otaki 1
Otaki Depot
Te Horo, Jonelle
Te Horo, Longcroft
Mangaone, Transmission Lines
Te Horo Beach
Reikorangi
Waikanae WTP
Warwicks
Arawhata
Paekakariki Hill
Paraparaumu Aero Aws
Paraparaumu Aero
Kapiti Island
GIS by SKM


Current - 1 in 50 year Rainfall Depths (mm)
KAPITI COAST DISTRICT COUNCIL
GIS by SKM
0 1 2 4 6 8 km
Mt Holdsworth Lodge
Oriwa
Manakau
Taungata
McIntosh
Otaki East
Otaki Temuera St
Otaki 1
Otaki Depot
Te Horo, Jonelle
Te Horo Longcroft
Te Horo Beach, Puruaha
Mangaone Transmission Lines
Kapakapanui
Reikorangi
Waikanae WTP
Warwicks
Arawhata
Paraparaumu Aero Aws
Paraparaumu Aero
Kapiti Island
Paekakariki Hill



Current - 1 in 100 year Rainfall Depths (mm)
KAPITI COAST DISTRICT COUNCIL
GIS by SKM
Mt Holdsworth Lodge
Oriwa
Manakau
Taungata
McIntosh
Otaki East
Otaki Depot
Otaki 1
Otaki,Temuera St
Te Horo, Jonelle
Te Horo,Longcroft
Te Horo Beach, Puruaha
Mangaone, Transmission Lines
Kapakapanui
Arawhata
Reikorangi
Waikanae WTP
Warwicks
Paraparaumu Aero Aws
Paraparaumu Aero
Paekakariki Hill
Kapiti Island


2090 - 1 in 2 year Rainfall Depths (mm)
Oriwa
Manakau
Otaki Temuera St
Otaki East
Otaki
Otaki Depot
Te Horo Jonelle
Taungata
Te Horo Longcroft
Te Horo Beach, Puruaha
Mangaone, Transmission Lines
Mt Holdsworth Lodge
McIntosh
Kapakapanui
Reikorangi
Waikanae WTP
Warwicks
Arawhata
Paekakariki Hill
Paraparaumu Aero Aws
Paraparaumu Aero
Kapiti Island
GIS by SKM
km


2090 - 1 in 5 year Rainfall Depths (mm)
KAPITI COAST DISTRICT COUNCIL
GIS by SKM
km
Oriwa
Manakau
Taungata
McIntosh
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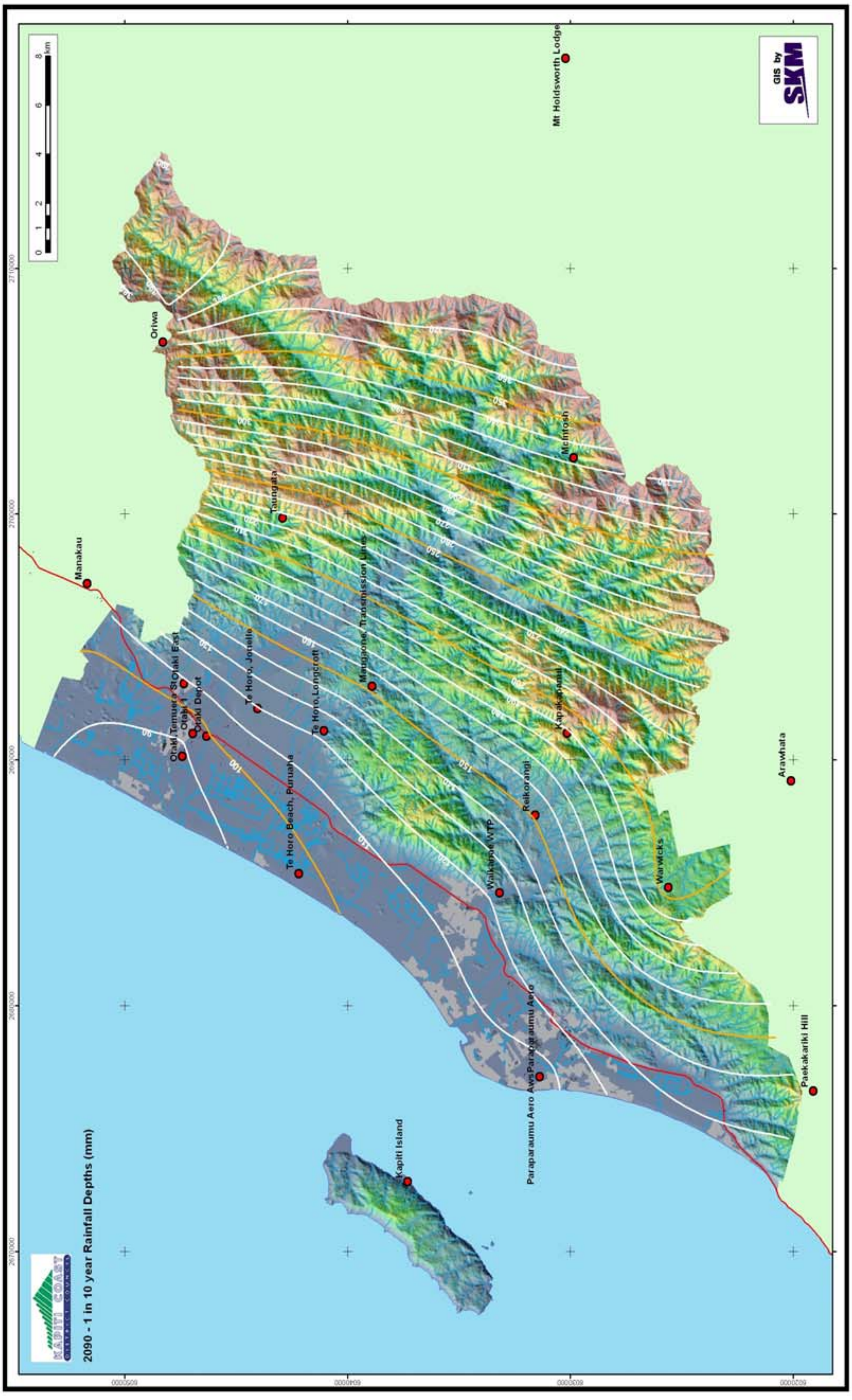
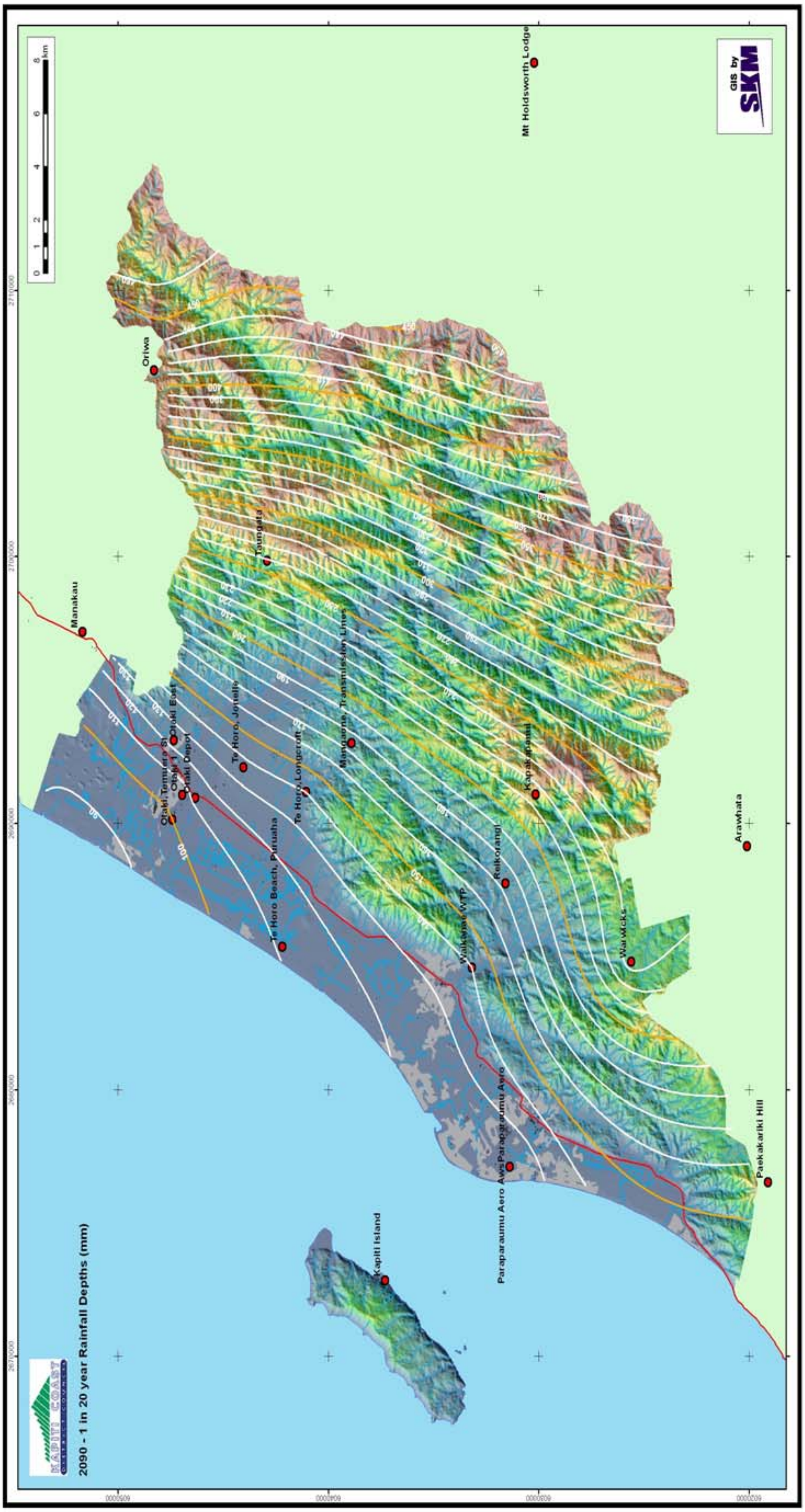
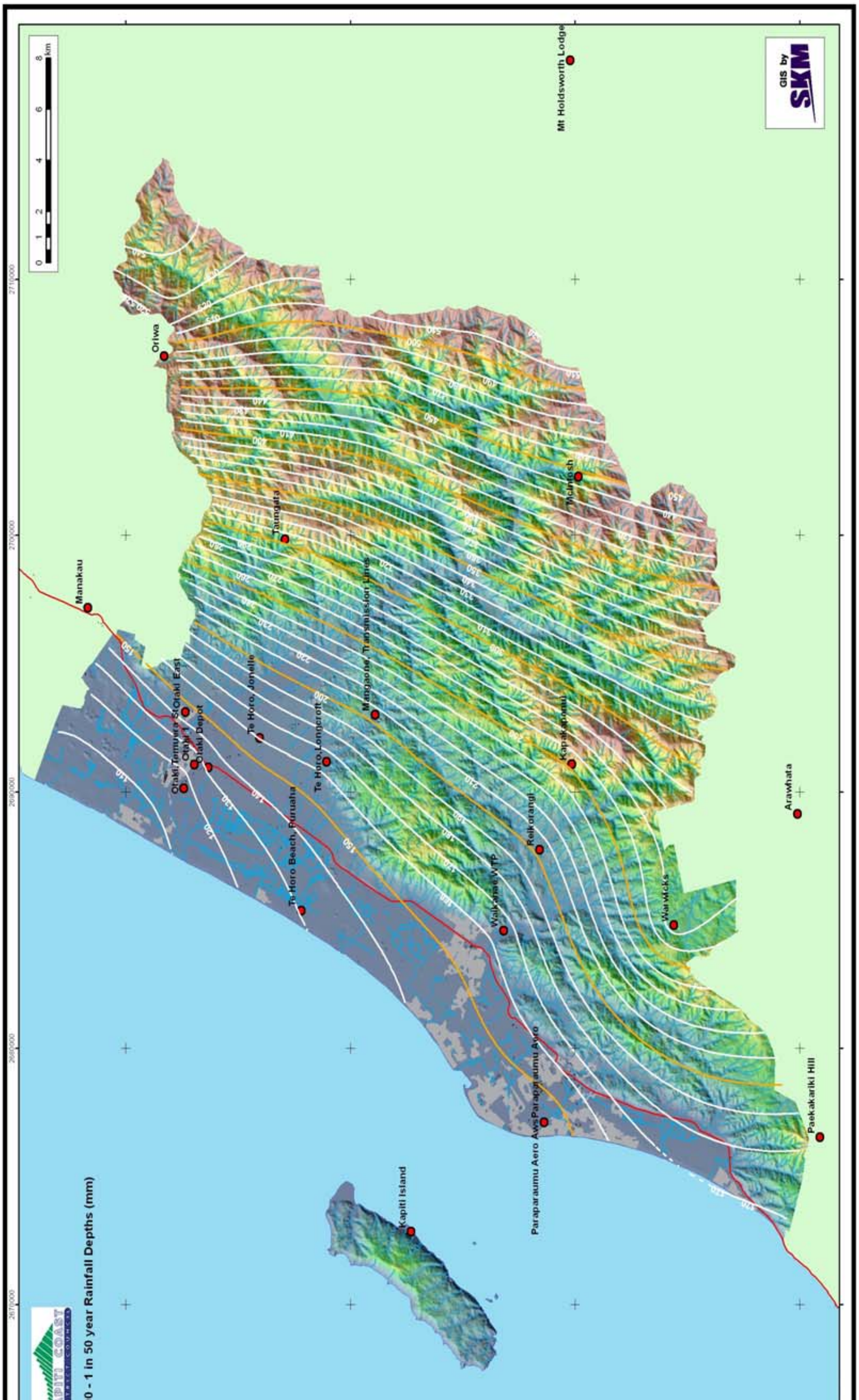
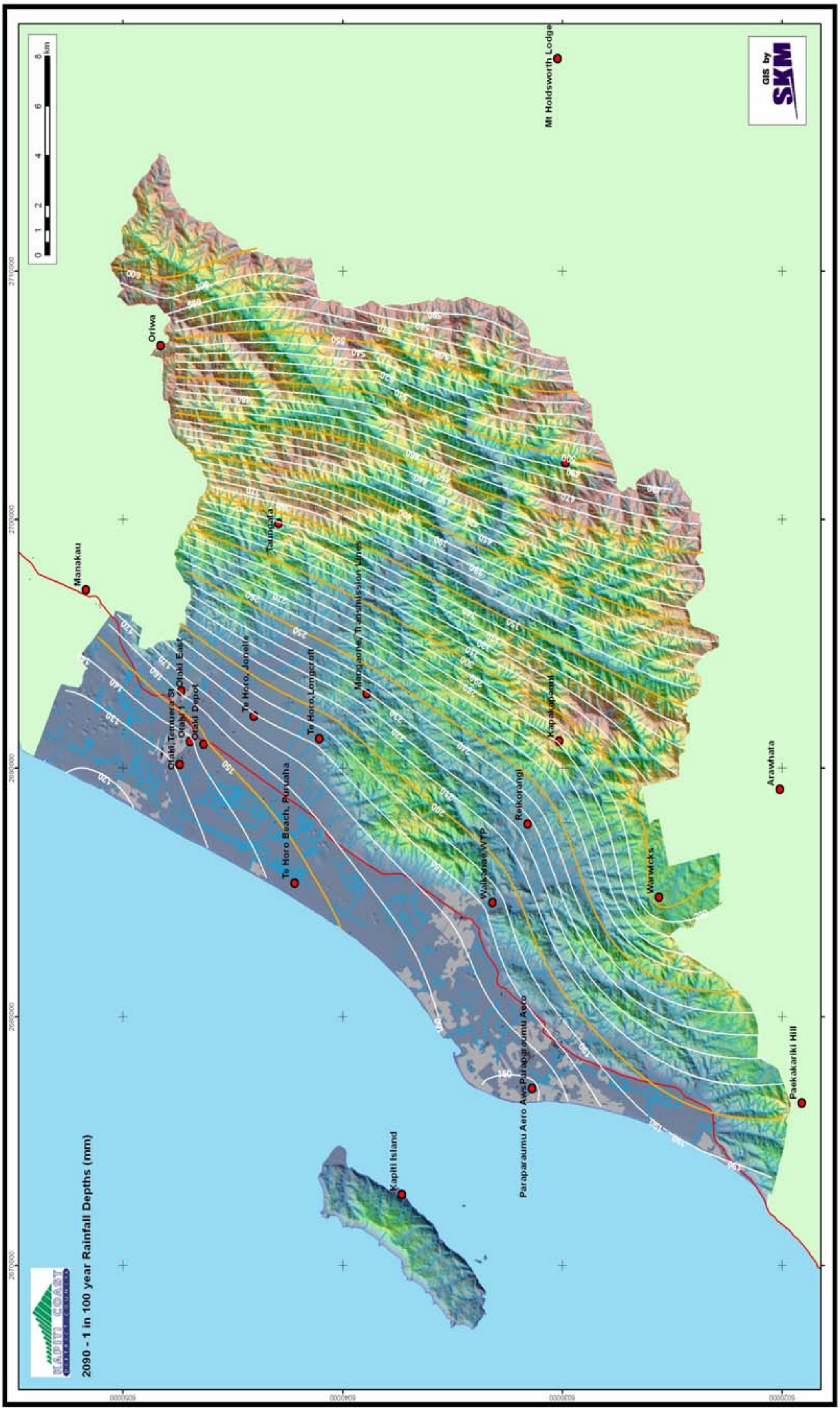
Otaki, Tamuere St
Otaki Depot
Te Horo, Jonelle
Te Horo, Longcroft
Mangaone, Transmission Lines
Kapakapanui
Te Horo Beach, Puruaha
Reikorangi
Arawhata
Waikanae WTP
Warwicks
Paraparaumu Aero Aws
Paraparaumu Aero
Paekakariki Hill
Kapiti Island


2090 - 1 in 10 year Rainfall Depths (mm)
Kapiti Island
Paraparaumu Aero Aws
Paraparaumu Aero
Paekakariki Hill
Waikanae WTP
Reikorangi
Warwicks
Arawhata
Te Horo Beach, Puruaha
Te Horo, Longcroft
Te Horo, Jonelle
Mangaone, Transmission Lines
Kapakapanui
Otaki Depot
Otaki, Temuera St
Otaki East
Manakau
Taungata
McIntosh
Oriwa
Mt Holdsworth Lodge
GIS by SKM


2090 - 1 in 20 year Rainfall Depths (mm)
GIS by SKM
Mt Holdsworth Lodge
Manakau
Oriwa
Otaki East
Otaki Depot
Taungata
Te Horo, Jonelle
Te Horo, Longcroft
Mangaone, Transmission Line
Kapakapanui
Reikorangi
Waikanae WTP
Warwicks
Arawhata
Te Horo Beach, Puruaha
Kapiti Island
Paraparaumu Aero AWS
Paraparaumu Aero
Paekakariki Hill


2090 - 1 in 50 year Rainfall Depths (mm)
Kapiti Island
Paraparaumu Aero
Paekakariki Hill
Arawhata
Mt Holdsworth Lodge
Waikanae WTP
Reikorangi
Kapakapanui
Warwicks
Oriwa
Manakau
Taungata
Mangaone Transmission Lines
Otaki Depot
Otaki East
GIS by SKM


2090 - 1 in 100 year Rainfall Depths (mm)
KAPITI COAST DISTRICT COUNCIL
GIS by SKM
km
Manakau
Oriwa
Otaki East
Otaki Depot
Te Horo, Longcroft
Mangaone Transmission Lines
Kapakapanui
Reikorangi
Waikanae WTP
Warwicks
Arawhata
Paekakariki Hill
Paraparaumu Aero
Kapiti Island
Mt Holdsworth Lodge

Appendix B Curve Number Delineation Tables

(Sourced from USACE, 2000)

Table 2-2a – Runoff curve numbers for urban areas[1] (SCS, 1986)

Cover Description		**Curve numbers for hydrologic soil group**			
Cover type and hydrologic condition	**Average percent impervious area[2]**	**A**	**B**	**C**	**D**
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, gold courses, cemeteries etc)[3]					
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 right-of-way)		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)[4]		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)	65	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)[5]		77	86	91	94
Idle lands (CN's are determined using cover types similar to those in table 2-2c)					

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

[2] The average percent impervious area shown was used to develop the composite CN's. 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. CN's for other combinations of conditions may be computed using figure 2-3 or 2-4.

[3] CN's shown are equivalent to those of pasture. Composite CN's may be computed for other combinations of open space cover type.

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

[5] Composite CN's to use for the design of temporary measures during grading and construction should be computed using figure 2-3 and 2-4, based on the degree of development (impervious area percentage) and the CN's for the newly graded pervious areas.

Table 2-2b – Runoff curve numbers cultivated agricultural lands[7] (SCS, 1986)

Cover Description			Curve numbers 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		Good	55	69	78	83
Meadow	C&T	Poor	63	73	80	83
		Good	51	67	76	80

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

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) percent of residue cover on the land surface (good ≥ 20%), and (e) degree of surface roughness.

Poor: Factors impair infiltration and tender to increase runoff.

Good: Factors encourage average and better than average infiltration and tend to decrease runoff.

Table 2-2c – Runoff curve numbers for other agricultural lands[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
1) 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: 5* 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 curve number is less than 30; use CN = 30 for runoff computations.

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

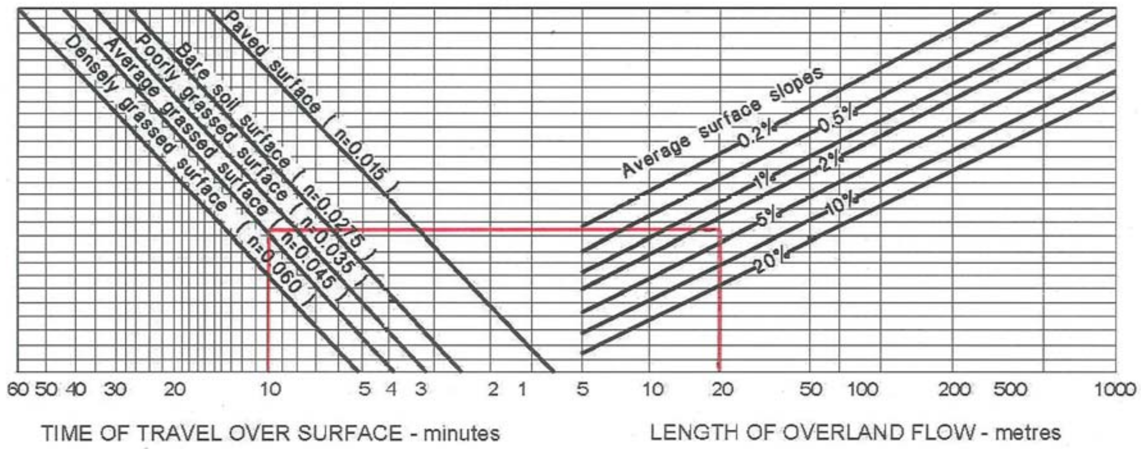
SCS TR-55 Table 2-2d – Runoff curve numbers for arid and semi-arid rangelands[16]

Cover Description		Curve numbers for hydrologic soil group			
Cover Type	Hydrologic Condition[17]	A[18]	B	C	D
Herbaceous – mixture of grass, weeds and low-growing brush, with brush the minor element	Poor		80	87	93
	Fair		71	81	89
	Good		62	74	85
Oak-aspen – mountain brush mixture of oak brush, 2) aspen, mountain mahogany, bitter brush, maple, and other brush	Poor		66	74	79
	Fair		48	57	63
	Good		30	41	48
Pinyon-juniper – pinyon, juniper or both; grass understorey	Poor		75	85	89
	Fair		58	73	80
	Good		41	61	71
Sagebrush with grass understory	Poor		67	80	85
	Fair		51	63	70
	Good		35	47	55
Desert shrub – major plants include saltbrush, Greasewood, creosotebush, black brush, bursage, Palo verde, mesquite and cactus	Poor	63	77	85	88
	Fair	55	72	81	86
	Good	49	68	79	84

[16] Average runoff condition, and $I_a = 0.2S$.
[17] *Poor :* <30% ground cover (litter, grass and brush overstory).
Fair: 30 to 70% ground cover
Good: >705 ground cover
[18] Curve numbers for group A have been developed only for desert shrub

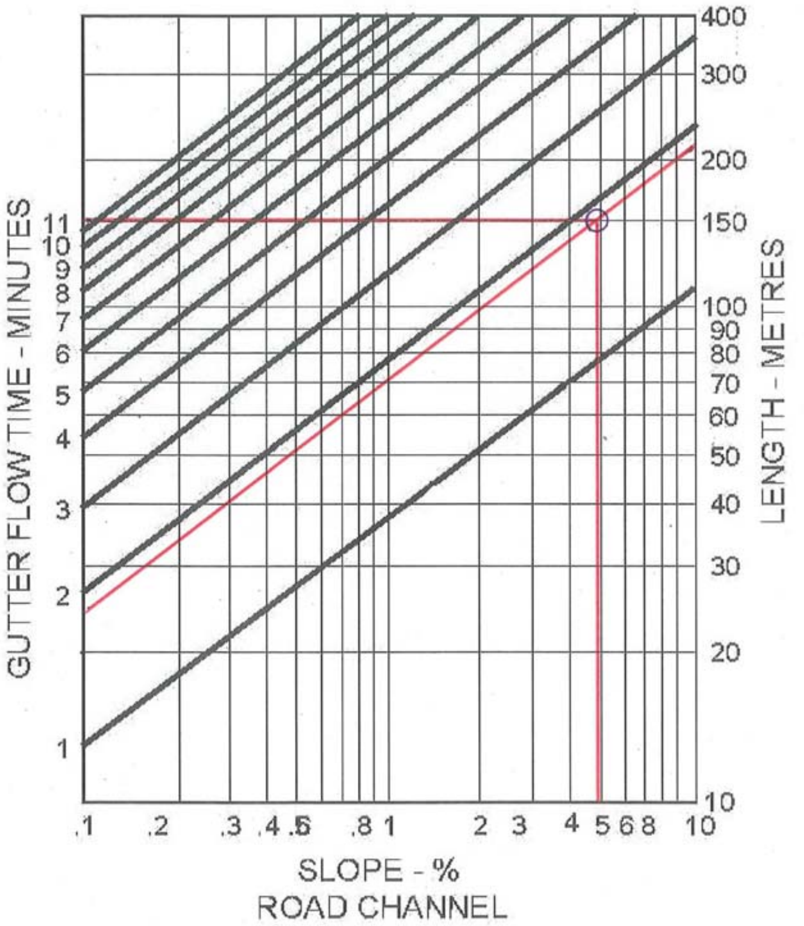
Appendix C Time of Concentration Calculations

Overland Flow Calculation



Source: Compliance Document for
New Zealand Building Code
Clause E1
Surface Water

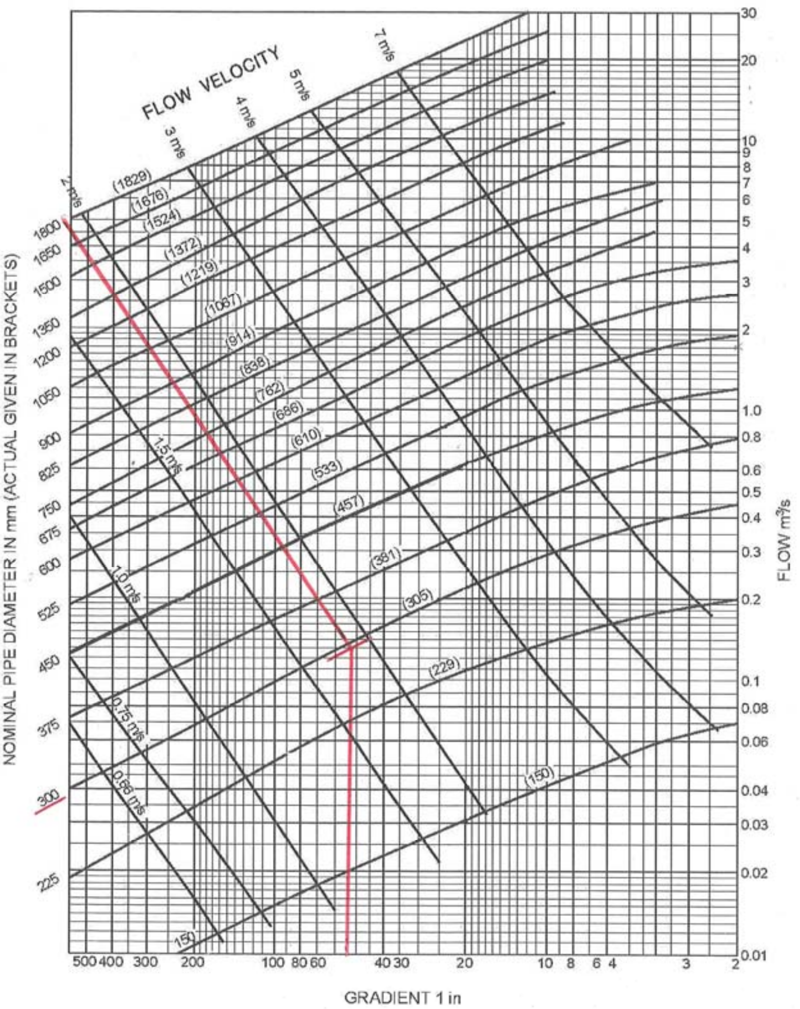
Gutter Flow Calculation



Source: Compliance Document for
New Zealand Building Code
Clause E1
Surface Water

Pipe Flow Calculation

(note: chart relates to concrete pipes)



Source: Compliance Document for
New Zealand Building Code
Clause E1
Surface Water