Impact of Land Use Change on Floods in the Upper Waikato

PHASE 2: MODEL CALIBRATION AND FLOOD HYDROGRAPH GENERATION

- FINAL
- 18 November 2009

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Executive Summary

Environment Waikato (EW) commissioned Sinclair Knight Merz (SKM) to develop a hydrological model of the upper Waikato catchment to assess potential impacts to floods from land use change. The work detailed in this document is the second of two concurrent modelling studies, the first of which was undertaken by NIWA using a gridded approach. The project was guided with assistance from a technical expert panel (TEP) comprising representatives from EW, SKM, NIWA and other individuals.

Development of the modelling was carried out using the HEC-HMS package with the Soil Moisture Accounting (SMA) algorithm selected as the primary rainfall-runoff modelling code. Model parameters were lumped for sub-basins (areas of similar soil and land use within hydrological catchments). Initial parameter values were assigned based on Land Resource Inventory (LRI) and field testing data. Parameters were then revised and refined through calibration to individual gauged catchments.

A common rainfall dataset was used as input to both NIWA and SKM models, comprising a spatially distributed (gridded) rainfall time series based on all available rainfall data. Gridded rainfall time series were distilled into lumped rainfall time series for each of the catchments to be simulated.

The performance targets of calibrations to five key gauged catchments were agreed by the TEP, namely:

- That the simulated distribution of three day flow volume annual maxima falls within the 90% confidence bands of the observed distribution; and,
- That simulated hydrographs of the observed July 1998 and February 2004 flood events reasonably match the observed event hydrographs.

Calibration targets to gauged catchments were achieved to an acceptable standard by the model detailed in this report.

Parameters selected in the calibration process were transposed to the ungauged parts of the study area based on the spatial distribution of soil type, land use and geology. The "whole of catchment" model was run and results of total catchment flow were compared (for validation) to differences between observed hydrolake outflows (i.e. incremental catchment flows). An acceptable performance target was agreed by the TEP that July 1998 and February 2004 flood flow volumes from the whole catchment be simulated within 20% of observations.

Model results were compared to differences between lake outflows and show a reasonable match. However, uncertainties in the data hindered direct comparison of simulated and observed data, particularly with respect to the inflow between Lakes Taupo and Whakamaru. Simulated flow volumes in the whole catchment and in the catchment between Lakes Whakamaru and Karapiro were both within 10% of observations during the July 1998 flood event.

Model simulations were run for a base case land use and a prescribed land use change scenario as agreed by the TEP based on current areas of forest deemed viable for grazed pasture use. A range of six storm magnitudes were simulated using the temporal rainfall pattern of the February 1958 storm event.

The results of numerical rainfall-runoff model simulations conducted to date suggest the following:

- Reduction of maximum soil infiltration rates is the principal mechanism by which flood magnitudes increase following forest to pasture conversion;
- The model calibration (supported by field testing) indicates very high infiltration rates in pumice soils under both forest and pasture land uses;
- 94% of the land use change in the specified scenario occurs on pumice soils;
- Model infiltration capacities of pumice soils in pasture are only exceeded at the catchment scale in the highest rainfall intensity events;
- Supported by the above evidence, the impacts of land use change on floods in the Upper Waikato catchment (Taupo – Karapiro) will be relatively minor (1% increase with 5 year frequency; 4-10% increase expected once in a person's lifetime and up to 16% increase to flood peaks occurring very rarely), and;
- While results of this study indicate relatively minor impacts from the simulated land use conversion scenario, any potential deforestation over less pervious soil types such as loams, podzols, silts or clays are expected to have local impacts of much greater severity. The regional impacts however will depend on the proportion of land of these soil types within the catchment that are to be converted.

Contents

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1. Introduction

1.1. Background

Environment Waikato (EW) is concerned about the possible flooding impacts of land use change from forest to pasture in the upper Waikato River catchment. A Technical Expert Panel (TEP) comprising representatives for various major stakeholders in the catchment was formed to assess this issue and commissioned two independent modelling studies. NIWA undertook the "first" model, which followed a continuous simulation approach, while Sinclair Knight Merz (SKM) and EW working together undertook the "second" model following a more event based approach with emphasis on simulating floods.

The "second" model study was undertaken in two phases, namely:

- Data collection and selection of a suitable model; and
- Calibration of the selected model and generation of flood hydrographs.

This report documents the development, calibration and simulation results from the modelling exercise undertaken using the selected HEC-HMS model.

1.2. Model Selection

The first phase of the study compared the SKM Soil Moisture Water Balance Model and the HEC-HMS model to assess their suitability as the "second" model to determine the impact of land use change on floods from the Upper Waikato Catchments. The first phase report (SKM, 2008) recommended that the U.S. Army Corps of Engineers' Hydrologic Engineering Center Hydrologic Modelling System (HEC-HMS) model be used in the detailed second phase of the study.

1.3. Objectives

The key objective of the study is to understand the relative impact of land use change on flood peaks and volumes through the hydrolake system ending at Lake Karapiro.

2. Methodology

2.1. Overview of Model Operation

HEC-HMS system incorporates a variety of algorithms that are used to simulate catchment processes to various degrees of complexity. The algorithms selected for this study are listed in **Table 1**.

Table 1. Selected components of the HEC-HMS model.

Model operation	Selected algorithm
Loss model	Soil Moisture Accounting (SMA) method
Runoff routing	Clark Unit Hydrograph method
Baseflow routing	Linear Reservoir

The flow of information between the model components is illustrated in **Figure 1**. All catchment losses such as evaporation from the canopy, soil zone and surface storage are calculated in the SMA routine. The primary input to this routine is precipitation, and the suite of parameters defining its operation. Outputs from the SMA are catchment losses, direct surface runoff, and baseflow. The SMA has two baseflow components, representing rapid groundwater response (interflow) and slower groundwater response (true baseflow).

Surface runoff output from the SMA routine is routed through a runoff routing model. The Clark Unit Hydrograph method was chosen for this study.

Similarly, baseflow is routed through a post-processor to simulate baseflow attenuation. For this application the linear reservoir option was selected. Separate linear reservoirs were used to route each of the two baseflow components produced by the SMA model.

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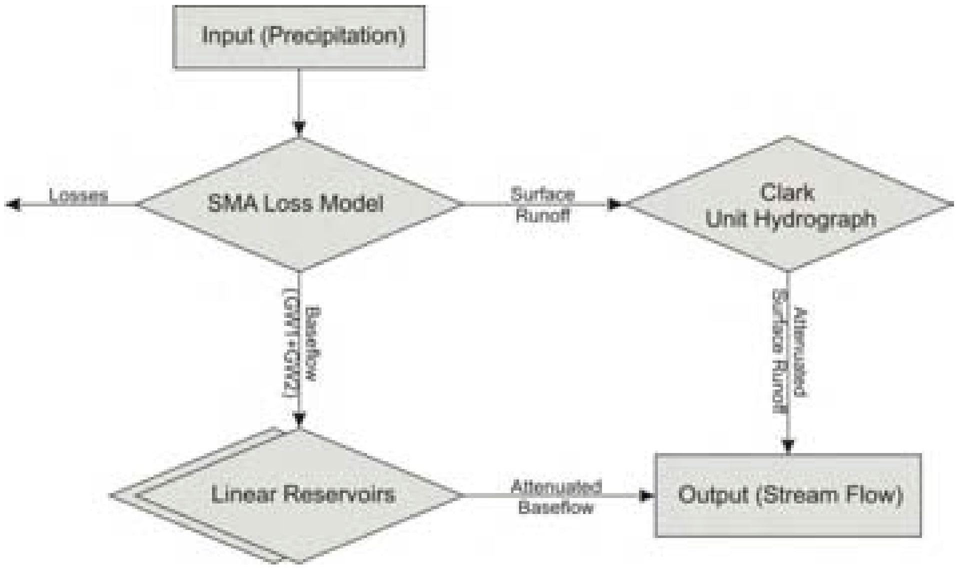


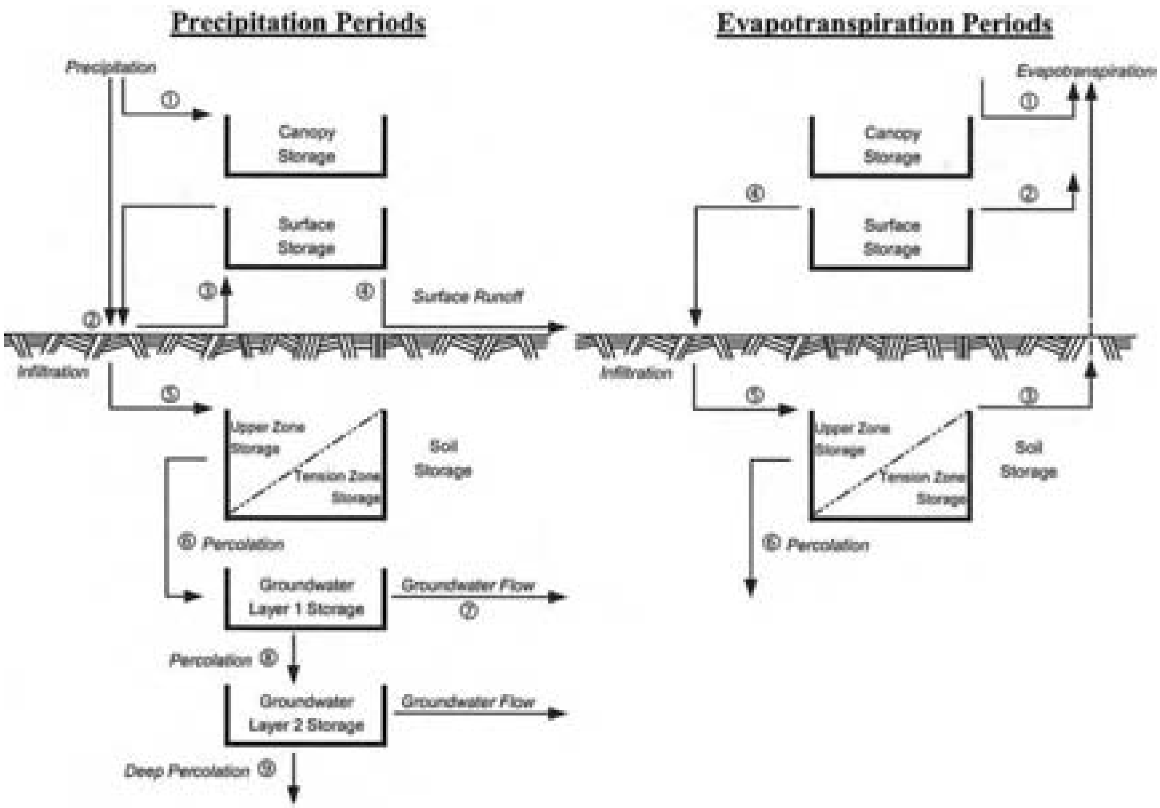
▪ **Figure 1. Interaction of HEC-HMS model components.**

2.1.1. SMA Loss Model Operation

The Soil Moisture Accounting method uses five storage components:

1) Canopy storage;
2) Surface (ponding) storage;
3) Soil moisture storage;
4) Groundwater layer 1 storage, and;
5) Groundwater layer 2 storage.

Basic operation of the SMA model is illustrated in **Figure 2**.



- **Figure 2. Operation of the SMA model (sourced from Bennett and Peters, 2000).**

The SMA model operates in two modes depending on the occurrence or absence of precipitation in the current time step (as illustrated in **Figure 2**).

While precipitation occurs, canopy storage must initially be satisfied (1) and once the canopy is full, remaining precipitation will be available for infiltration (5) and surface storage (3). Water available for infiltration is the combination of any surface storage and precipitation reaching the surface (2). When this exceeds infiltration capacity, surface storage must then be filled before surface runoff (4) occurs. No evapotranspiration occurs in the SMA model while precipitation is occurring.

Infiltrated water (5) fills the soil moisture storage component, which is made up of two compartments (upper zone storage and tension zone storage). Soil evaporation can occur from the whole soil zone while there is no precipitation, but percolation (6) can only occur from the upper zone storage.

Water that percolates from the soil zone (6) enters the upper groundwater layer (GW1) where it is divided into two components, groundwater flow and percolation to the second or lower

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groundwater layer (GW2). Water stored in GW2 may leave as baseflow and as deep percolation out of the catchment system (9 – optional).

In the three subsurface storage components, flow between each layer is controlled by model parameters and the storage level within the donating and receiving storage zones. As such, parameter selection is complex due to interdependences with results sensitive to changes.

Model Parameters

A summary of the parameters used in the SMA model is provided in **Table 2**. A more detailed description of model computations is provided in **Appendix A**.

- **Table 2. Summary of SMA model parameters.**

Parameter	Units	Comments
Canopy storage capacity	mm	Depth of water potentially held by the canopy storage zone.
Surface storage capacity	mm	Depth of water potentially held by the surface storage zone. This is essentially the initial loss, and becomes less influential with increasing flood magnitude.
Maximum infiltration	mm/hr	Upper limit to the soil infiltration rate. Actual infiltration capacity is scaled based on the soil moisture deficit.
Impervious area	%	Impervious proportion of the catchment connected to drainage channels.
Soil storage capacity	mm	Depth of water potentially held in the soil moisture storage zone. Equal to tension zone storage plus upper zone storage.
Tension zone capacity	mm	Depth of water potentially held in the tension zone compartment of soil moisture storage. Must be less than or equal to the soil storage capacity.
Maximum soil percolation rate	mm/hr	Upper limit of the rate of percolation to GW1. Actual percolation is limited based on the GW1 storage deficit and the amount of soil moisture storage.
GW1 storage capacity	mm	Depth of water potentially held in GW1.
GW1 percolation rate	mm/hr	Upper limit of the rate of percolation from GW1 into GW2. Actual GW1 percolation is limited based on the storage values of GW1 and GW2.
GW1 coefficient	hr	Determines the proportion of storage in GW1 that is routed to stream flow in each time step.
GW2 storage capacity	mm	Depth of water potentially held in GW2.
GW2 percolation rate	mm/hr	Upper limit of the rate of percolation from GW2 out of the system (i.e. deep percolation). Actual GW2 percolation is limited based on the storage value of GW2.
GW2 coefficient	hr	Determines the proportion of storage in GW2 that is routed to stream flow in each time step.

Initial conditions for each of the storage components must also be defined.

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2.1.2. Clark Unit Hydrograph

Routing of any surface runoff was carried out using the Clark Unit Hydrograph method. This attenuates runoff based on a time of concentration (T_c) and a storage lag coefficient.

2.1.3. Linear Reservoir Baseflow Routing

Baseflow routing was modelled using a linear reservoir post-processor. This model requires two baseflow recession coefficients, one for each of the groundwater components produced by the SMA model.

2.1.4. Model Hierarchy

Within HEC-HMS, the core modelling element is the basin. A basin can comprise a number of sub-basins connected by channel routing elements, storage reservoirs, sources and sinks etc.

For the purpose of this investigation, each significant catchment to be modelled (either a gauged catchment or tributary to the hydro reservoirs) was modelled as a separate basin element.

The rainfall-runoff process was modelled at the sub-basin level within HEC-HMS. For this investigation, each basin was divided into a set of homogeneous sub-basins each having a single soil type and land use type. The sub-basins are lumped catchments and are not necessarily a single contiguous area. The definition of homogeneous sub-basin areas is discussed later in this report (**Section 4**).

2.2. Calibration Approach

The following sections describe the initial approach taken to calibrate the models. The approach was refined during the initial stages of model calibration, as a greater appreciation of parameter sensitivity was developed.

2.2.1. Parameter Definition

To facilitate the final process of assigning model parameters into the ungauged areas of the catchment, rules to define each parameter were developed to form the basis for transposition. The levels at which parameters were defined are as follows:

- ***Global level*** – the parameter is assigned a single value for the whole model.
- ***Basin level*** – the parameter value relates to the physical catchment and is assigned the same value for each sub-basin element within the basin.
- ***Sub-basin level*** – the parameter is linked to a homogeneous sub-basin type. Parameters may be defined for either soil type only, land use only, or the combination of both.

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The definition levels applied to each model parameter are provided in **Table 3** as well as the basis for parameterisation, which is discussed further in the next section.

- **Table 3. Summary of parameter definition.**

Parameter	Definition level	Basis for parameterisation
SMA Loss Model		
Canopy storage	Sub-basin (land use)	Pre-defined*
Surface storage	Global	Pre-defined*
Maximum soil infiltration	Sub-basin	Calibrated parameter
Impervious area	Global	Pre-defined*
Soil storage	Sub-basin	Pre-defined*
Tension storage	Sub-basin	Pre-defined*
Maximum soil percolation	Sub-basin	Pre-defined*
GW1 storage	Basin (geology)	Calibrated parameter
GW1 percolation rate	Basin (geology)	Calibrated parameter
GW1 coefficient	Basin (geology)	Calibrated parameter
GW2 storage	Basin (geology)	Calibrated parameter
GW2 percolation rate	Basin (geology)	Calibrated parameter
GW2 coefficient	Basin (geology)	Calibrated parameter
***Baseflow Linear Reservoir*[1]**		
GW1 baseflow recession	Basin (geology)	Calibrated parameter
GW2 baseflow recession	Basin (geology)	Calibrated parameter
Clark Unit Hydrograph		
Time of concentration	Basin	USSCS T_c calculation
Storage	Basin	Calibrated

*See following section for details; [1]These parameters have been reduced where possible so that baseflow attenuation is modelled mainly within the SMA package.

The parameters that control sub-soil hydrology (GW1 and GW2 storage, percolation rate and recession coefficient) were calibrated at the basin level and defined for the predominant basin geology, rather than soil type at the sub-basin level. This approach was selected because during the calibration process, it was found that each gauged catchment had a unique groundwater response, irrespective of soil type (i.e. driven by geology).

Specifically, recessions for the gauged catchments in the western part of the study area showed a more typical linear baseflow recession response, whereas recessions for rest of the study area appeared to have a more attenuated and steady baseflow component. Analysis of regional geology suggested that the difference is governed by the nature of the underlying geological formations. Further details are provided in **Section 4.3.3**.

2.2.2. Pre-defined Parameters

Due to the large number of parameters required for the SMA model, some of the model parameters were pre-defined based on existing information. These parameters were kept unchanged during the calibration process, thus reducing the number of adjusted parameters. A summary of the pre-defined parameters and basis for assignment is provided below.

- ***Canopy storage*** – This was assigned a parameter of 2 mm for all non-forest areas and 2.5 mm for all forested areas (after Fleming and Neary, 2004).
- ***Surface storage*** – This parameter was assigned a value of 9.6 mm globally (after Fleming and Neary, 2004). This parameter essentially equates to the initial loss component of flood events, and becomes of less significance with increasing flood magnitude.
- ***Soil storage capacity*** – Defined for each homogeneous sub-basin type (soil type/vegetation cover) based on spatially averaged potential rooting depth held in the NZLRI database, and average porosity information held by Environment Waikato. Values vary from 790 to 1070 mm from loam to podzol soils.
- ***Tension storage capacity*** – Defined for each homogeneous sub-basin type based on potential rooting depth and microporosity. Values vary from 380 to 625 mm from loam to podzol soils.
- ***Maximum soil percolation*** – Assigned as the soil infiltration capacity of the soil type under forest to promote routing of infiltrated water through GW1.
- ***Impervious area*** – Assigned as zero globally.
- ***Time of concentration*** – T_c was calculated using the USSCS formula (a function of flow path length and elevation change) for each basin.
- ***Storage parameter (Clark Unit Hydrograph)*** – Values of the storage coefficient (T_s) were assessed for a number of the gauged catchments by measuring the maximum slope of flood recessions. A linear relationship was used to relate T_s to T_c based on theory.

2.2.3. Calibrated Parameters

The remaining parameters were changed iteratively during the calibration of each gauged catchment so that selected criteria of the simulated flows matched those from the observed flows.

The main parameters that were adjusted were:

- Soil infiltration capacity;

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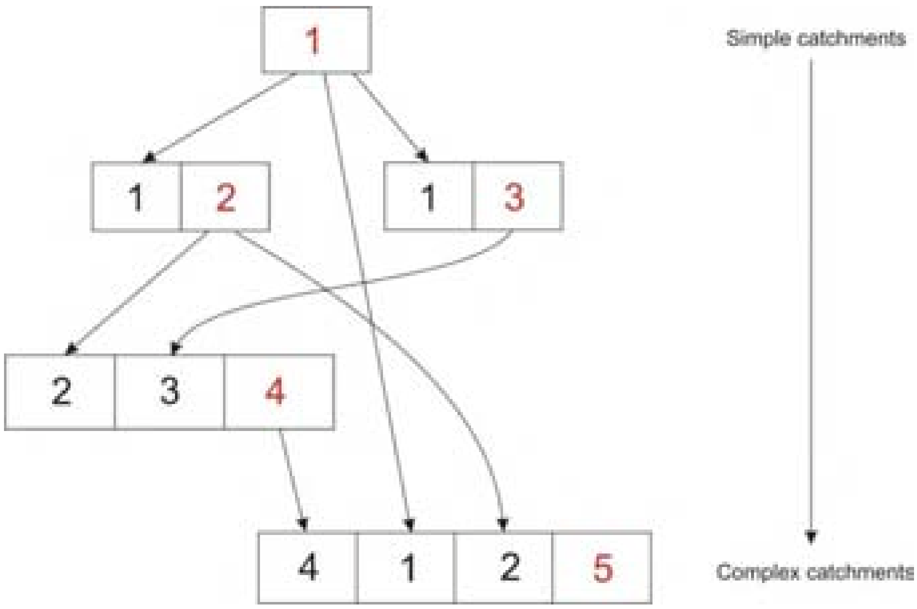
- GW1 and GW2 storage;
- GW1 and GW2 recession coefficients, and;
- GW1 and GW2 percolation rates.

2.2.4. Calibration Sequence

The gauged catchments have differing degrees of complexity in terms of the number of homogeneous sub-basins within each catchment. It was also recognised that parameterisation of individual homogeneous sub-basin types would be more viable for catchments with single or few sub-basin types.

The logical progression for model calibration initially adopted for this study was to start by calibrating the simple gauged catchments before progressing to the more complex catchments. Homogeneous sub-basins parameterised for the simple catchments were then transposed to the more complex catchments. In complex catchments, parameters for unparameterised sub-basins were adjusted until the simulated matched the observed.

The concept is illustrated in **Figure 3**. Groups of boxes represent gauged catchments and numbers represent the homogeneous sub-basin types within each gauged catchment (i.e. soil type and land use combinations). Red numbers indicate sub-basins for which parameters were adjusted for the calibration of that gauged catchment and black numbers are sub-basins for which parameters have already been derived from a previous calibration.



- **Figure 3. Schematic diagram of calibration sequence.**

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2.2.5. Calibration Focus

For this investigation, the calibration focus was to match the higher part of the observed 72-hour (3-day) flood volume distribution. This was agreed by the technical expert panel (TEP) on the basis that longer duration floods such as the July 1998 event are of most concern.

It is also important that the catchment water balance is represented by the model in a realistic manner, however base flows and smaller floods were not a focus of the calibration.

2.2.6. Temporal Control

The HEC-HMS model was run using a one-hour time step for both the calibration and simulation phases of modelling.

Model time step selection depends on the sensitivity of short duration, high intensity rainfall on the floods of interest. For this study, floods at the hydrolake basin scale are the primary focus. Because the time of concentration in these basins is greater than one hour, it is not necessary to model processes at a sub-hourly iteration.

The other factor influencing time step selection is the availability of input data at the given temporal resolution. The bulk of available rainfall data exist at hourly intervals, with few records available at sub-hourly intervals.

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3. Preparation of Observed Data

This section documents the preparation of stream flow and rainfall data used for the model calibration exercise.

3.1. Available Data

3.1.1. Flow Gauges

Continuous flow records were obtained for 18 sites from Environment Waikato. A summary of these records and their duration is provided in **Table 4**. Flow records with a resolution of less than 1 hour were aggregated to hourly.

- **Table 4. Summary of available stream flow records.**

Site ID	River	Site	Area (km^2)	Start Date	End Date
1043434	Mangakara	Hirsts	22	Jun-69	Apr-93
1443462	Mangahanene	Sh1	8.75	Sep-72	Jan-07
1043427	Mangakino	Dillon Rd	337	Apr-64	Jan-07
2143404	Mangatete	Te Weta Rd	30.6	Dec-86	Dec-94
2043446	Mokauteure	Forest Rd	38	Jul-86	Aug-91
2043497	Orakonui	Ngatamariki	73.5	Sep-87	Mar-92
2143401	Otamakokore	Hossock Rd	40.1	Dec-86	Jan-07
2143412	Otumaheke	Spa Hotel	9.1	Dec-86	Jan-03
43411	Pokaiwhenua	Forest Products Weir	62.1	Jan-60	Nov-99
1043419	Pokaiwhenua	Puketurua	448	Oct-63	Jan-07
1143409	Purukohukohu	Puruki	0.344	Dec-68	Jan-07
1143407	Purukohukohu	Weir	1.69	Mar-70	May-84
1143442	Purukohukohu Stream	Purutaka	0.225	Dec-68	May-06
1043428	Tahunaatara	Ohakuri Rd	210	Apr-64	Jan-07
2043493	Waiotapu	Campbell Rd	47.6	Dec-86	Jul-01
43472	Waiotapu	Reporoa	228	Feb-60	Jan-07
2043441	Waipapa	Mulberry Rd	85.4	May-86	Sep-95
43435	Waipapa	Ngaroma Rd	137	Apr-64	Jan-07

3.1.2. Rainfall

Rainfall for input to the calibration and simulation models was developed in grid format by NIWA for consistent use in both models. Details of the methodology used for generating the hourly rainfall grids are available in the first model (Topnet) report.

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A summary of the key rainfall gauges used to generate the hourly grids is provided in **Table 5**.

- **Table 5. Summary of available rainfall data (hourly timescale).**

Site ID	Site Name	Start Date	End Date
759610	Mangahanene at Kentucky Farm	Sep-75	Aug-91
853510	Puniu at Ngaroma	Jun-82	Aug-07
855510	Mangaokewa at Wharekiri Stn	Jun-89	Aug-07
862010	Pokaiwhenua at New North Rd	May-63	Jan-94
863136	Tahunaatara at Ohakuri Road	Sep-91	Nov-07
864201	Purukohukohu at No 4	May-69	Oct-07
864210	Mangakara at M1	Aug-64	Jan-94
864336	Waiotapu at Reporoa	Sep-91	Nov-07
865304	Torepatutahi at Sylvan Lodge	Sep-95	May-01
866110	Otumuheke at Tauhara	Dec-84	Aug-91

A number of daily rainfall gauges were also used to provide additional spatial definition of rainfall events. A map showing the location of the rainfall (with hourly data) and stream flow gauges is provided in **Figure 4**.

- **Figure 4. Map of rainfall stations and stream flow gauges.**

(See A3 attachment at rear.)

The gridded rainfall was processed before being used in the HEC-HMS basin models. Spatial analysis identified the rainfall grid points that were situated within each of the basins to be modelled. Hourly time series at each of the identified grid points were averaged to give a single basin rainfall time series for use in the HEC-HMS model.

4. Delineation of Homogeneous Sub-basins

4.1. Introduction

The study area comprises a variety of catchment characteristics that influence runoff. In order to transfer model parameters from gauged catchments to ungauged catchments in the study area, parameters need to be defined for physical land characteristics that are described for the whole study area.

This chapter documents definition of spatial zones with similar hydrological character to support the model calibration process.

4.2. Available Data

Two spatial data sets that contain attributes relating to catchment runoff processes formed a basis for dividing the study area into relatively homogeneous, with respect to runoff characteristics) sub-catchments. These are the New Zealand Land Resource Inventory (NZLRI) database and the New Zealand Land Cover Database Version 2 (LCDB2) and are described below. Standard background information such as topography, rivers, etc. was also available.

4.2.1. NZLRI

The New Zealand Land Resource Inventory database was developed and is maintained by Landcare Research. The database subdivides land into irregular parcels containing information on:

- Rock type;
- Soil type;
- Slope;
- Erosion potential; and,
- Vegetation.

The database also contains a Land Use Capability (LUC) rating, assessing the suitability of land parcels for crop production.

4.2.2. LCDB2

The New Zealand Land Cover Database is a spatial dataset developed by Ministry for the Environment (MfE). It subdivides the land into parcels based on 61 categories describing the physical land cover. The classification is hierarchical, with eight broad classes in the first order of classification.

The classification is based on satellite imagery captured in 1996/97. A national evaluation of map accuracy was carried out in 2000 by Forest Research and estimated to be 93.9% accurate based on 17,000 evaluation points. Land cover change occurring post-2000 is not captured in this database.

4.3. Data Selection and Generalisation

The key land attributes that influence runoff from a catchment are:

1) Land cover (forest/pasture);
2) Soil type; and,
3) Catchment topography (slope).

Land cover and slope characteristics were evaluated independently of one another as they control separate components of the runoff generation process. While land cover influences losses (i.e. affects parameters within the SMA model), catchment topography influences surface runoff routing (i.e. mainly affects Clark Unit Hydrograph parameters).

4.3.1. Land Cover

The LCDB2 dataset was used as a basis for defining broad land cover within the study area. The dataset was aggregated into two main classes (forest and non-forest). Isolated areas of less than 0.5 km^2 of one land cover surrounded by another land cover were ignored to avoid unnecessarily complicating the model.

A map of generalised land cover is presented in **Figure 5**.

- **Figure 5. Generalised land cover map.**
  (See A3 attachment at rear.)

4.3.2. Soil Type

The NZLRI soil group field was used as an identifier of soil type. There are 16 soil types within the study area, as shown in **Table 6** below. By far the most common soil group is the yellow-brown pumice soil (YBP), covering over 3,200 km^2, 71% of the total study area. The yellow-brown loams (YBL) and podzols (POD) are the next most common soil types. Various composite soils and other surfaces make up the remaining small areas of the catchment.

The 16 soil groups have been merged into 3 main types (plus open water) based on the expected hydrological characteristics. These are:

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1) ***Pumice soils (PUM)*** – Occur in relatively young sandy or pumiceous volcanic ash deposits. Characterised by high infiltration capacity and free drainage. Significant depth to groundwater in elevated areas can result in large groundwater storage capacities, which can buffer the peak runoff during floods.
2) ***Loamy soils (LOAM)*** – Finer textured soils (mixture of sand, silt and clay), typically moderately well drained and lower infiltration capacity than pumice soils.
3) ***Podzols (POD)*** – Soils formed under native forest conditions and typically in areas of higher rainfall. Have a horizon with an accumulation of aluminium and/or iron due to acid leaching. Typically moderately to poorly draining.

The reclassification of soil groups is shown in **Table 6**.

- **Table 6. Soil type classification.**

LRI Soil Group Code	LRI Soil Group Name	Simplified Classification	Area (km^2)
YBP	Yellow-brown pumice soil	PUM	3,275.4
YBL	Yellow-brown loam	LOAM	870.5
POD	Podzol	POD	178.8
YBP/YBL	Composite yellow-brown pumice soil on yellow-brown loam	LOAM	62.9
RE	Recent soil	LOAM	38.5
YB	Yellow-brown earth	LOAM	29.0
OR	Organic soil	Surrounding*	27.8
lake	Lake	WAT	27.4
BGC	Brown granular clay	POD	25.4
rive	River	WAT	19.3
town	Town	Surrounding*	11.8
GY	Gley soil	Surrounding*	7.3
PYBL	Podzolised yellow-brown loam	POD	6.2
RE/YBP	Composite recent soil on yellow-brown pumice soil	PUM	4.0
PYBP/YBL	Podzolised composite yellow-brown pumice soil on yellow-brown loam	PUM	0.4
BRock	Exposed bedrock	Surrounding*	0.4

NB: WAT refers to open water areas; "Surrounding" means that isolated areas have been assigned the surrounding soil type.

A map of the soil zones described above is presented in **Figure 6**.

- **Figure 6. Soil type map.**

(See A3 attachment at rear.)

4.3.3. Geology

As discussed in **Section 2.2.1**, a range of baseflow responses (regardless of soil type) were linked to the nature of the underlying geological formations.

The western gauged catchments (Waipapa at Ngaroma Rd and Mangakino at Dillon Rd) overly densely welded Pakaumanu ignimbrites, whereas younger and more pumicious ignimbrites and other formations are predominant in other areas (e.g. the Whakamaru, Mamaku and Mokai ignimbrites). Further detail on calibration of the parameters linked to geology is provided in **Section 5.2.2**.

- **Figure 7. Geology map.**

  (See A3 attachment at rear.)

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5. Model Calibration

This section describes the model calibration process and demonstrates the ability of the model to match observed flow events. The model parameter values derived from the model calibration process are listed (in **Section 5.2**) and form the basis to expand the model to the ungauged parts of the study area for simulation of floods under land use change scenarios.

5.1. Calibrated Catchments

The calibration at each gauge was given a weighting depending on:

- Catchment size relative to the study area;
- Reliability of data;
- The presence of unusual hydrological behaviour relative to apparent similar areas, and;
- Proximity of other calibrated gauges.

On the basis of the considerations above, five key gauged catchments were selected as the focus of calibration. Additional gauged catchments were included based on their unique hydrological regime and the relevance to ungauged areas. These catchments are summarised in **Table 7**.

- **Table 7. Relative weight of each gauged catchment to model calibration.**

Site ID	River	Site	Comment
1043419	Pokaiwhenua	Puketurua	Five largest gauged catchments with a variety of hydrological responses
1043428	Tahunaatara	Ohakuri Rd	
43472	Waiotapu	Reporoa	
43435	Waipapa	Ngaroma Rd	
1043427	Mangakino	Dillon Rd	
1443462	Mangahanene	SH1	Only gauged catchment in the hydrologically responsive northern extent of the study area
2043497	Orakonui	Ngatamariki	Only gauged catchment displaying the extremely subdued hydrology typical of the southern area

5.2. Calibrated Model Parameters

As discussed in **Section 2.2.1**, the model parameters are transposed to areas within the wider catchment at different levels (i.e. globally, basin level and sub-basin level). Calibrated model parameters are presented below in terms of their definition level.

5.2.1. Sub-basin Level Parameters

The calibrated model parameters linked at the sub-basin level (grouped by land cover and soil type) are shown in **Table 8**.

- **Table 8. Calibrated model parameters (sub-basin level).**

Parameter	Units	Forest			Pasture		
		LOAM	POD	PUM	LOAM	POD	PUM
Infiltration capacity	mm/hr	100	9.3	100	7.3	3	15.8
Canopy storage	mm	2.5			2		
Soil zone thickness	mm	791	1066	854	863	1059	930
Tension zone thickness	mm	383	613	514	497	625	594
Soil percolation capacity	mm/hr	100	9.3	100	100	9.3	100

Simulation results are most sensitive to the infiltration capacity and less sensitive to soil zone thickness. Low sensitivity to soil zone thickness occurs because the soil percolation parameters are assigned high values, meaning that water passes through this storage rapidly and rarely fills. The vast majority of modelled soil moisture is held in the tension zone, which can only be depleted by evapotranspiration. This model configuration has been selected to adequately simulate hydrological processes of the free draining pumiceous soils.

The initial definition of maximum soil infiltration rates for the different soil and land use categories were derived from available field testing information.

Infiltration parameters were adjusted during the model calibration process to best replicate the observed runoff characteristics of the gauged catchments on a sub-basin scale. Infiltration excess runoff was visually identifiable in the observed flow records due to its amplified signature compared to subsurface flow processes. Infiltration rates (at the catchment scale) derived from model calibration were approximately an order of magnitude lower than the majority of available spot measurements of infiltration. This can be attributed to:

- the large degree of variability in catchment soil infiltration rates coupled with the fact that the model sub-basins cover a wide area; and,
- the limited number of infiltration measurements.

5.2.2. Basin Level Parameters

Parameters defined at the basin level that were subject to variation during the calibration process are listed in **Table 9**.

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Eight parameters were estimated at the basin level based on different catchment characteristics, namely:

- Time of concentration;
- Surface runoff storage coefficient;
- GW1 and GW2 storage capacities;
- GW1 and GW2 percolation rates; and
- GW1 and GW2 outflow coefficients.

Time of concentration was estimated using the USSCS formula. An approximate relationship between the surface runoff storage coefficient and time of concentration has been developed to allow estimation of this parameter for ungauged catchments and was defined as 1.8 × T_c.

- **Table 9. Calibrated model parameters (basin level) for selected gauged catchments.**

Site Name	GW1 storage (mm)	GW1 percolation rate (mm/hr)	GW1 coeff (hr)	GW2 storage (mm)	GW2 percolation rate (mm/hr)	GW2 coeff (hr)
Pokaiwhenua at Puketurua	60	10	200	1200	0.25	10000
Tahunaatara at Ohakuri Rd	60	6	250	900	0.05	8000
Waiotapu at Reporoa	60	6	300	900	0.05	7000
Waipapa at Ngaroma Rd	500	5	140	700	0	5000
Mangakino at Dillon Rd	500	30	150	800	0	5000
Mangahanene at SH1	250	15	50	1000	0	800
Orakonui at Ngatamariki*	50	50	200	1000	0.18	10000

* Additional groundwater linear reservoir routing parameters of 20 hr and 5000 hr were necessary to calibrate to this catchment (i.e. there were four linear reservoirs operating in series instead of two).

5.3. Calibration Results

Model calibration was evaluated on the basis of the two performance criteria, as follows:

- ***Hydrograph comparison*** – Simulated and observed hydrographs for key flood events (July 1998 and February/March 2004) were compared visually; and
- ***3-day flow annual maxima*** – Graphs of three-day flow volume annual maxima distributions for observed and simulated flow.

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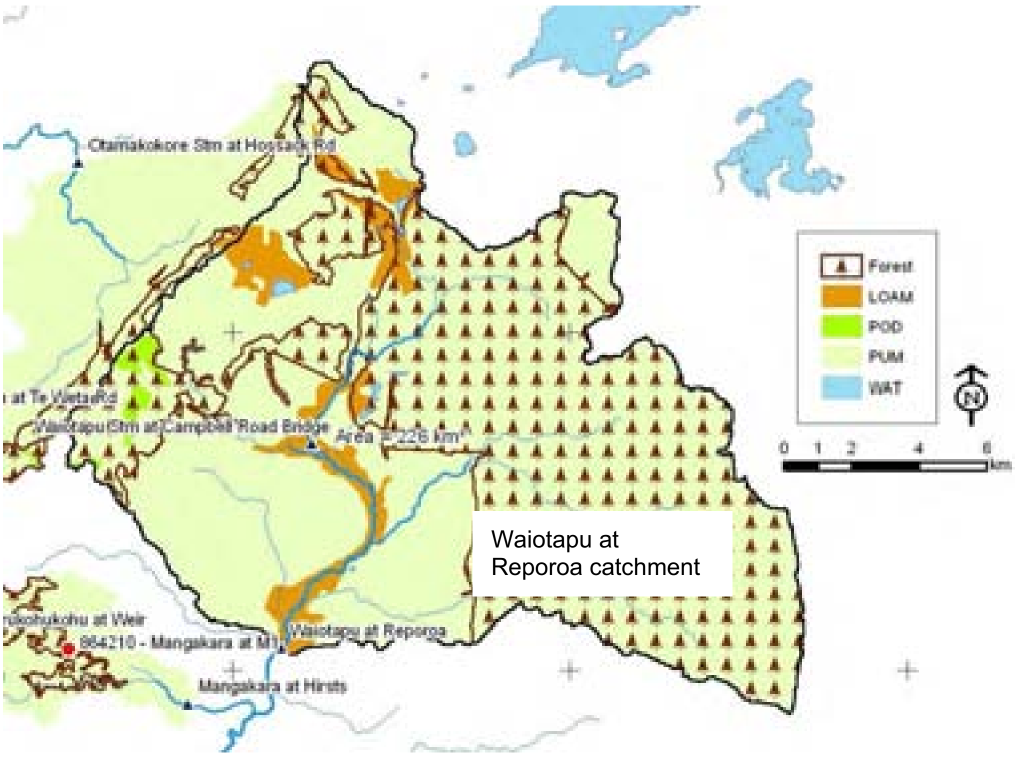
This section illustrates the model calibration process and performance for two gauged catchments. Details of the remaining five calibrated catchments are provided in **Appendix B**.

5.3.1. Waiotapu at Reporoa

The Waiotapu gauge at Reporoa has a catchment area of 226 km^2. The maximum elevation difference is approximately 45 m over a flow path length of approximately 26 km. The southern part of the catchment is flat while the northern and eastern areas are steeper. The eastern part of the catchment drains part of the Kaingaroa Plateau. Catchment relief is visible in **Figure 4**.

The catchment predominantly comprises pumice, with small areas of loam soils. The underlying geology comprises poorly consolidated Taupo pumice alluvium and Hinuera formation in the lower catchment. The upper catchment comprises Kaiangaroa ignimbrite to the east and a mixture of dacite and rhyolite domes and ignimbrites in the northern catchment. The layout of this catchment is shown in **Figure 8**.

The catchment has been divided into three homogeneous sub-basins based on the physical characteristics described above. The calibrated parameters for each sub-basin are provided in **Table 10**.



■ **Figure 8. Layout of the Waiotapu at Reporoa gauged catchment.**

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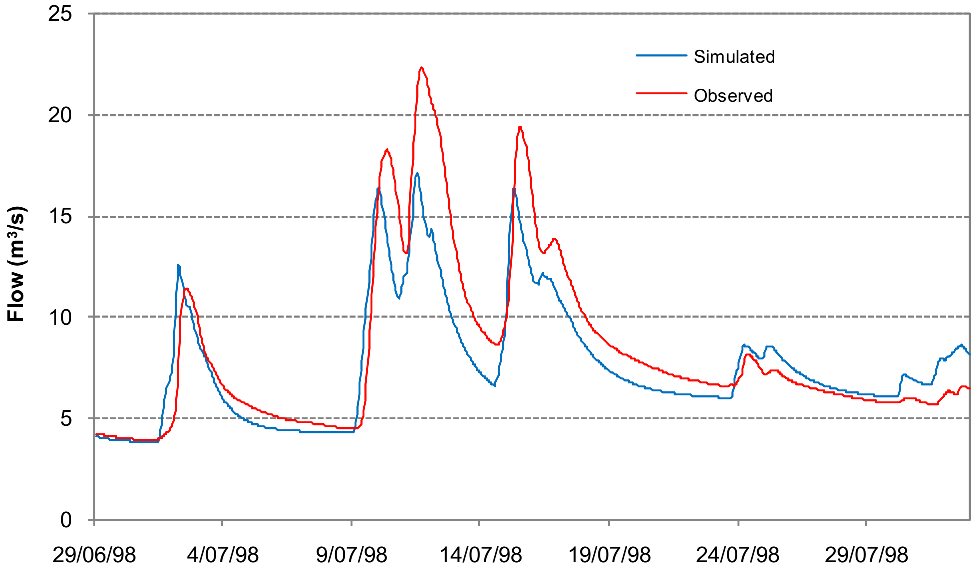
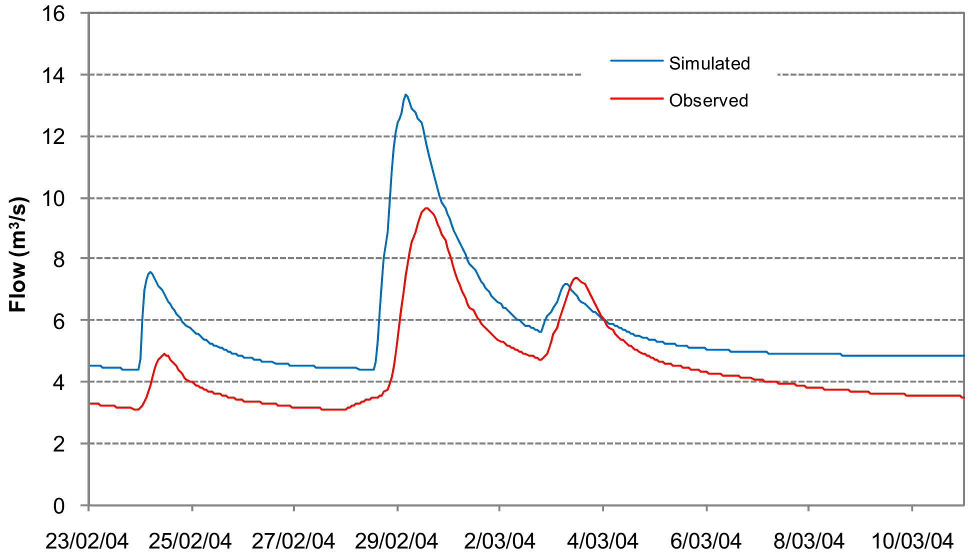
- **Table 10. Calibrated model parameters for the Waipapa at Ngaroma Rd gauged catchment.**

Parameter	Loam, Forest	Pumice, Forest	Pumice, Pasture
Sub-basin area (km^2)	35.1	77.3	24.7
Canopy storage (mm)	2.5	2.5	2
Surface Storage (mm)		9.6	
Maximum soil infiltration (mm/hr)	100	98.6	15.8
Impervious area (%)		0	
Soil zone storage (mm)	791	854	930
Tension zone storage (mm)	383	514	594
Maximum soil percolation rate (mm/hr)	100	98.6	100
GW1 storage (mm)		60	
GW1 percolation rate (mm/hr)		6	
GW1 recession coefficient (hr)		300	
GW2 storage (mm)		900	
GW2 percolation rate (mm/hr)		0.05	
GW2 recession coefficient		7000	
Clark unit hydrograph runoff routing			
Time of concentration (hr)		5.9	
Storage coefficient (hr)		14.6	
Baseflow linear reservoir model			
GW1 baseflow storage coefficient (hr)		0.5	
GW2 baseflow storage coefficient (hr)		5	

Figure 9 and **Figure 10** show the observed and simulated hydrographs for the July 1998 and February 2004 floods, respectively.

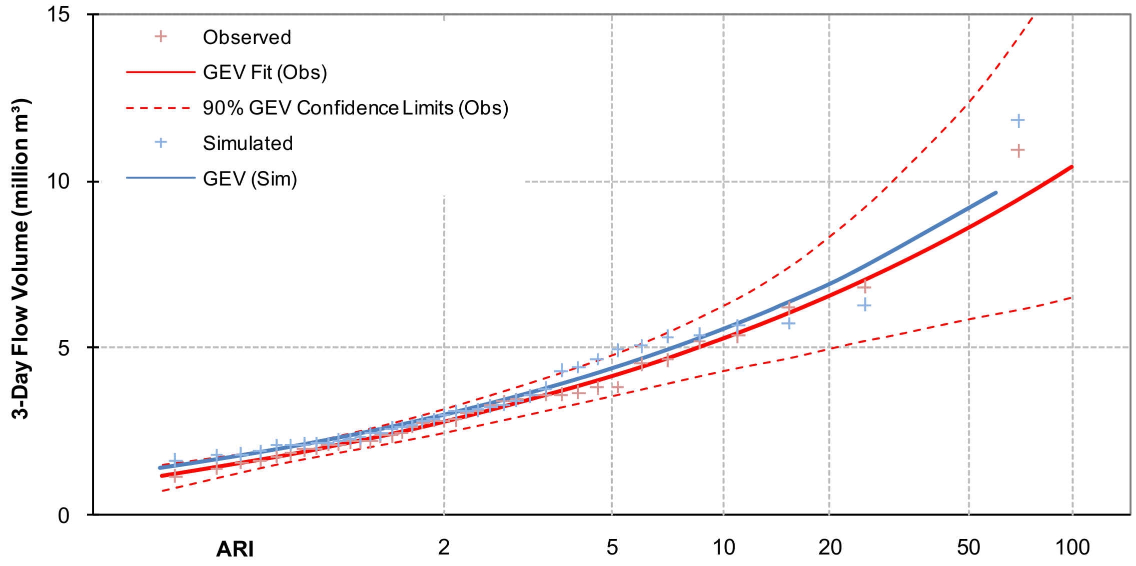


- **Figure 9. Observed and simulated flows for Waiotapu at Reporoa calibration (July 1998 flood).**

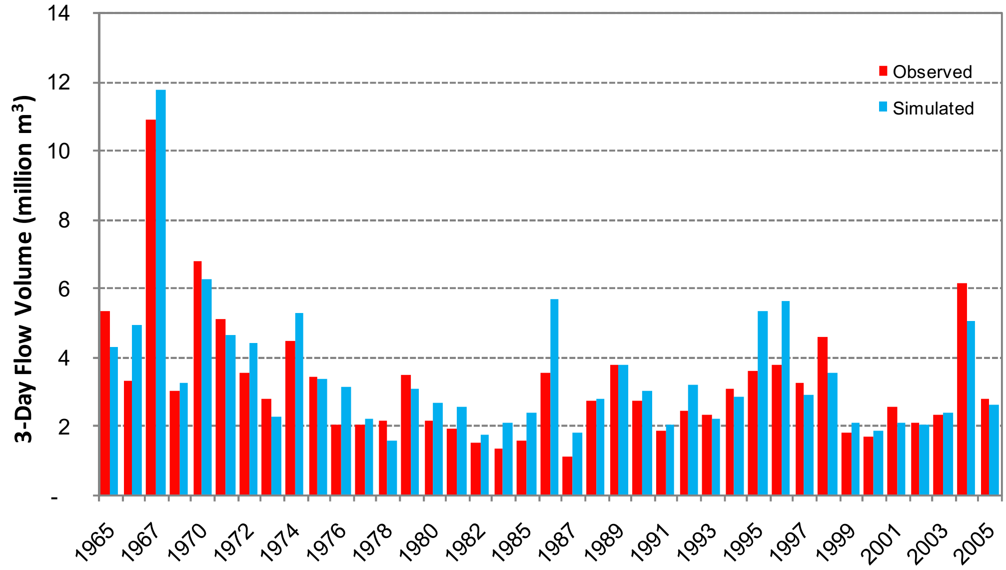


- **Figure 10. Observed and simulated flows for Waiotapu at Reporoa calibration (February 2004 flood).**

The three day flow volume annual maxima were calculated for the overlapping period of observed and simulated flow records. These results are shown in terms of the distribution of 3-day peaks (**Figure 11**) and by calendar year (**Figure 12**).



▪ **Figure 11. Distribution of observed and simulated 3-day flow volume annual maxima for Waiotapu at Reporoa calibration (using Gringorton plotting positions).**



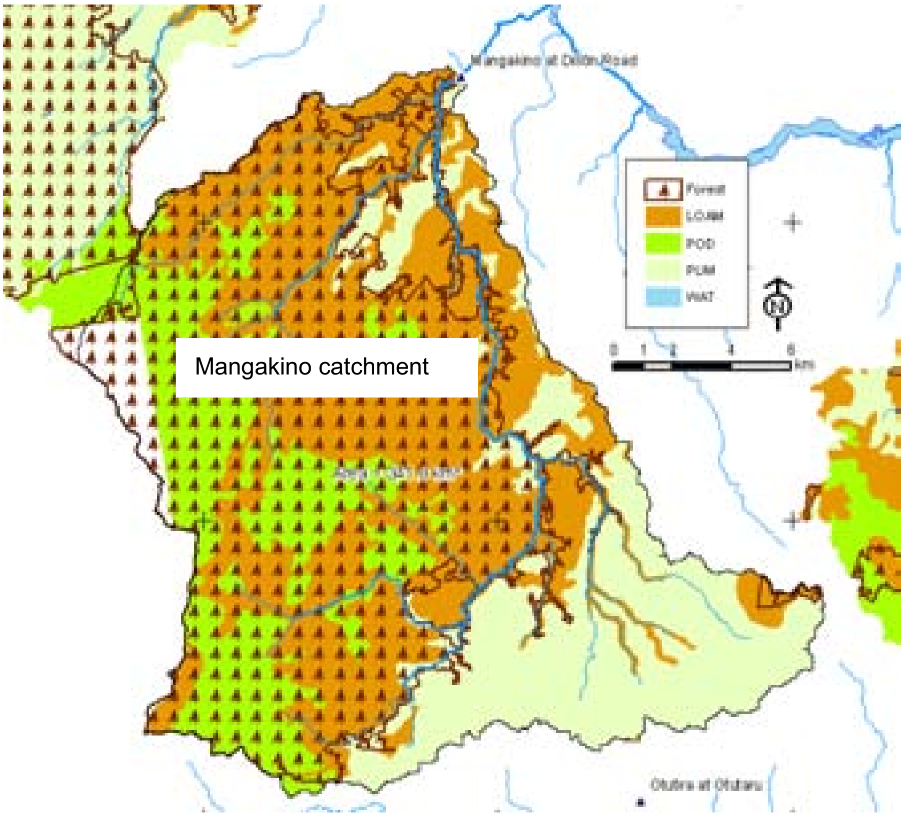
▪ **Figure 12. Observed and simulated 3-day flow volume annual maxima for Waiotapu at Reporoa calibration.**

The calibration is considered to reasonably simulate the observed range of 3-day peak flow events and falls within the 90% confidence bands. Year to year variations in the ability of the model to match flow events are expected in any calibration and can be attributed to uncertainty at a number of levels. In particular, the representativeness of rainfall to average catchment rainfall will change from one event to the next due to spatial and temporal rainfall variability.

5.3.2. Mangakino at Dillon Rd

The Mangakino at Dillon Rd gauge has a catchment area of 342 km^2 and has an elevation difference of approximately 136 m and a stream flow length of approximately 37 km. The catchment comprises some steeper terrain associated with incised stream valleys and andesite cones. General catchment relief is visible in **Figure 4**.

The catchment comprises a relatively even mixture of pumice, loam and podzolic soils. The underlying geology comprises andesite cones, densely welded Pakamanu ignimbrites in the upper catchment and Whakamaru ignimbrites in the lower catchment. The layout of this catchment is shown in **Figure 13**.



- **Figure 13. Layout of the Mangakino at Dillon Rd gauged catchment.**

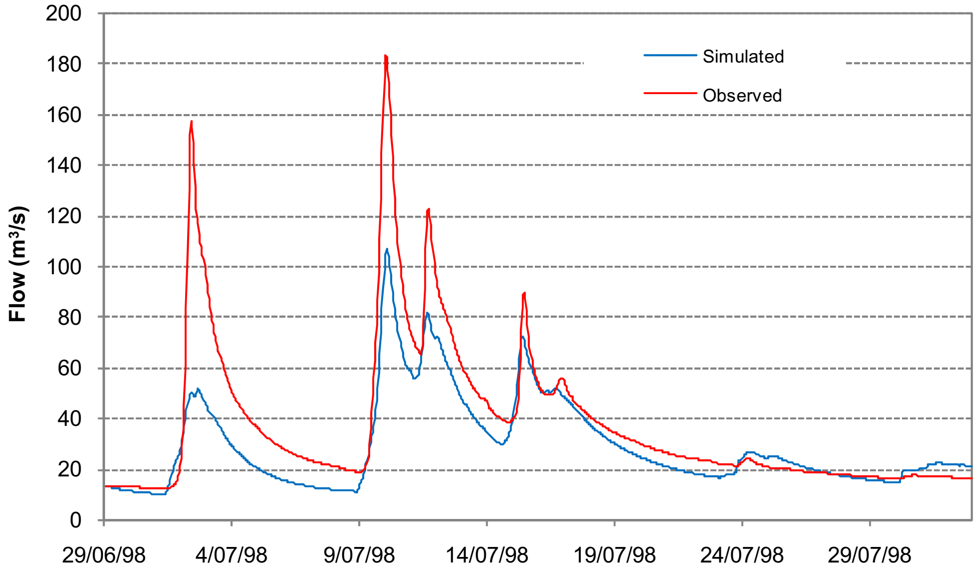
The catchment was divided into four homogeneous sub-basins based on the distribution of physical characteristics described above. The calibrated model parameters for this catchment are shown in **Table 11**.

- **Table 11. Calibrated model parameters for the Mangakino at Dillon Rd gauged catchment.**

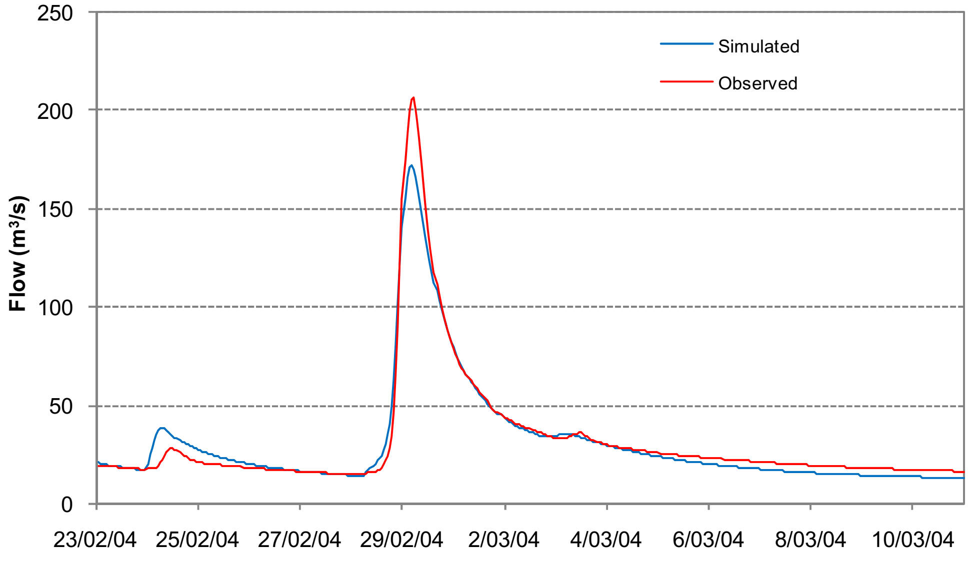
Parameter	Pumice, Forest	Pumice, Pasture	Loam, Forest	Loam, Pasture
Sub-basin area (km^2)	77.2	71.8	35.6	27.4
Canopy storage (mm)	2.5	2	2.5	2
Surface Storage (mm)	9.6			
Maximum soil infiltration (mm/hr)	98.6	15.8	100	7.3
Impervious area (%)	0			
Soil zone storage (mm)	854	930	791	863
Tension zone storage (mm)	514	594	383	497
Maximum soil percolation rate (mm/hr)	98.6	98.6	100	100
GW1 storage (mm)	500			
GW1 percolation rate (mm/hr)	30			
GW1 recession coefficient (hr)	150			
GW2 storage (mm)	800			
GW2 percolation rate (mm/hr)	0			
GW2 recession coefficient	5000			
Clark unit hydrograph runoff routing				
Time of concentration (hr)	6.9			
Storage coefficient (hr)	13.1			
Baseflow linear reservoir model				
GW1 baseflow storage coefficient (hr)	0.5			
GW2 baseflow storage coefficient (hr)	5			

Simulated and observed hydrographs for the July 1998 and February 2004 flood events are provided in **Figure 14** and **Figure 15**, respectively. The three day flow volume annual maxima were calculated for the overlapping period of observed and simulated flow records. These results are shown in terms of the distribution of 3-day peaks (**Figure 16**) and by calendar year (**Figure 17**).

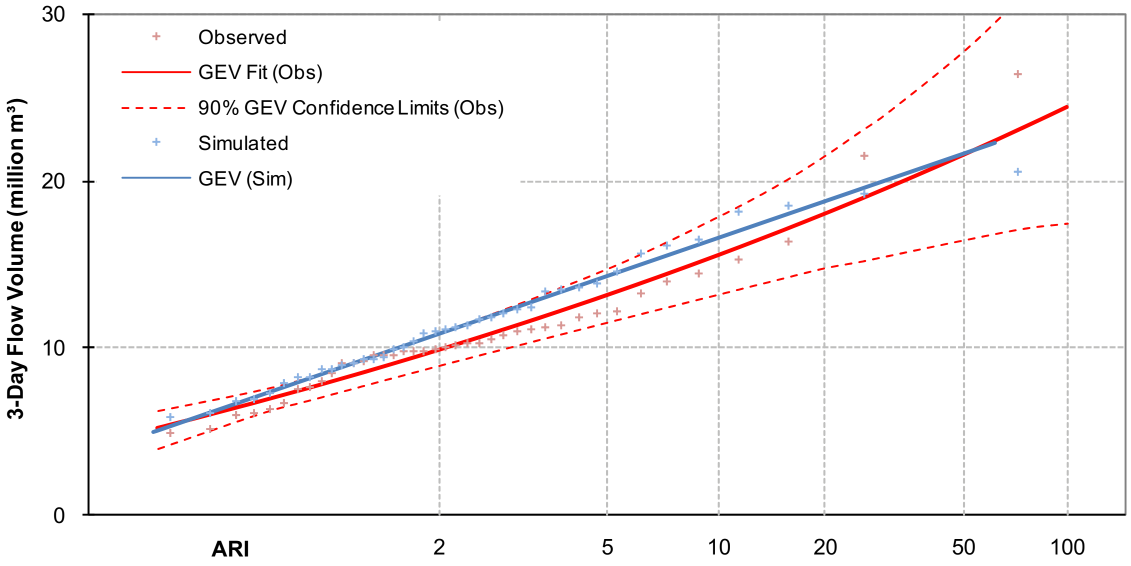
The calibration aimed to representatively simulate the distribution of three day flood volumes, as well as the 1998 and 2004 flood event hydrographs. For this calibration, the 1998 flood is under simulated, but more importantly the distribution of three day flows is simulated mostly within the 90% confidence bands. Additionally, the simulated February 2004 flows are similar to the observed.



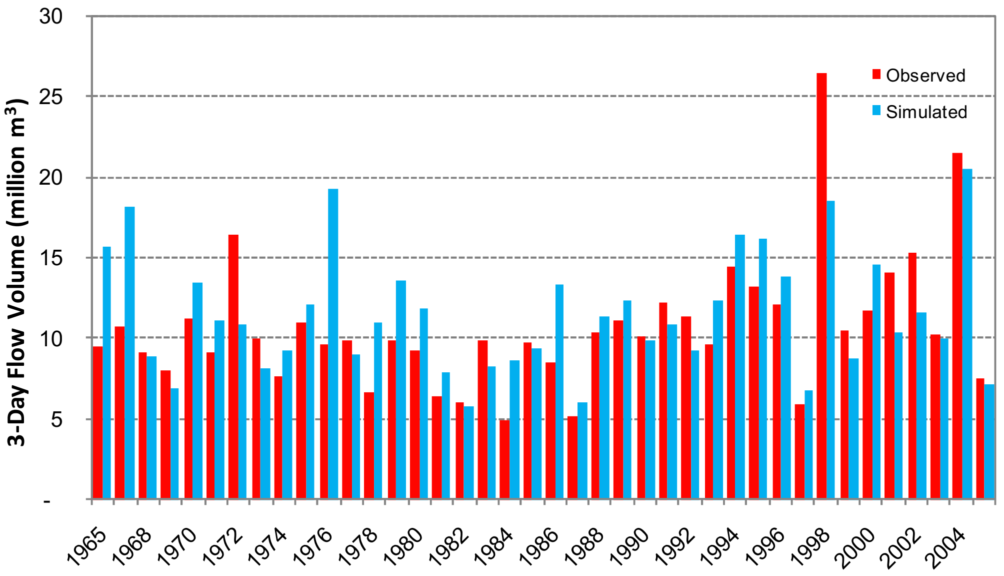
- **Figure 14. Simulated and observed flows for Mangakino at Dillon Rd calibration (July 1998 flood).**



- **Figure 15. Simulated and observed flows for Mangakino at Dillon Rd calibration (February 2004 flood).**



- **Figure 16. Distribution of observed and simulated 3-day flow volume annual maxima for Mangakino at Dillon Rd calibration (using Gringorton plotting positions).**



- **Figure 17. Observed and simulated 3-day flow volume annual maxima for Mangakino at Dillon Rd calibration.**

6. Development of Whole Catchment Model

To enable simulation of the impacts of land use change to floods in the Upper Waikato, the calibrated model was up-scaled to the whole catchment by transposing model parameters to ungauged areas.

6.1. Model Setup

This section describes the process and methodology of developing the whole of catchment model by transposing parameters from gauged to ungauged areas.

6.1.1. Spatial Discretisation

Simulation results are required for each of the eight hydrolakes along the Waikato River from Aratiatia to Karapiro. As such, the HEC-HMS whole catchment model was subdivided into basins corresponding to the hydrolake catchments, although sub-basin configurations used in the model calibration stage were maintained. Some of the basins were subdivided further, either into left and right bank or due to size. The layout of the hydrolake basins is shown in **Figure 18**. The proportions of homogeneous sub-basins in each of the catchments are provided in **Table 12**.

- **Figure 18. Hydrolake basin map.**

  (See A3 attachment at rear.)

- **Table 12. Homogeneous sub-basin areas (km^2) for hydrolake basins (base case land use).**

	Forest			Pasture				
Basin	**LOAM**	**POD**	**PUM**	**LOAM**	**POD**	**PUM**	**Open Water**	**Total**
Arapuni left	9.8		11.3	26.8		118.9	8.8	**175.7**
Arapuni right	7.7		59.3	0.2		0.7	0.6	**68.5**
Aratiatia	1.2	1.1	16.3	3.8	2.2	98.9		**123.5**
Atiamuri	32.5	9.3	116.6	28.9		117.2	2.3	**306.8**
Karapiro left	2.7	19.1		117.9	6.9	0.9	4.2	**151.7**
Karapiro right	16.6	3.0	286.1	126.2		244.4	4.0	**680.2**
Maraetai left	142.6	72.4	6.8	104.5	2.9	144.3	1.4	**474.8**
Maraetai right	28.0		142.8	0.8		11.3	3.3	**186.2**
Ohakuri left	9.7	13.5	153.3	7.8	13.0	65.6	5.1	**268.0**
Ohakuri right (a)			357.1			189.8	0.6	**547.5**
Ohakuri right (b)	4.7	7.7	218.4	33.2		390.8	8.6	**663.6**
Waipapa	82.4	5.9	95.2	23.4	4.7	41.1	1.4	**254.1**
Whakamaru left	63.2	17.3	87.0	88.8	27.1	45.5	3.9	**332.8**
Whakamaru right	35.0		123.8	0.9		9.4	2.8	**171.8**
Total	**436.1**	**149.3**	**1,674.0**	**563.2**	**56.8**	**1,478.8**	**47.0**	**4,405.2**

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6.1.2. Parameterisation

Parameters associated with each homogeneous sub-basin were assigned based on the calibrated model parameters (see **Table 8**). Areas identified as open water (i.e. the hydro-lakes themselves) were assigned an impervious catchment proportion of 100%, meaning that all rainfall to these areas is converted directly to flow.

The unit hydrograph parameters (T_c and storage) were calculated based on the USSGS time of concentration formula and as $1.8 \times T_c$, respectively. Final values are shown in **Table 13**.

Table 13. Unit Hydrograph parameters assigned to hydrolake basins.

Basin	Basin area (km^2)	T_c (hrs)	Storage (hrs)
Arapuni left	175.7	1.48	2.7
Arapuni right	68.5	2.08	3.7
Aratiatia	123.5	1.79	3.2
Atiamuri	306.8	8.38	15.1
Karapiro left	151.7	0.65	1.2
Karapiro right	680.2	8.84	15.9
Maraetai left	474.8	6.37	11.5
Maraetai right	186.2	3.20	5.8
Ohakuri left	268.0	3.03	5.5
Ohakuri right A	547.5	4.07	7.3
Ohakuri right B	663.6	7.00	12.6
Waipapa	254.1	3.61	6.5
Whakamaru left	332.8	3.57	6.4
Whakamaru right	171.8	2.90	5.2

Groundwater related parameters (assigned at the basin level) were transposed to the ungauged areas of the whole catchment. Parameters were transposed such that sets of parameters were maintained. This was done because of the interdependency between parameters (i.e. changes to individual parameters affect the functioning of other parameters).

Selection of the appropriate gauged catchment calibration parameters for transposition into hydro-lake basins followed a logical process. Hydrolake basins containing one of the calibrated catchments were automatically assigned those parameters. Basins containing no calibrated catchments were assigned the parameter sets of an adjacent basin following the conceptual understanding of the spatial trends of geology and hydrological regimes. **Table 14** shows the gauged catchment parameter sets selected for transposition into each of the hydrolake basins.

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- **Table 14. Groundwater parameters assigned hydrolake basins and source of parameter transposition.**

Basin	Source calibration catchment	GW1 storage (mm)	GW1 percolation (mm/hr)	GW1 coeff (hr)	GW2 storage (mm)	GW2 percolation (mm/hr)	GW2 coeff (hr)
Arapuni left	Waipapa	500	5	140	700	0	5000
Arapuni right	Pokaiwhenua	60	10	200	1200	0.25	10000
Aratiatia	Orakonui	60	60	200	1000	0.18	10000
Atiamuri*	Tahunaatara	60	6	250	900	0.05	8000
Karapiro left	Mangahanene	250	15	50	1000	0	800
Karapiro right*	Pokaiwhenua	60	10	200	1200	0.25	10000
Maraetai left*	Mangakino	500	30	150	800	0	5000
Maraetai right	Tahunaatara	60	6	250	900	0.05	8000
Ohakuri left*	Orakonui	60	60	200	1000	0.18	10000
Ohakuri right A	Orakonui	60	60	200	1000	0.18	10000
Ohakuri right B*	Waiotapu	60	6	300	900	0.05	7000
Waipapa*	Waipapa	500	5	140	700	0	5000
Whakamaru left	Waiotapu	60	6	300	900	0.05	7000
Whakamaru right	Tahunaatara	60	6	250	900	0.05	8000

*Indicates hydrolake basins containing a calibrated gauged catchment.

6.1.3. Rainfall Input Data

Consistent with the approach used during calibration to individual gauged catchments, the grids of hourly rainfall were used for the whole of catchment model. Rainfall time series were assigned to each of the fourteen basins in the whole catchment model as the mean of time series of grid points situated within each basin. The rainfall period spans 42 years from 1964 to 2006.

6.2. Validation

6.2.1. Total Catchment Flow

The whole of catchment model was run using the gridded historical rainfall. As a validation exercise, a comparison was made of total simulated flow from the catchment against observations. This exercise was intended to act as a sanity check of simulated hydrology within the ungauged parts of the catchment. This comparison was not used as a calibration target (i.e. no adjustment to parameters was made following the check).

Data from three flow monitoring sites on the Waikato River at the outlets of lakes Taupo and Karapiro were available. The difference in flow between these sites over an extended period equates to the flow generated from the catchment simulated in this model and changes in storage within the eight hydrolakes.

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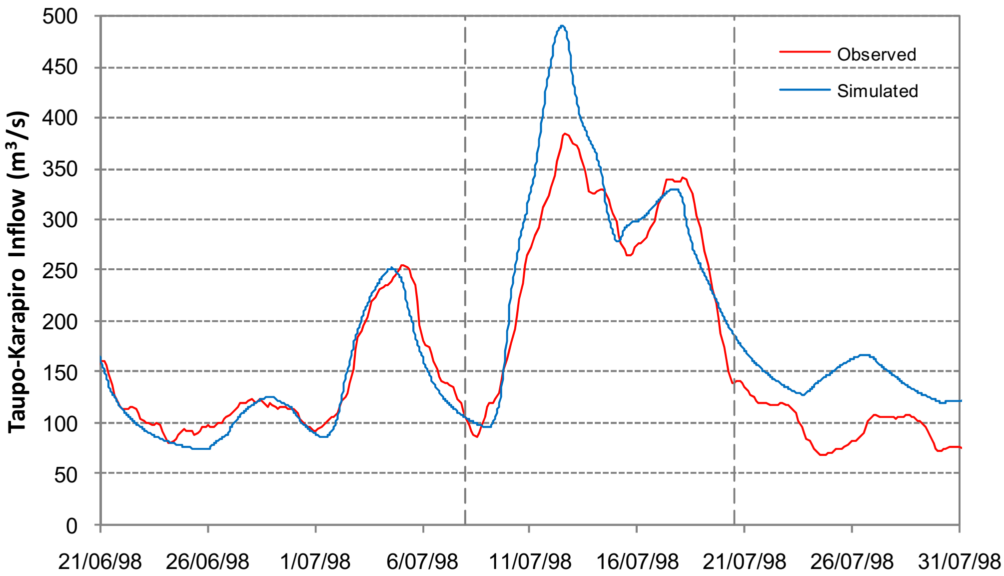
The 1998 flood event was chosen as the primary focus for the validation exercise due to its significance as a large flood that affected the lower Waikato. Both observed and simulated records were smoothed (using a 72-hour moving mean) to remove noise.

No correction has been made to these data for storage fluctuations within the hydrolakes. It is expected that the observed difference between Taupo and Karapiro inflows under-reports peak catchment inflow due to the effect of storage fluctuations.

The comparison of simulated and observed total catchment flow is shown in **Figure 19**.



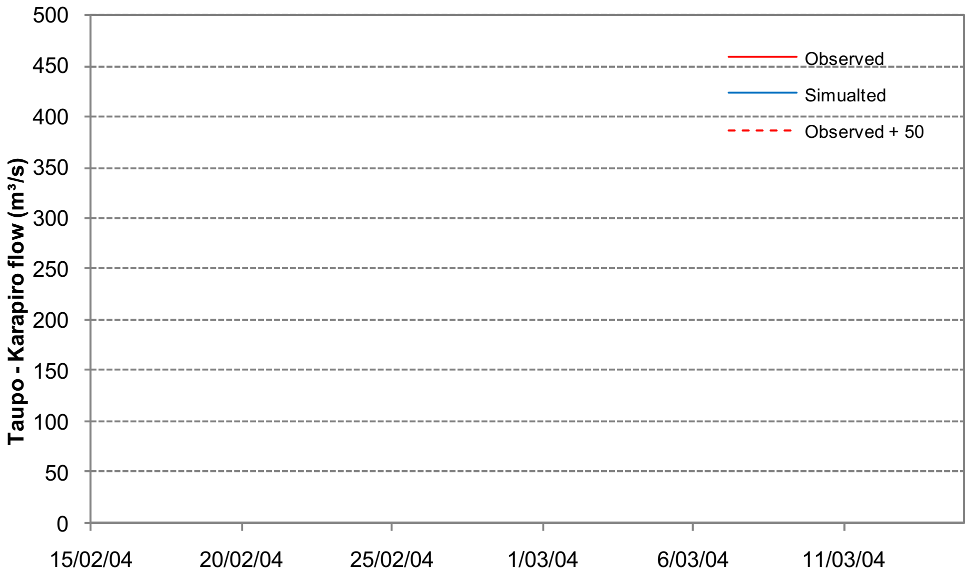
- **Figure 19. Observed difference between Taupo and Karapiro outflows and simulated catchment flow for the 1998 flood event (72-hour moving means).**

The graph shows the following:

- The difference between simulated and observed 72-hour flood peaks is 28% over the July 1998 event;
- The simulated 72-hour peak of the event is 490 m^3/s compared to the observed 384 m^3/s; and,
- The total simulated flood volume over the event (8 to 20 July; marked by dashed vertical lines) is 314 million m^3 compared to the observed 288 million m^3 (a difference of 9%).

The same comparison was made for the February 2004 flood event. This flood occurred during summer months, meaning that the potential for the hydrolakes to buffer the peak flows is greater because the storm had a smaller flow volume and lake levels are more likely to be lower.

The comparison of simulated to uncorrected observed total catchment inflow is provided in **Figure 20**.



- **Figure 20. Observed difference between Taupo and Karapiro outflows and simulated catchment flow for the February 2004 flood event (72-hour moving means).**

The difference between simulated and uncorrected observed total catchment inflows are greater for this event compared to the July 1998 event. A possible explanation for this is that more accession to lake storage occurred during the summer 2004 event. The dashed line represents the equivalent catchment inflow if a constant 50 m^3/s were being taken into storage. In this scenario, the volumes of observed and simulated catchment inflow match reasonably well.

6.2.2. Incremental Catchment Flow

Additional lake outflow information was sourced for Lake Whakamaru and incremental catchment inflows for Taupo – Whakamaru and Whakamaru to Karapiro were calculated. These records were processed to correct for operational storage changes within the hydrolakes (Jowett, pers. comm.).

Analysis of the difference in flows between Lakes Taupo and Whakamaru indicated a significant shortfall compared to gauged catchment flows at Waiotapu and Tahunaatara. The implication of this finding is that Taupo – Whakamaru catchment inflow data may be significantly under-reported.

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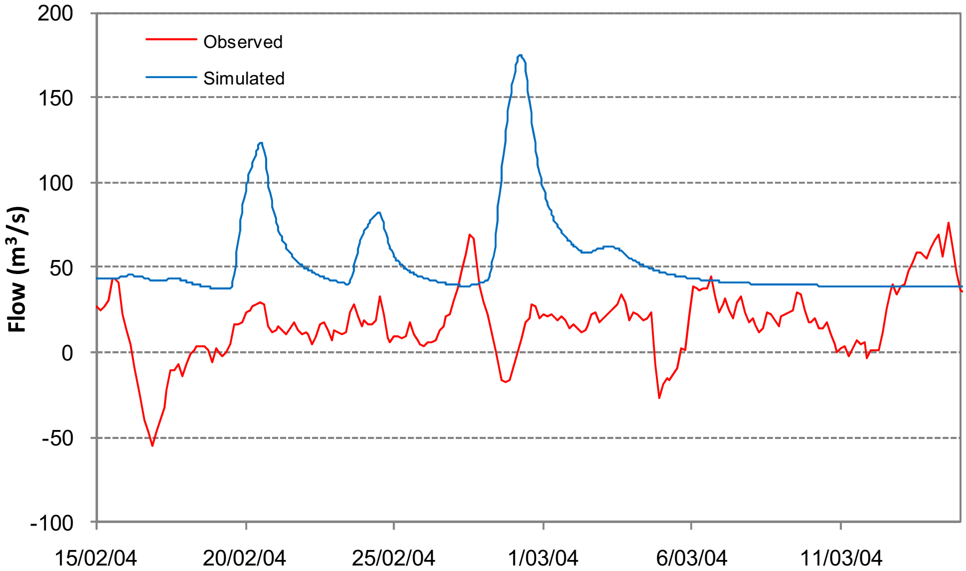
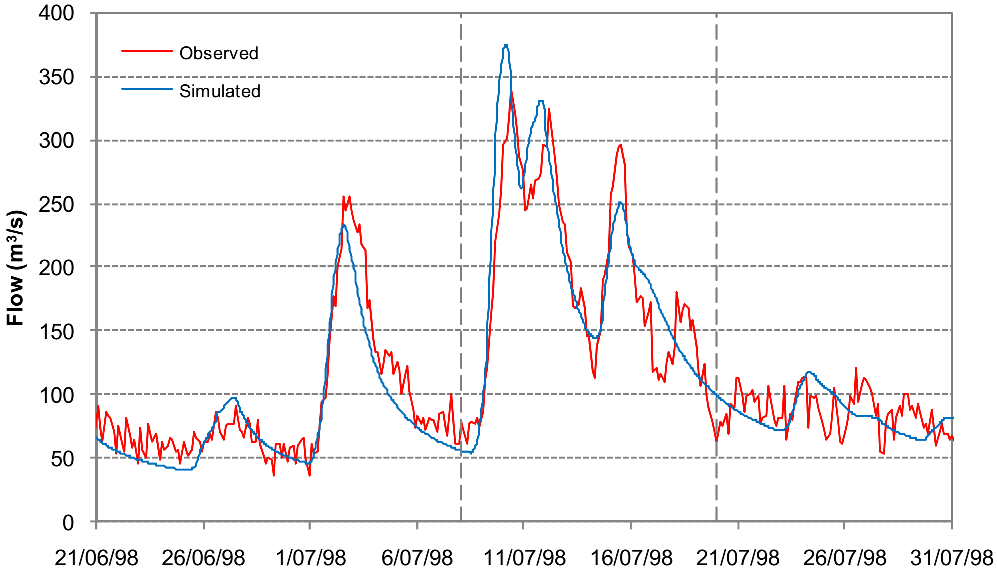
Given the potential data quality issues discussed above, there is significant doubt relating to the calculated Taupo to Whakamaru incremental inflows. This is supported by the fact that differences between the lake outflows are on average very small, and often become negative (as shown in **Figure 21**). The reported average Taupo – Whakamaru catchment flow equates to a long term runoff coefficient of approximately 10% of rainfall. As such, the Taupo – Whakamaru incremental flow has been ignored.

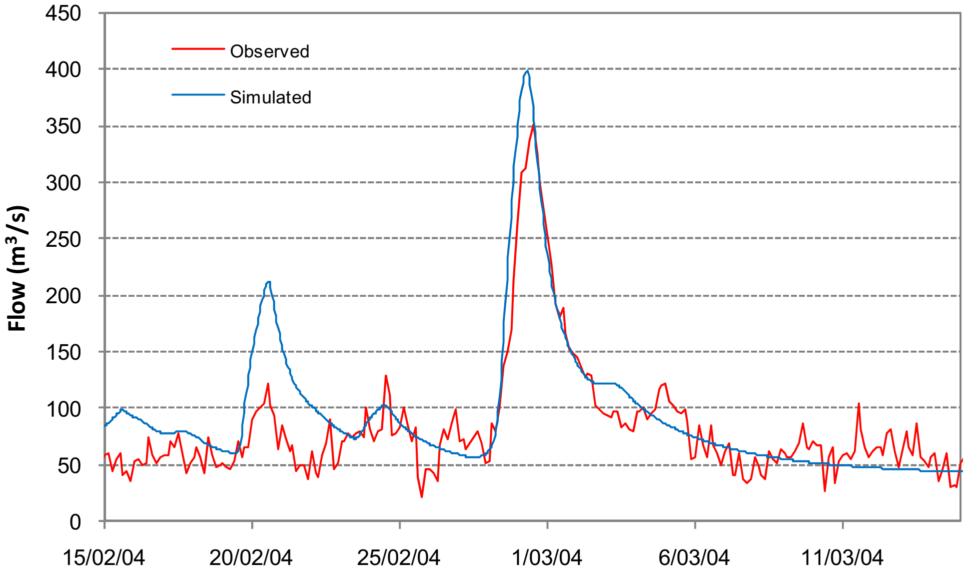


- **Figure 21. Simulated and "observed" inflow to the catchment between Lakes Taupo and Whakamaru for the February 2004 flood event (24-hour moving mean).**

Estimates of storage corrected incremental flows from the catchment between lakes Whakamaru and Karapiro do not appear to be significantly affected by the suspected data quality issues. **Figure 22** and **Figure 23** compare the observed and simulated Whakamaru – Karapiro flow for the July 1998 and February 2004 floods, respectively. The figures show a strong match between observed and simulated for both the 1998 and 2004 events. Simulated flow volume over the peak July 1998 storm period (8 to 20 July) is 202 million m^3 compared to the observed 194 million m^3 (i.e. a difference of 4%).



- **Figure 22. Simulated and observed inflow to the catchment between Lakes Whakamaru and Karapiro for the July 1998 flood event (24-hour moving mean).**



- **Figure 23. Simulated and observed inflow to the catchment between Lakes Whakamaru and Karapiro for the February 2004 flood event (24-hour moving mean).**

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6.3. Land Use Change Sensitivity Analysis

It is necessary to understand the mechanisms within the model that are responsible for changes in simulated flood volumes due to land use change. This involves identification of the parameter or parameters driving the impacts and qualification of their assignment to each land use.

There are four model parameters that change according to their land use specification, as shown in **Table 15**.

- **Table 15. Model parameters relating to land use specification.**

Parameter	Units	Forest			Pasture		
		LOAM	POD	PUM	LOAM	POD	PUM
Maximum soil infiltration rate	mm/hr	100	9.3	100	7.3	3	15.8
Canopy storage	mm	2.5			2		
Soil zone thickness	mm	791	1066	854	863	1059	930
Tension zone thickness	mm	383	613	514	497	625	594

The model parameters that relate to land use are maximum soil infiltration rate, canopy storage capacity and soil and tension zone thicknesses. Conceptually, the parameter expected to generate the greatest flood impacts from land use change is the maximum soil infiltration rate. The canopy storage does not change significantly and its influence to larger events is negligible.

Soil and tension zone thicknesses do not vary significantly from forest to pasture and are not influential in flood generation due to the way in which the model has been configured for this application[1]. It is recognised that parameters selected for the soil and tension zone thicknesses do not conform to conventional physical reasoning, in particular larger soil zone thickness values assigned to pasture. This is attributable to a number of reasons, including:

- An acceptable calibration was achieved using the initial values (based on LRI data); and,
- Model results were not sensitive to changes in these parameters.

To verify this theory, the internal operation of the model was scrutinised for an area that showed the greatest disparity in simulated runoff between forest and pasture (with all other factors

[1] The SMA algorithm has been parameterised to route infiltrated water quickly through the soil zone and into the upper groundwater layer while some soil moisture is retained within the tension zone. This allows for soil ET losses to occur, but maintains the conceptual understanding that no strong subsoil permeability interfaces exist (such as in hard rock geologies).

remaining consistent). This assessment enabled isolation of the mechanism (and parameters that are responsible for the difference in runoff.

Appendix C contains example model water balance outputs for loam soil under forest and pasture land uses within the Lake Whakamaru basin (left bank). All results are provided in mm or mm/hr units irrespective of catchment area. Water balance summaries over the assessment time period suggest that:

- Impacts to evapotranspiration losses are negligible (<0.1 mm), therefore changes in canopy storage do not have a noticeable effect on the water balance;
- The largest change to the water balance was within the surface runoff component, which changed from 0 to 3.1% of total system efflux. Reduction of the soil infiltration rate parameter was the reason for this increase.

The results show an increase in flood flow from this area between forest and pasture which is due to maximum soil infiltration rates decreasing from 100 mm/hr under forest to 7.3 mm/hr under pasture[2]. For forest, rainfall does not exceed the forest infiltration rate and no infiltration excess runoff is produced (i.e. all stream flow is baseflow and interflow). The reduction of infiltration rate under pasture results in some of the rainfall exceeding this rate and infiltration excess runoff results.

[2] Note that the actual infiltration rate is calculated in the model as maximum infiltration rate × soil moisture storage deficit as a proportion of capacity. This explains why lower than maximum infiltration rates are exceeded in the model water balance.

7. Model Simulations

7.1. Overview

The objective of the model simulations is to demonstrate the likely impacts on flood flows after conversion from forest to pastoral land use of parts of the upper Waikato catchment. Details of the land use change scenario adopted for the model simulations are provided in **Section 7.2**.

A number of historic storm events were considered to select a suitable temporal pattern of rainfall for the simulation analysis. From these the February 1958 and July 1998 storms were selected.

The July 1998 storm was a long duration winter storm with relatively uniform rainfall intensity extending over a period of many days. Because the effect of land use change is likely to be related to rainfall intensity the temporal pattern from the 1998 storm is likely to show an unconservative impact.

The February 1958 storm resulted from a late summer tropical weather system that moved across the catchment from the north-west before becoming stationary over the centre of the North Island. Historically these types of storms have created the largest flooding events in the catchment. The duration of the storm was approximately equivalent to that of the chosen simulation events (i.e. 72 hours) and was considered to have a reasonably uniform rainfall distribution across the catchment.

Simulations were carried out using the temporal pattern of both these storms to assess the relative impact of land use change on storm runoff for a range of storm events. The method of determining the rainfall used in the simulations is included in the sections describing the analyses because the same method was not used for both the storm patterns.

7.2. Details of Land Use Change Scenario

Areas identified as having potential for land use change from forest to pasture were supplied by EW. The total area of forest conversion specified in this scenario is 542 km^2, representing 24% of the approximate 2,255 km^2 of existing forest (pre-2004). A map showing the distribution of the potential land use change within each of the hydrolake basins is provided in **Figure 24**.

- **Figure 24. Hydrolake basin map (land use change scenario).**
  (See A3 attachment at rear.)

The spatial analysis of soil type and land use combinations (homogeneous sub-basins) was reproduced following removal of forest for those areas identified in the land use change scenario. The resulting distribution of homogeneous sub-basins within each hydrolake basin is provided in **Table 16** for reference purposes.

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Table 16. Homogeneous sub-basin areas (km²) for hydrolake basins (land use change scenario).

Basin	Forest			Pasture			Open Water	Total
	LOAM	POD	PUM	LOAM	POD	PUM		
Arapuni left*	9.8		11.3	26.8		118.9	8.8	**175.7**
Arapuni right	4.5		27.3	3.5		32.7	0.6	**68.5**
Aratiatia*	1.2	1.1	16.3	3.8	2.2	98.9		**123.5**
Atiamuri	30.2	9.2	95.9	31.2		137.9	2.3	**306.8**
Karapiro left*	2.7	19.1		117.9	6.9	0.9	4.2	**151.7**
Karapiro right	16.4	2.9	180.0	126.4		350.5	4.0	**680.2**
Maraetai left*	142.6	72.4	6.8	104.5	2.9	144.3	1.4	**474.8**
Maraetai right	27.0		95.9	1.8		58.2	3.3	**186.2**
Ohakuri left	7.9	12.4	35.2	9.6	14.2	183.6	5.1	**268.0**
Ohakuri right (a)			216.8			330.2	0.6	**547.5**
Ohakuri right (b)*	4.7	7.7	218.4	33.2		390.8	8.6	**663.6**
Waipapa	82.3	5.9	88.0	23.5	4.7	48.3	1.4	**254.1**
Whakamaru left	42.2	16.1	68.9	109.9	28.3	63.7	3.9	**332.8**
Whakamaru right	33.9		104.4	2.1		28.8	2.8	**171.8**
Total	**405.4**	**146.8**	**1165.2**	**594.2**	**59.2**	**1987.7**	**47.0**	**4405.2**

NB: Red numbers indicate a change in area from the base case scenario. * indicates no changes within basin.

Within areas of land identified for potential deforestation, the vast majority (94%) overlies pumice soils (**Figure 25**). This has implications to the results of land use change flood simulations because of the different hydrological (particularly infiltration) characteristics of the different soil types.

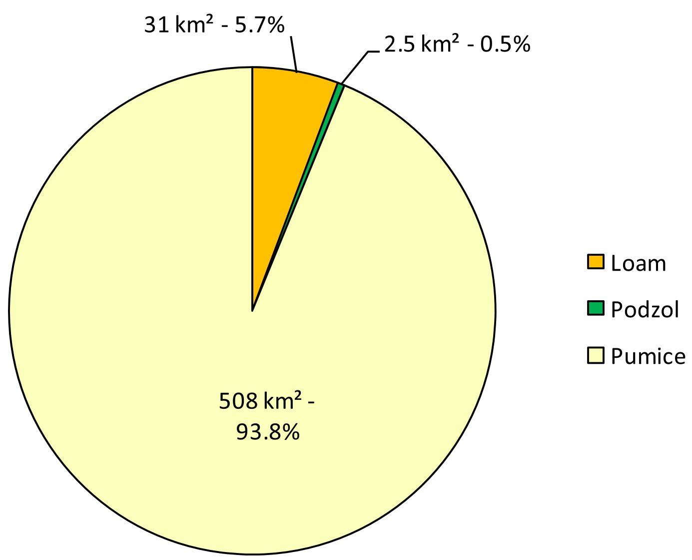

Figure 25. Soil type distribution of land identified for potential deforestation.

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7.3. July 1998 Simulations

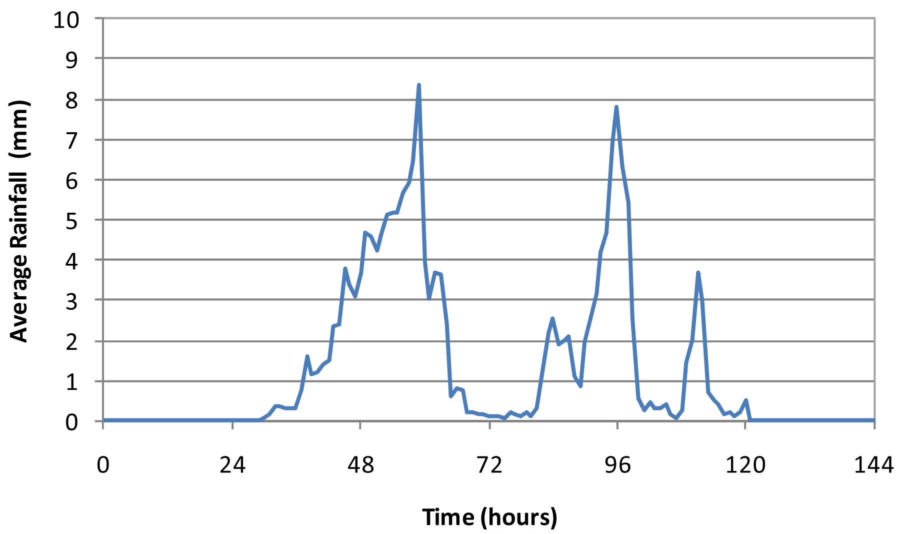
A range of rainfall magnitudes nominally associated with storm annual return periods of 5, 10, 20, 50, 100 and 500 years were simulated for the two land use scenarios to test the relative impacts on floods.

7.3.1. Rainfall

The temporal and spatial distribution of rainfall from the July 1998 storm was maintained and the event rainfall for each basin was scaled up or down to represent the six nominal return period events. The period of time subject to scaling ran for 144 hours from 9:00 am on 7 July 1998. The average rainfall over the catchment during this period is shown in **Figure 26**.

The NIWA High Intensity Rainfall Design System (HIRDS) was used to estimate 72-hour storm rainfall for each return period. Factors were determined by NIWA to adjust the July 1998 storm rainfall to the HIRDS rainfall and at the same time apply appropriate areal reduction to the rainfall. These factors are listed in **Table 17** together with the 72-hour average catchment rainfall for the period starting at 3:00pm on 8 July 1998. These factors were agreed by the TEP and were applied to rainfall input to both models (Topnet and HEC-HMS) so that the models would provide comparable results.

Note that it is not intended that the event rainfalls or flood responses correspond to particular return period or "design" events, as the ultimate goal of this study is to investigate the changes to flood response from land use change. In this regard we have labelled the storms "test" events.



■ **Figure 26. Average catchment rainfall (Starting at 09:00 on 7 July 1998)**

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- **Table 17. Scaling factors applied to the July 1998 rainfall with 72-hour storm rainfall depth**

Notional storm ARI (years)	Scaling factor	72 hour catchment average rainfall [1] (mm)
5 Year Rainfall	0.538	91
10 Year Rainfall	0.621	105
20 Year Rainfall	0.708	120
50 Year Rainfall	0.840	143
100 Year Rainfall	0.972	165
500 Year Rainfall	1.237	210

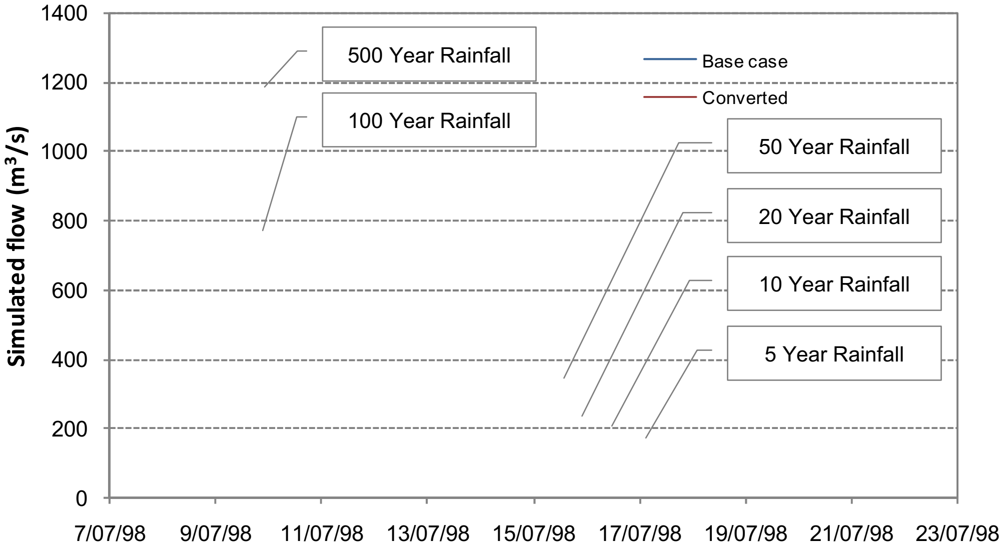
1 72-hour period from 15:00 on 8 July 1998 to 14:00 on 11 July 1998.

A lead-in period using the observed rainfall prior to the storm event was used in the simulations to allow the model to have consistent and realistic initial conditions.

7.3.2. Results (July 1998 Rainfall Pattern)

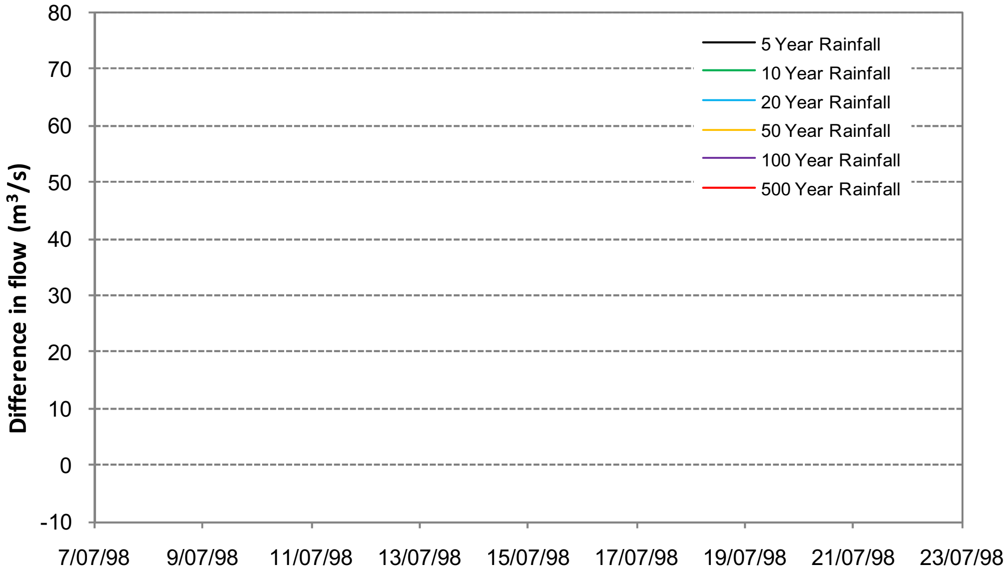
The fourteen basin models were run for each of the twelve rainfall/land use scenarios. For each of the runs, simulated flows were condensed into contributions from the eight hydrolake basins and then summed for the whole catchment. Simulated outputs from the individual hydrolake basins were submitted for input to the routing model (undertaken externally by Ian Jowett).

Figure 27 displays the model results as hydrographs of total outflow from the study area for the base case and converted land use scenarios during the six storm events described in **Section 7.3.1**. The increase in flood flows following land use change is small and only detectable in this plot for the largest magnitude storm events.



- **Figure 27. Simulated Taupo – Karapiro inflow hydrographs of six notional magnitude storm events under base case and converted land use scenarios.**

Figure 28 presents the difference in total catchment flow following potential land use change. The greatest increases in flow occur near the peaks of the flood events. The magnitude of the increase in catchment flow increases greatly with increasing storm magnitude.



- **Figure 28. Difference in simulated Taupo – Karapiro flow due to land use change for range of notional storm magnitudes.**

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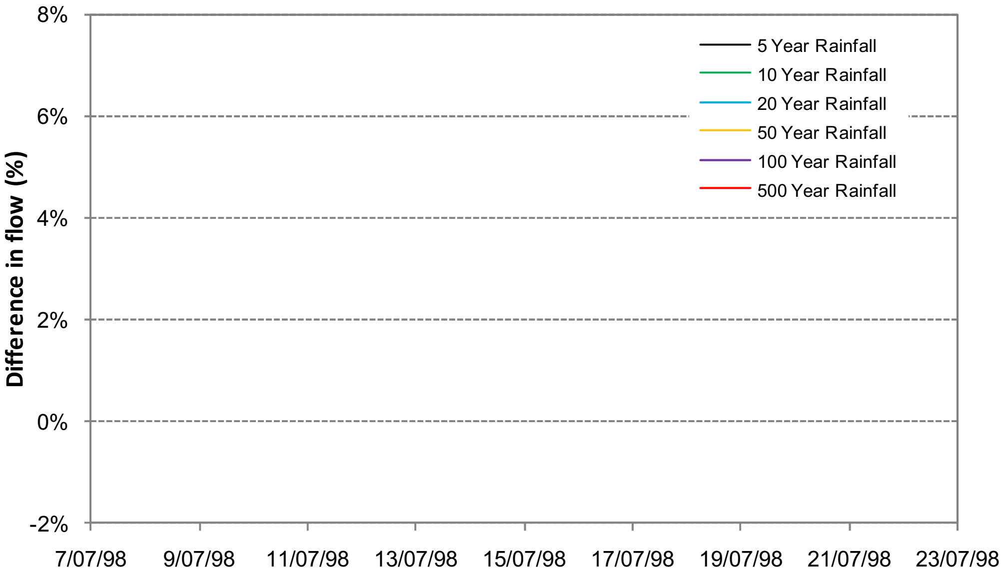
Figure 29 presents the results as a percentage change in flow. The differences in flood flows following land use change (when reported as a ratio of the existing land use flood flows) are simulated to increase with increasing event rainfall. This finding is contrary to the conventional understanding but can be explained in the context of this study. **Section 7.5** includes further discussion of this result and a possible rationale for its occurrence.



- **Figure 29. Percentage difference in simulated Taupo – Karapiro flow due to land use change for a range of notional storm magnitudes.**

Table 18 summarises the results in terms of hourly peak catchment flows. The discrepancy between the peaks in **Figure 29** and the percent difference in peak flows reported in the table is due to the largest differences in flow occurring slightly after the base case hydrograph peak.

- **Table 18. Simulated peak hourly Taupo – Karapiro flows for base case and converted land use scenarios (July 1998 storm).**

Notional Storm Average Return Interval	Base case	Converted	Difference	
	m^3/s			%
5 Year Rainfall	353.3	353.8	0.5	0.2
10 Year Rainfall	394.9	395.6	0.6	0.2
20 Year Rainfall	450.6	453.6	3.0	0.7
50 Year Rainfall	617.2	626.2	9.0	1.5
100 Year Rainfall	803.7	816.7	12.9	1.6
500 Year Rainfall	1224.3	1282.4	58.1	4.7

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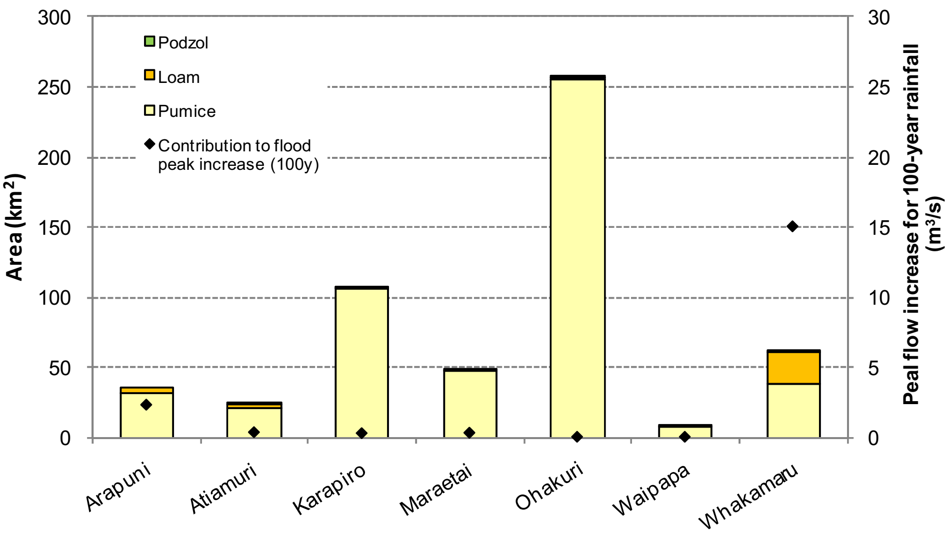
7.3.3. Discussion on Simulation Results (July 1998 Rainfall Pattern)

The results from the model simulations using the July 1998 rainfall pattern suggest that the impact on floods due to the potential land use change in the catchment will be minor. For the maximum magnitude rainfall event tested, the increase in flood peak for the whole catchment to Lake Karapiro was simulated as less than 5%. The relatively small increase in flood discharge is attributed to:

- The area converted from forest to pasture is only 12% of the full catchment;
- 94% of the area identified for deforestation overlies pumice soils (see **Figure 25**) that have a high maximum infiltration rate and generate a very subdued hydrological response; and
- The intensity of the July 1998 storm was only moderate and did not exceed soil infiltration rates for pumice soils in either forest or pasture land use. Thus conversion resulted in negligible change in flood runoff from these areas.
- Most of the simulated increase in flow was derived from the areas overlying loam and podzol soils that represents only 6% of the area where land use conversion was simulated.

Figure 30 shows the distribution of soil types within areas identified for potential land use change by the hydrolake basin in which they reside. The data points show the total increase in flood peak simulated from each basin following land use change for the nominal 100-year event. This illustrates the link between loam and podzol soils and land use change impacts to flooding and reinforces that land use change induces little effect in areas with pumice soils.



- **Figure 30. Distribution of soil types within land use change areas and contributions to flood peak increases for the hydrolake basins.**

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7.4. February 1958 Simulations

7.4.1. Rainfall

For each basin, the maximum 72-hour rainfall for six return periods was obtained from the NIWA High Intensity Rainfall Design System (HIRDS). An areal reduction factor of 0.75 was applied to the HIRDS values to determine the catchment average storm rainfall shown in **Table 19**.

▪ **Table 19. Maximum HIRDS 72-hour rainfall totals within each model basin.**

Basin	Average return interval (years)					
	5*	10	20	50	100	500*
Arapuni_left	102	117	133	158	182	234
Arapuni_right	99	113	129	153	176	227
Aratiatia	84	96	109	131	152	197
Atiamuri	106	122	140	168	195	254
Karapiro_left	92	106	121	145	168	218
Karapiro_right	97	111	126	152	175	227
Maraetai_left	96	109	123	147	169	217
Maraetai_right	95	108	123	147	169	218
Ohakuri _left	91	105	120	144	167	218
Ohakuri_right_a	91	104	119	144	167	218
Ohakuri_right_b	103	119	136	164	191	248
Waipapa	105	119	135	160	184	237
Whakamaru_left	92	105	119	143	166	214
Whakamaru_right	97	111	126	151	174	226
Area weighted average	97	111	127	152	176	228

*Denotes interpolated or extrapolated values.

Synthetic event rainfall time series were generated by multiplying the 72-hour temporal distribution of the February 1958 storm event (**Figure 31**) by the reduced HIRDS rainfall totals.

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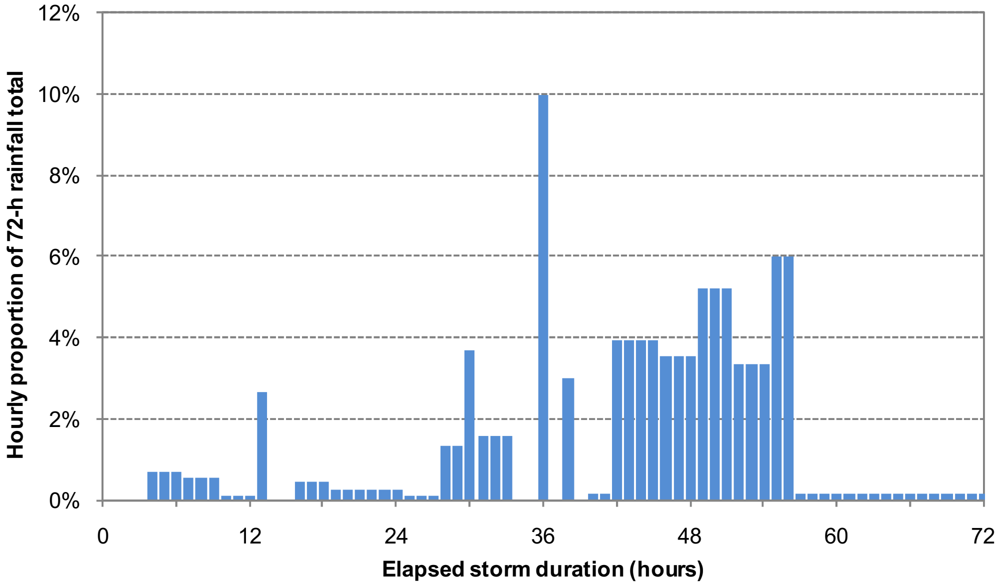


- **Figure 31. 72-hour temporal pattern of the February 1958 storm rainfall event.**

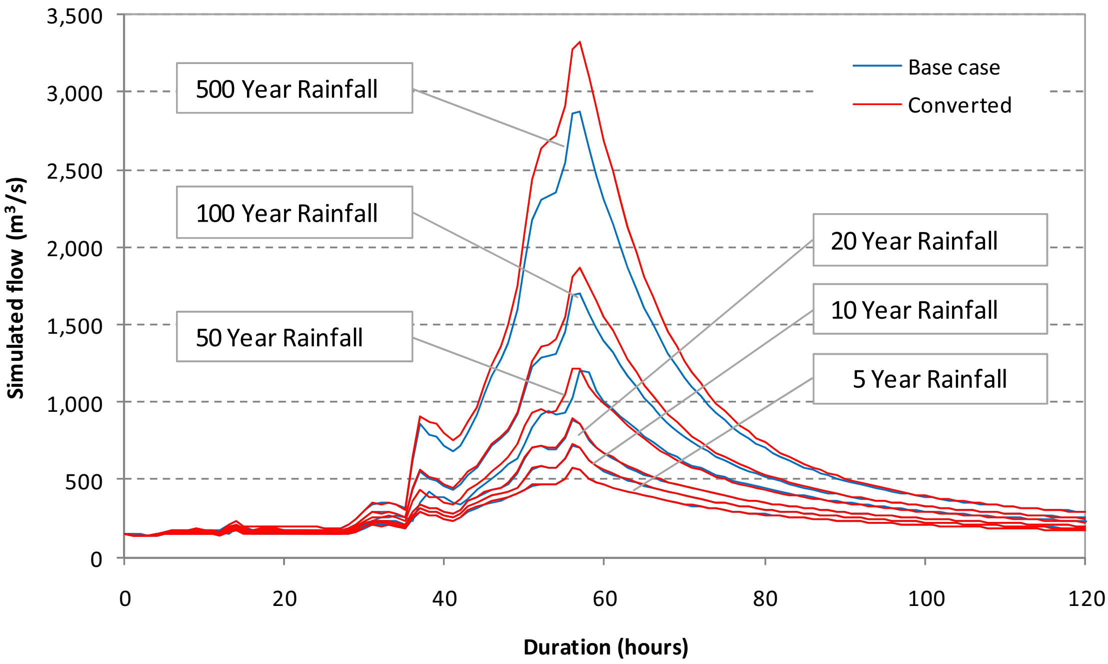
A lead-in rainfall period prior to the storm event was used in the simulations to allow the model to have consistent and realistic initial conditions. The observed rainfall data used for this purpose was the rainfall leading up to 23 February 2004. This was chosen because it corresponded to the same time of the year as the 1958 storm and was considered to have a similar antecedent soil moisture condition.

Note that it is not intended that the simulated flood responses correspond to particular return period or "design" events, as the ultimate goal of this study is to investigate the changes to flood response from land use change. In this regard we have labelled the storms "test" events.

7.4.2. Results (February 1958 Rainfall Pattern)

Simulations were carried out using the model following the same procedure used in the analysis of the July 1998 storm described in **Section 7.3.2**.

Figure 32 displays the model results as hydrographs of total outflow from the study area for the base case and converted land use scenarios during the six storm events described in **Section 7.4.1**.



- **Figure 32. Simulated Taupo – Karapiro inflow hydrographs of six notional magnitude storm rainfall events under base case and converted land use scenarios.**

Figure 33 presents the results as a percentage change in flow. The differences in flood flows following land use change (when reported as a ratio of the existing land use flood flows) are simulated to increase rapidly with increasing event rainfall, ranging from 1% to 16% for the 5 year and 500 year rainfall simulations, respectively. This finding is contrary to the conventional understanding but may be explained in the context of this study. **Section 7.5** includes further discussion of this result and a possible rationale for its occurrence.

Table 20 summarises the results in terms of hourly peak catchment flows. The discrepancy between the peaks in **Figure 33** and the percent difference in peak flows reported in the table is due to the largest differences in flow occurring slightly after the hydrograph peak of the base case.

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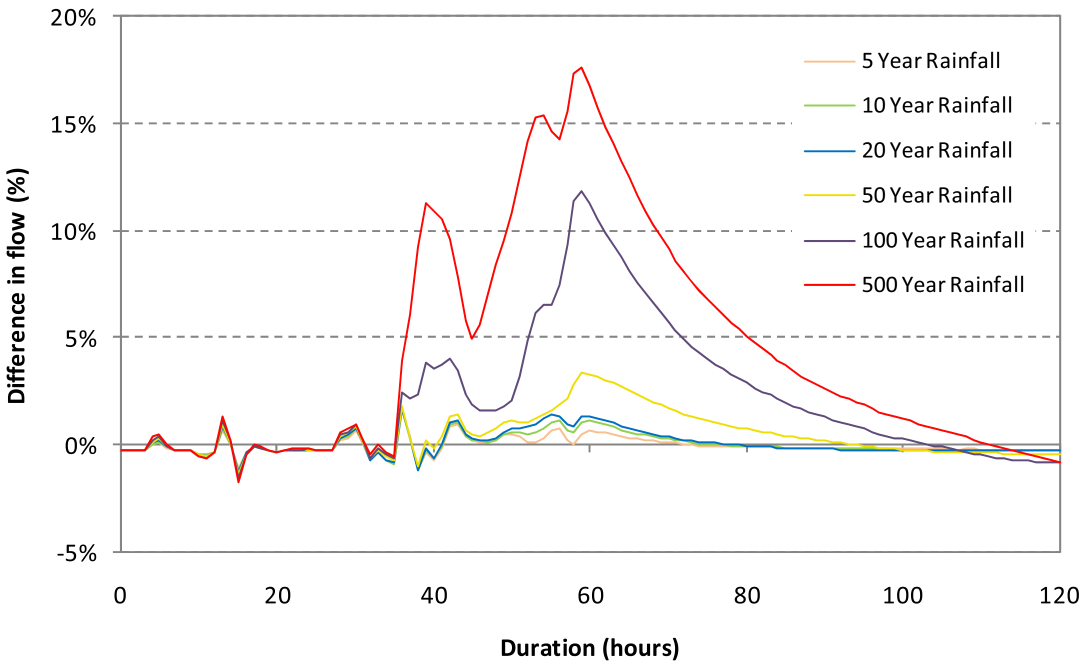


- **Figure 33. Percentage difference in simulated Taupo – Karapiro flow due to land use change for a range of notional storm rainfall magnitudes.**

- **Table 20. Simulated peak hourly Taupo – Karapiro flows for base case and converted land use scenarios (February 1958 storm).**

Notional Storm Average Return Interval	Base Case	Converted	Difference	
	m^3/s			%
5 Year Rainfall	571.2	575.8	4.6	0.8
10 Year Rainfall	722.0	730.1	8.2	1.1
20 Year Rainfall	882.0	893.9	11.9	1.3
50 Year Rainfall	1198.7	1221.3	22.5	1.9
100 Year Rainfall	1704.0	1863.4	159.4	9.4
500 Year Rainfall	2874.9	3323.3	448.4	15.6

7.4.3. Discussion on Simulation Results (February 1958 Rainfall Pattern)

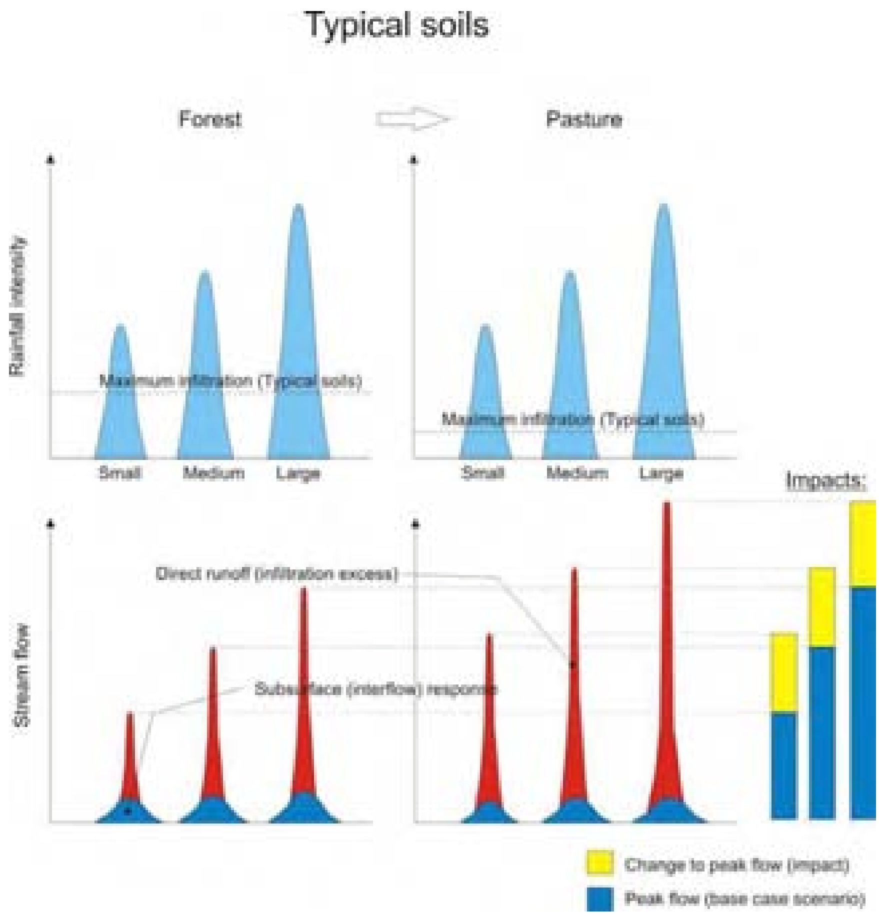
The results from model simulations using the February 1958 rainfall pattern suggest that the impact on floods due to the potential land use change in the catchment will still be relatively minor ranging from 1% to 16% for the 5 year and 500 year rainfall test events respectively. Comparing the results to the July 1998 simulation shows an increase in percentage impact that is attributed to the temporal rainfall pattern of the February 1958 storm that has higher intensity rainfall. However, the impact is still relatively small because of the scale of conversion area to the overall catchment.

7.5. Flood Impacts and Storm Event Magnitude

Conventional understanding of the impact on flood peaks of changing land use from forest to pasture is that the percentage change in flood peak decreases as the rainfall intensity increases. This is contrary to the simulation results presented in **Section 7.3.2** and **Section 7.4.2**.

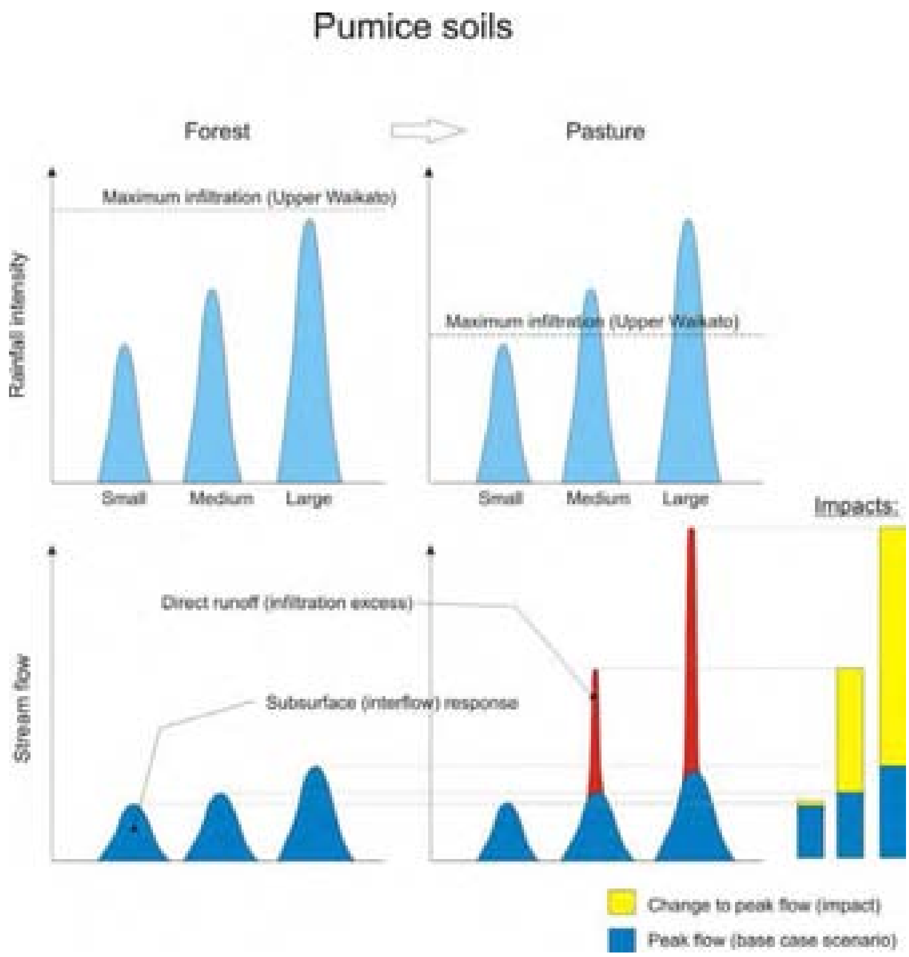
A simplified representation of the conventional understanding is illustrated in

Figure 34. This applies to more typical soil types that, compared to pumice soils, have significantly lower infiltration capacities that are more readily exceeded during storms under both forest and pasture land use. The additional runoff generated (shown as yellow bar) will remain relatively constant as storm size increases, thus its influence relative to runoff before land use change (shown as blue bars) diminishes.



- **Figure 34. Schematic diagram relating land use change impact to floods with increasing storm intensity (low infiltration setting).**

On the other hand **Figure 35** illustrates the possible process for the high infiltration situation found in the Upper Waikato catchment, where surface infiltration capacities are not exceeded during any storms under forest conditions. After converting to pasture the maximum infiltration rate decreases significantly to below the rainfall intensities of the test events [3]. This results in flood peaks increasing under pasture land use as the event rainfall intensity increase. Thus as the storm magnitude increases the percentage change in floods also increases.



- **Figure 35. Schematic diagram relating land use change impact to floods with increasing storm intensity (high infiltration setting).**

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8. Conclusions

The key objective of the study was to understand the relative impact of land use change on flood peaks and volumes through the hydrolake system ending at Lake Karapiro.

The work documented in this report represents the current progress through project objectives and does not yet address all aims that were originally set out to be achieved, namely an assessment of land use change impacts to floods in tributaries within the Upper Waikato catchment.

The results of numerical rainfall-runoff modelling conducted to date suggest the following:

- Reduction of maximum soil infiltration rates is the principal mechanism by which flood magnitudes increase following forest to pasture conversion;
- The model calibration (supported by field testing) indicates very high infiltration rates in pumice soils under both forest and pasture land uses;
- 94% of the land use change in the specified scenario occurs on pumice soils;
- Model infiltration capacities of pumice soils in pasture are only exceeded at the catchment scale in the highest rainfall intensity events;
- Supported by the above evidence, the impacts of land use change on floods in the Upper Waikato catchment (Taupo – Karapiro) will be relatively minor (1% increase with 5 year frequency; 4-10% increase expected once in a person's lifetime and up to 16% increase to flood peaks occurring very rarely), and;
- While results of this study indicate relatively minor impacts from the simulated land use conversion scenario, any potential deforestation over less pervious soil types such as loams, podzols, silts or clays are expected to have local impacts of much greater severity. The regional impacts however will depend on the proportion of land of these soil types within the catchment that are to be converted.

8.1. Limitations

The approach described in this report presents a defensible approach to the estimation of land-use change impacts on floods at the catchment scale of interest, subject to recognition of the salient limitations of the analysis. These limitations include:

- Paucity of data confounds the ability to parameterise the different models resulting in a standard of calibration varying from poor to good, over a range of catchment scales;
- The required use of a number of simplifying assumptions in the specification of design inputs which could be improved upon with further effort; and,

- A limited assessment of model sensitivity to different flood producing factors.

Despite these limitations, the amount of effort expended on this study to date is considerable and the results obtained are largely consistent with physical reasoning.

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References

Bennett, T.H. and Peters, J.C., 2000. Continuous Soil Moisture Accounting in the Hydrologic Engineering Center Hydrologic Modelling System (HEC-HMS). ASCE Technical Publication.

Flemming, M. and Neary, V., 2004. Continuous Hydraulic Modelling Study with the Hydrologic Modeling System. Journal of Hydrologic Engineering, May/June 2004, 175-183

Sinclair Knight Merz, 2008. Impact of Land Use Change on Floods in the Upper Waikato – Data Collection and Selection of a Second Model. Report prepared for Environment Waikato.

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Appendix A Details of SMA Model Function

This appendix provides mathematical formulae of model operation for the Soil Moisture Accounting loss model (Bennett and Peters, 2000). Refer to **Section 2.1.1** for an overview of operation.

The potential rate of infiltration to soil is calculated as:

$$PotSoilInfil = MaxSoilInfil - \frac{CurSoilStor}{MaxSoilStor} MaxSoilInfil$$

where *PotSoilInfil* is potential infiltration (mm/hr); *MaxSoilInfil* is user specified maximum rate of infiltration (mm/hr); *MaxSoilStor* is the user specified maximum capacity of the soil storage (mm); and *CurSoilStor* is the current storage in the soil profile (mm).

The potential rate of percolation out of the soil zone is calculated as:

PotSoilPerc = *MaxSoilPerc* * (Fraction full upper storage) * (1 – Fraction full lower storage)

The same relationship applies for percolation from groundwater layers.

The groundwater flow (baseflow) from each groundwater layer is calculated based on the storage level in the groundwater store (mm) and the groundwater recession coefficient (hours) and can be simplified to:

GWFlow ≈ Volume available in GW store ÷ GW recession coefficient

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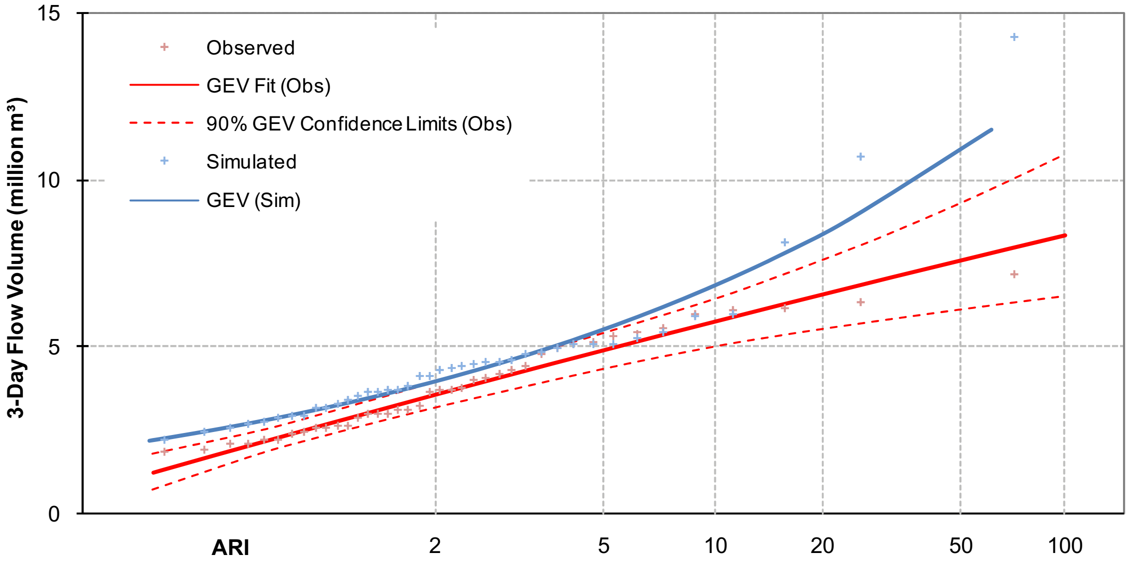
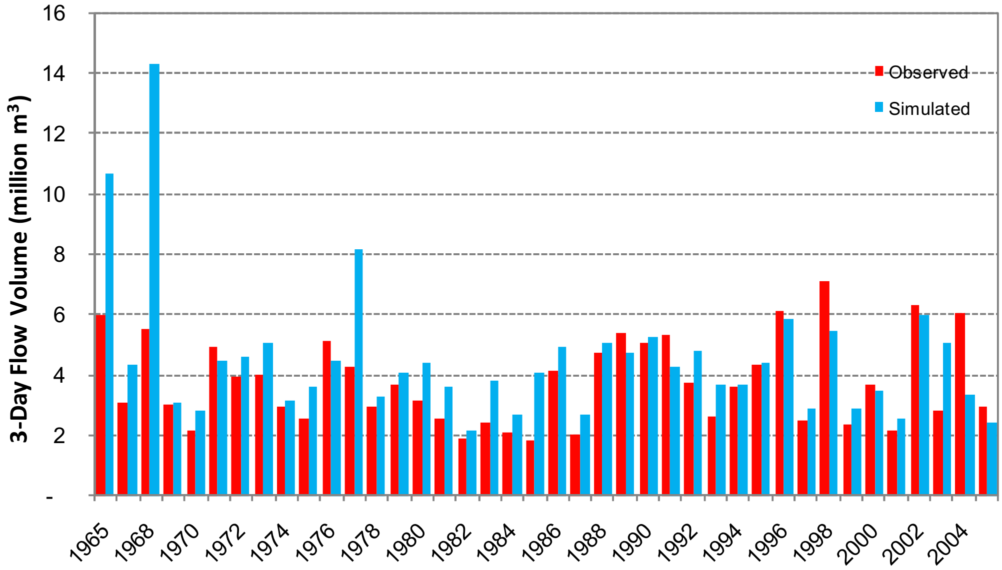
Appendix B Individual Calibration Results

This appendix provides calibration plots for the remainder of the calibrated gauged catchments within the study area.

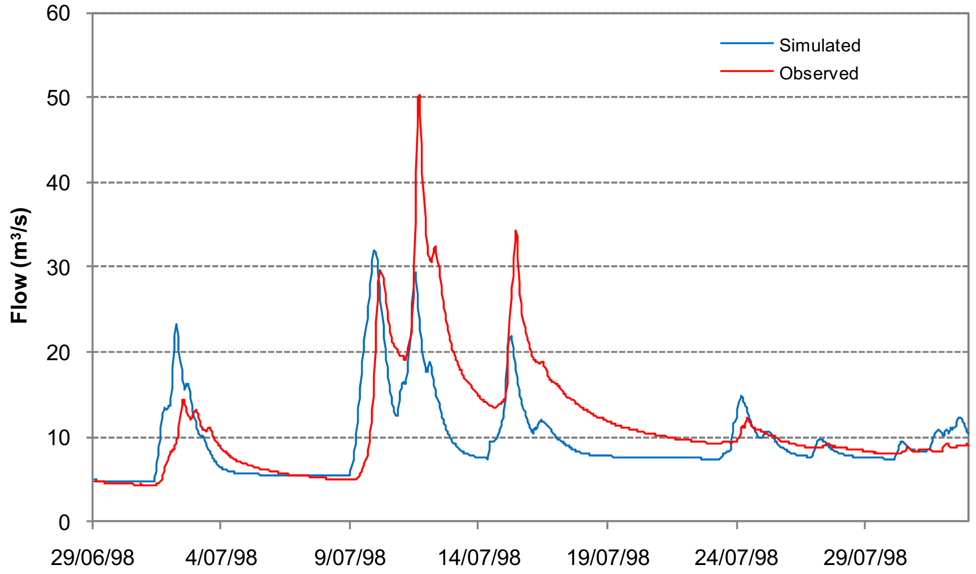
B.1 Pokaiwhenua at Puketurua



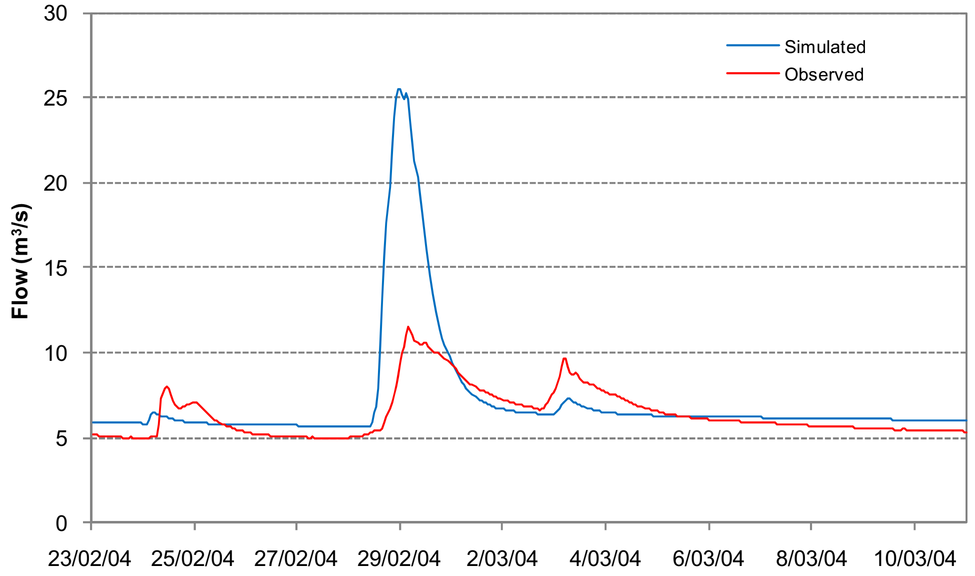
- **Figure B1. Distribution of observed and simulated 3-day flow volume annual maxima for Pokaiwhenua at Puketurua calibration (using Gringorton plotting positions).**



- **Figure B2. Observed and simulated 3-day flow volume annual maxima for Pokaiwhenua at Puketurua calibration.**

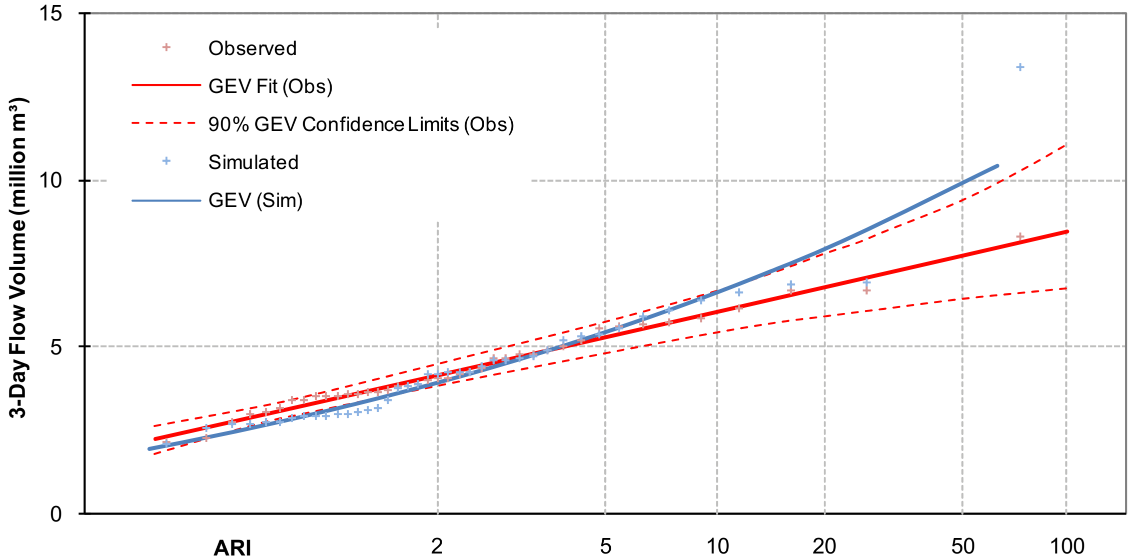


- **Figure B3. Observed and simulated flow at Pokaiwhenua at Puketurua calibration for the July 1998 flood.**

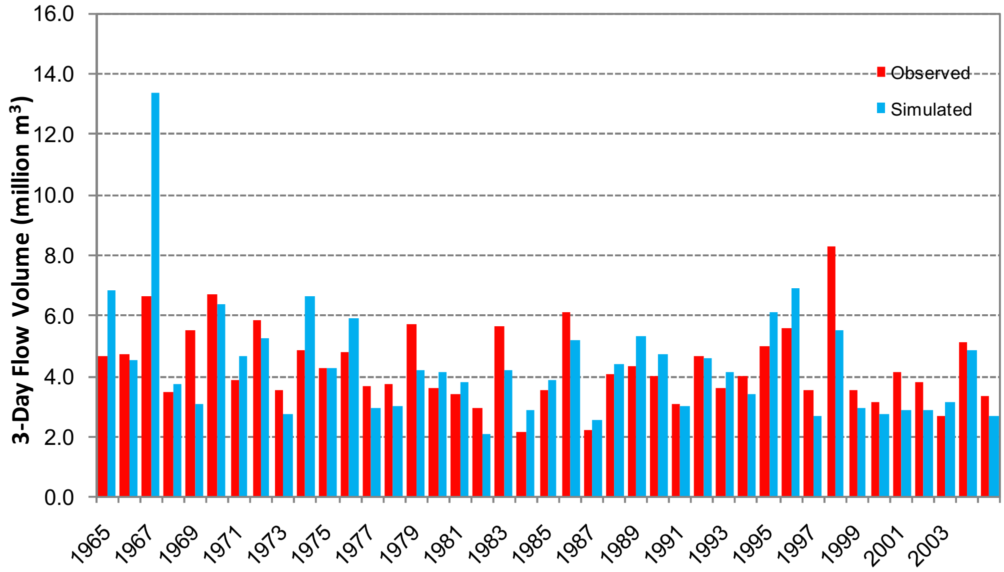


- **Figure B4. Observed and simulated flow at Pokaiwhenua at Puketurua calibration for the February 2004 flood.**

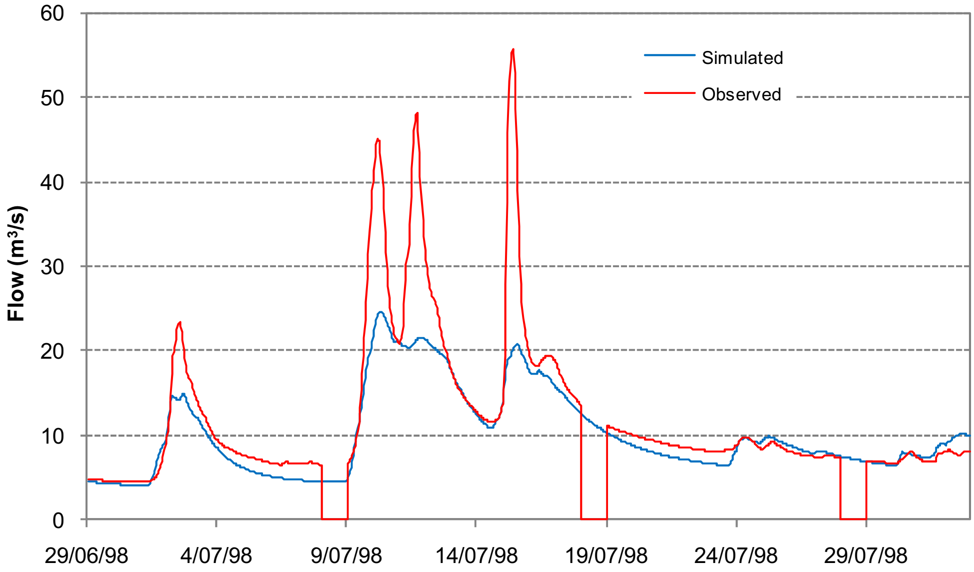
B.2 Tahunaatara at Ohakuri



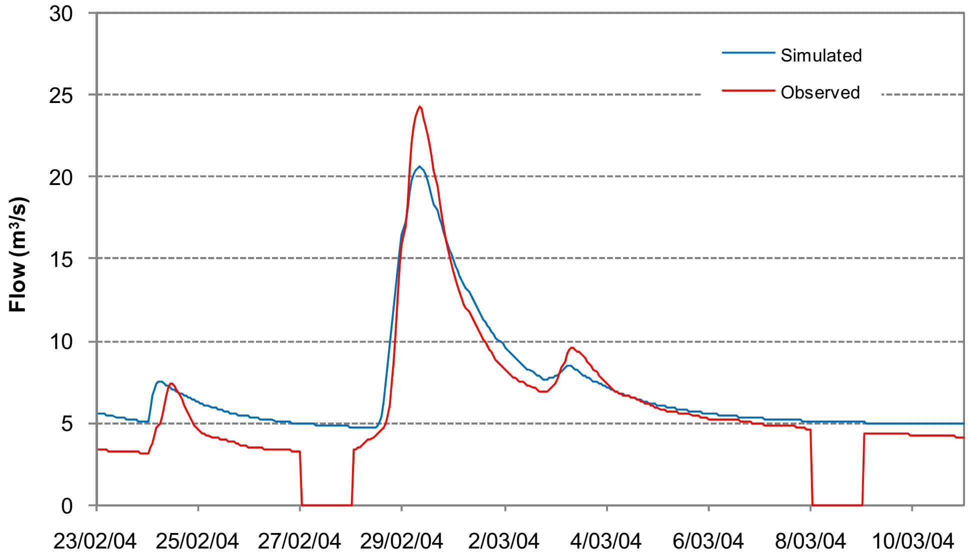
- **Figure B5. Distribution of observed and simulated 3-day flow volume annual maxima for Tahunaatara at Ohakuri calibration (using Gringorton plotting positions).**



- **Figure B6. Observed and simulated 3-day flow volume annual maxima for Tahunaatara at Ohakuri calibration.**



▪ **Figure B7. Observed and simulated flow at Tahunaatara at Ohakuri calibration for the July 1998 flood.**



▪ **Figure B8. Observed and simulated flow at Tahunaatara at Ohakuri calibration for the February 2004 flood.**

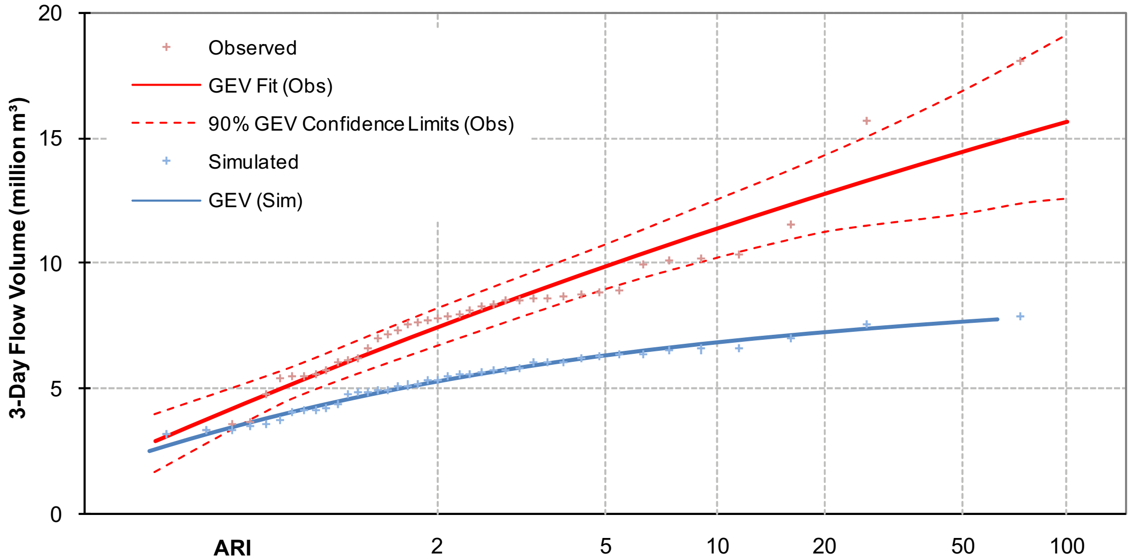
B.3 Waiotapu at Reporoa

Refer to **Section 5.3.1** in the main report.

B.4 Mangakino at Dillon Rd

Refer to **Section 5.3.2** in the main report.

B.5 Waipapa at Ngaroma Rd



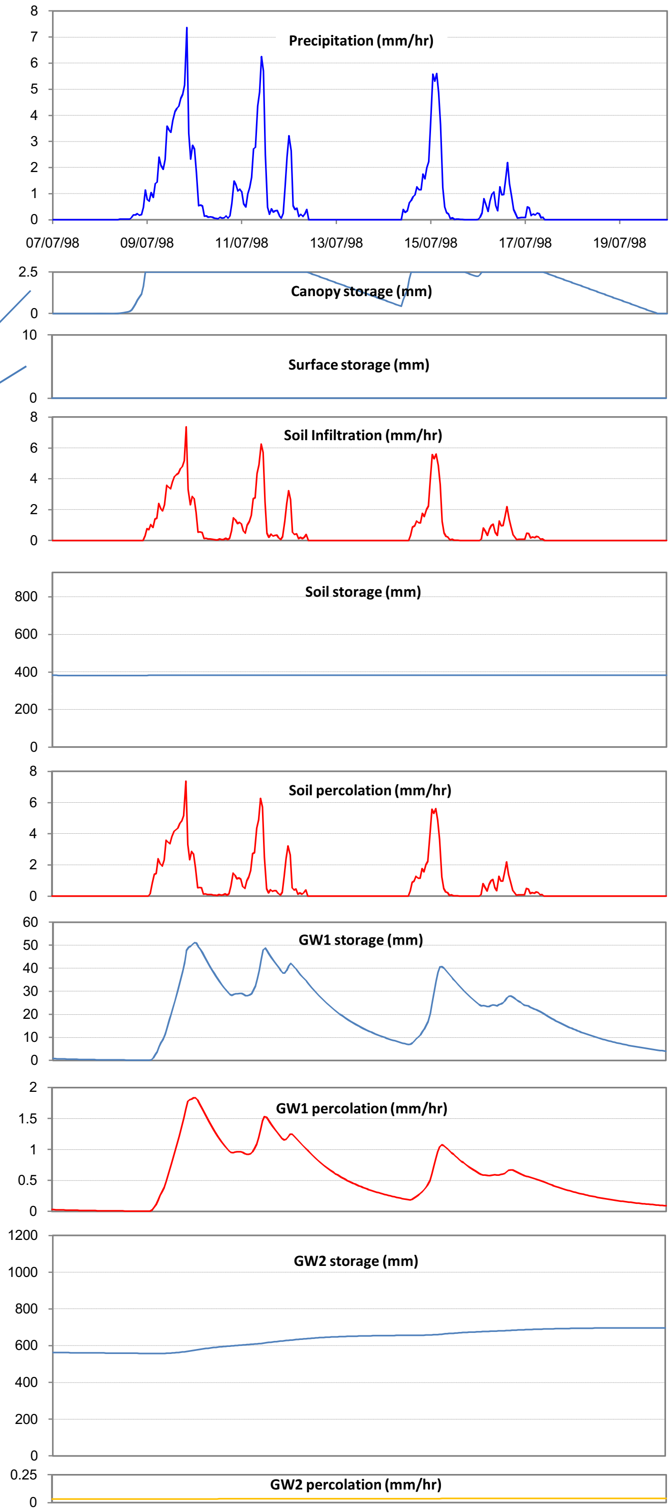
- **Figure B5. Distribution of observed and simulated 3-day flow volume annual maxima for Waipapa at Ngaroma Rd calibration (using Gringorton plotting positions).**

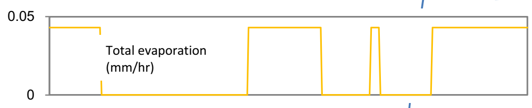
Note that for this calibrated catchment, a discrepancy has been identified in the gridded rainfall at this location. A water balance check showed more observed runoff than catchment rainfall meaning that at this location, the gridded rainfall is significantly underestimated. It is assumed that this discrepancy is localised and does not have a significant impact to the whole of catchment model results.

Appendix C Internal Model Water Balances

IN		
Rainfall	202.9 mm	100%
Total In	**202.9 mm**	**100%**
OUT		
Streamflow:		
Surface runoff	0.0 mm	0.0%
Interflow	-19.8 mm	9.7%
Baseflow	-28.4 mm	14.0%
Subtotal	**-48.2 mm**	**23.7%**
Losses:		
Evap	-6.5 mm	3.2%
Deep perc	-11.1 mm	5.4%
Subtotal	**-17.6 mm**	**8.6%**
Accessions to storage:		
Canopy	0.0 mm	0%
Surface	0.0 mm	0%
Soil	-1.0 mm	0.5%
GW1	-3.2 mm	2%
GW2	-133.0 mm	65.5%
Subtotal	**-137.3 mm**	**67.6%**
Total Out	**-203.0 mm**	**100%**
Residual	*-0.2 mm*	*-0.1%*

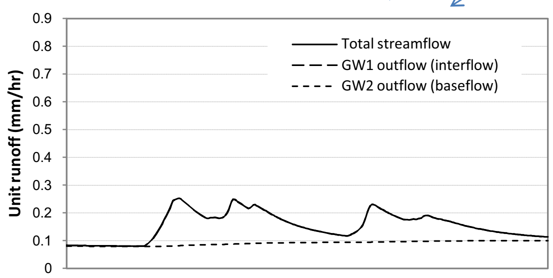
Catchment: Whakamaru_left **Landuse, soil type:** Forest, loam **Event:** 20y





LEGEND:

- Store (units in mm)
- Flux (units in mm/hr)
- Stream flow (units in mm/hr)
- Evaporation losses (mm/hr)
- Percolation losses (mm/hr)

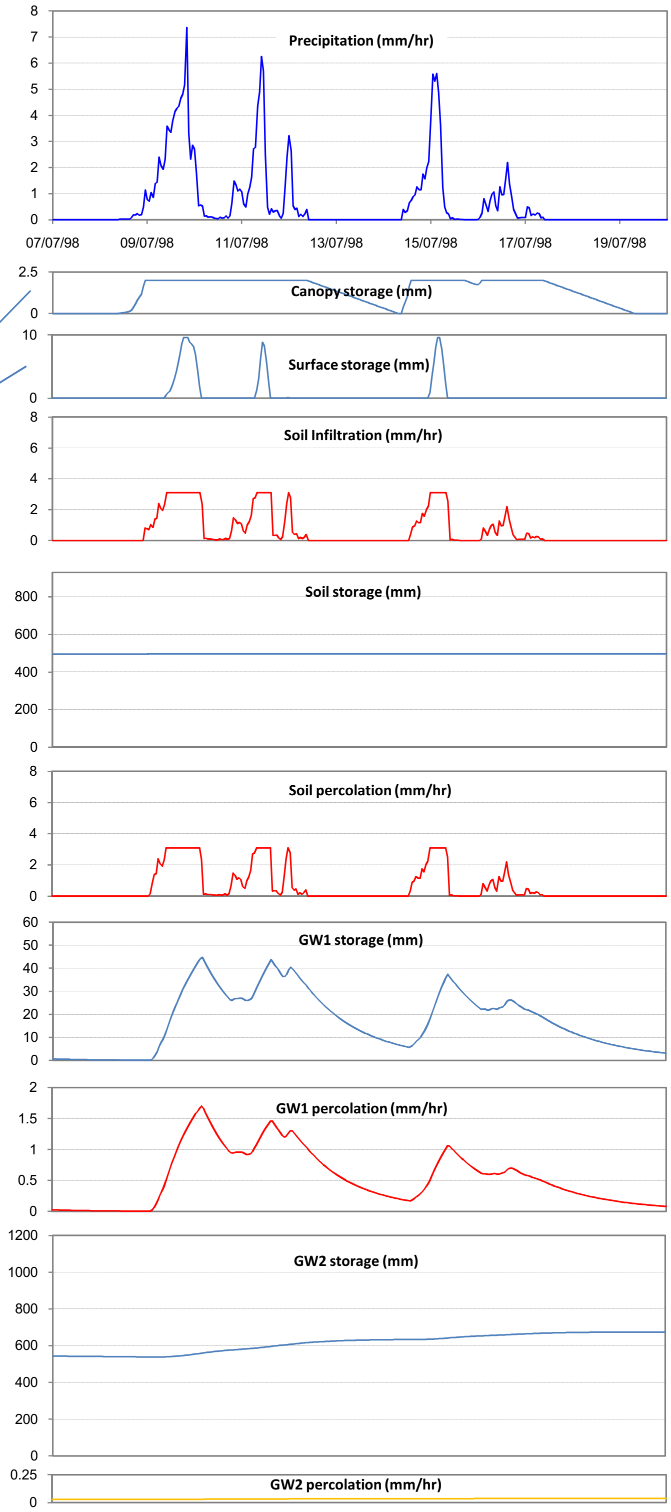


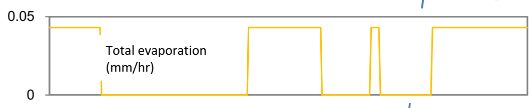
IN		
Rainfall	202.9 mm	100%
Total In	**202.9 mm**	**100%**
OUT		
Streamflow:		
Surface runoff	-6.3 mm	3.1%
Interflow	-17.8 mm	8.8%
Baseflow	-27.5 mm	13.5%
Subtotal	**-51.6 mm**	**25.4%**
Losses:		
Evap	-6.5 mm	3.2%
Deep perc	-10.7 mm	5.3%
Subtotal	**-17.2 mm**	**8.5%**
Accessions to storage:		
Canopy	0.0 mm	0%
Surface	0.0 mm	0%
Soil	-1.0 mm	0.5%
GW1	-2.5 mm	1%
GW2	-130.7 mm	64.4%
Subtotal	**-134.3 mm**	**66.1%**
Total Out	**-203.0 mm**	**100%**
Residual	*-0.2 mm*	*-0.1%*

Catchment: Whakamaru_left

Landuse, soil type: Pasture, loam

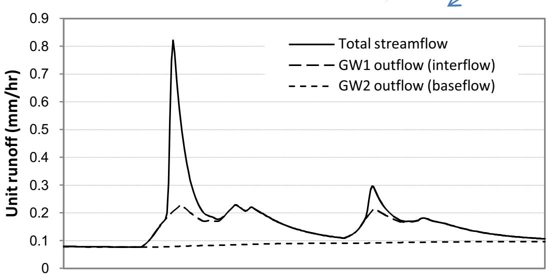
Event: 20y

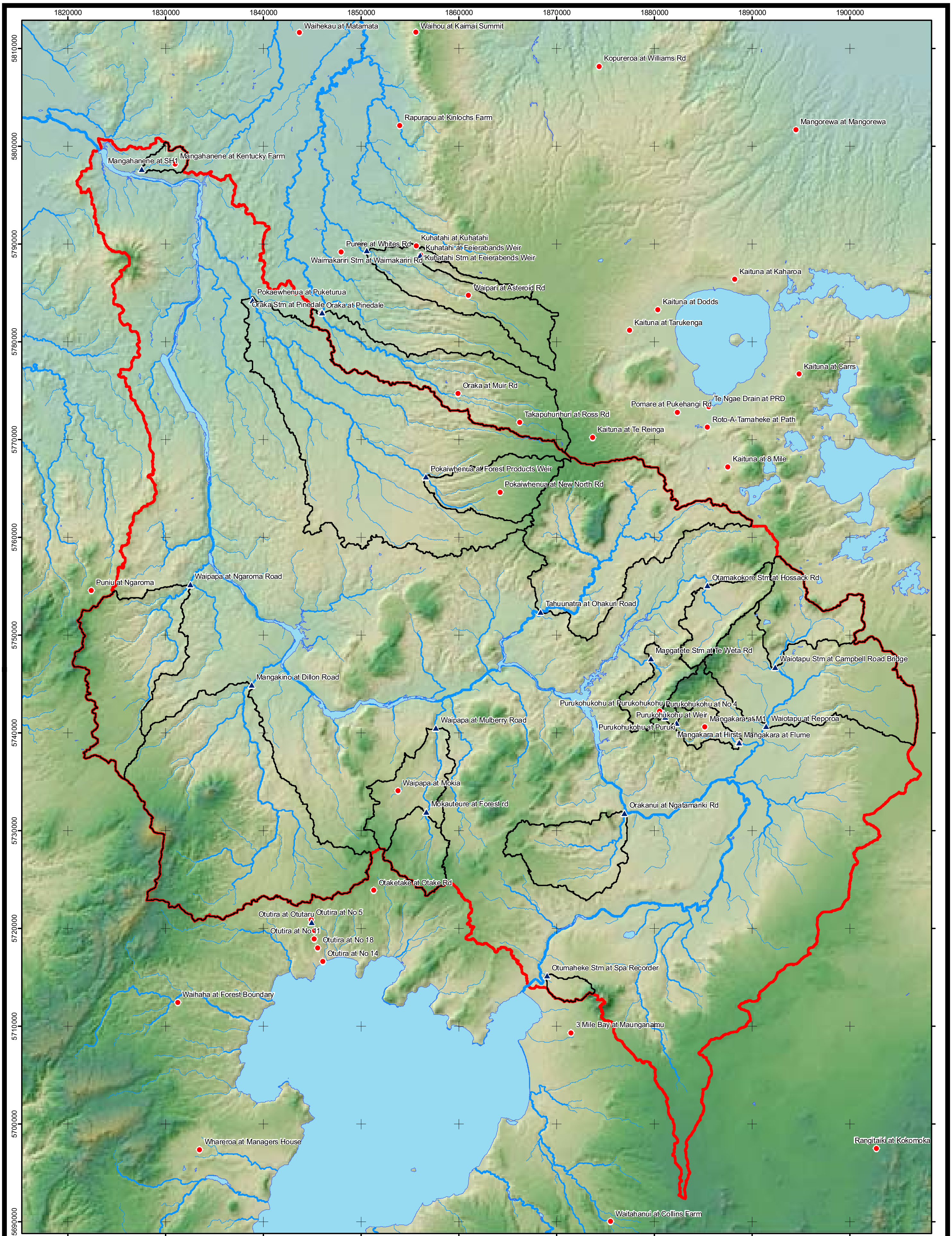




LEGEND:

- Store (units in mm)
- Flux (units in mm/hr)
- Stream flow (units in mm/hr)
- Evaporation losses (mm/hr)
- Percolation losses (mm/hr)





LEGEND

- Flow gauges
- Rain Gauges
- Gauged Catchments
- Upper Waikato River Catchment

Document Status:
SKM-AUCK I:\AENVA\Projects\AE03513\WP00 - Model Selection Study\TECHNICAL\Drawings\GIS\MXD

	Name	Date
Fig4_Flow+Rfall.mxd	BRT	Oct 08

Data Notes:
Site locations sourced from EnvironmentWaikato.

Background data sourced from Land Information New Zealand

1:350,000

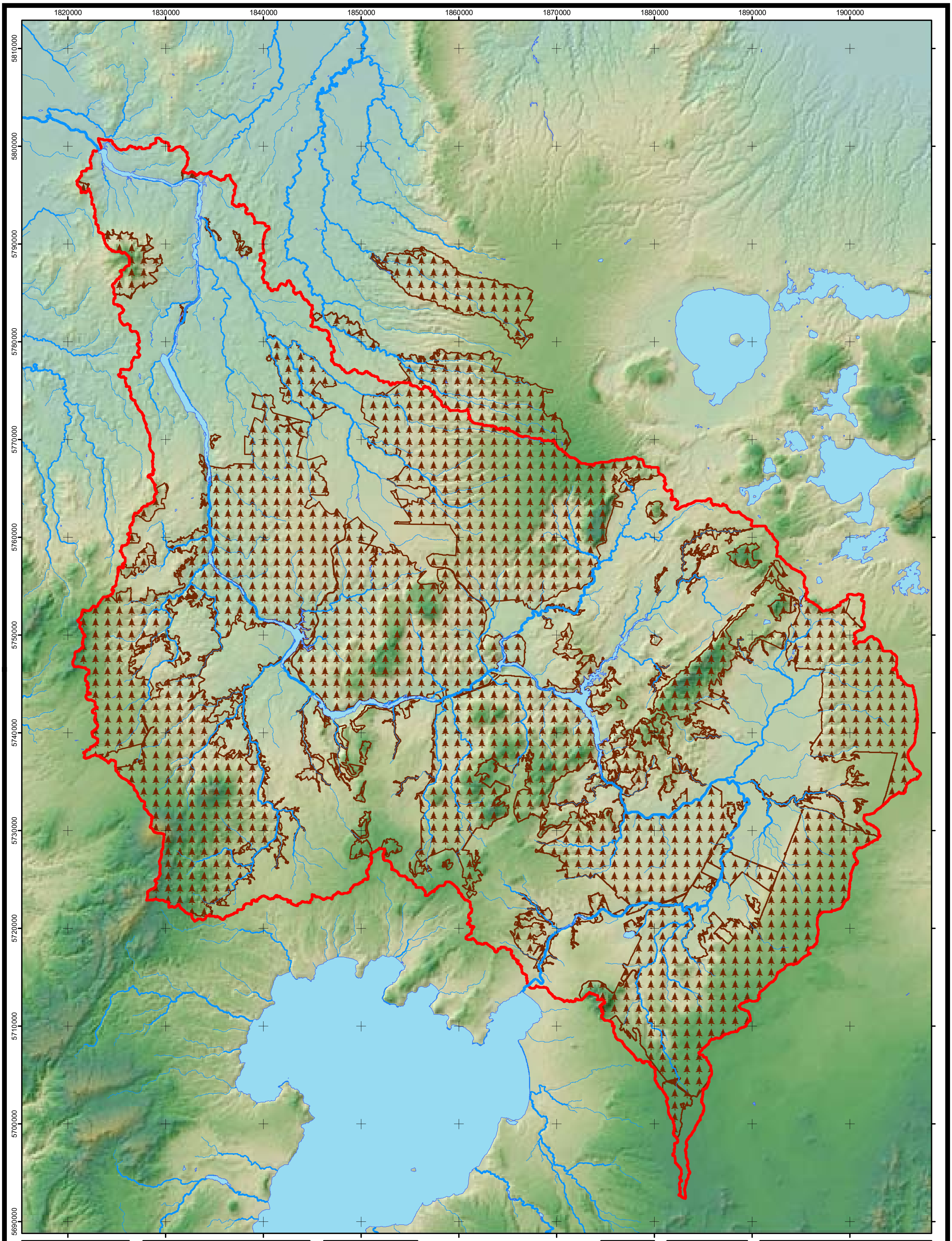
0 2.5 5 10 15 km

N

GIS by SKM

Map of rainfall stations and stream flow gauges

Figure 4.



LEGEND

- Upper Waikato River Catchment
- Forest

Document Status:

SKM-AUCK I:\AENVA\Projects\AE03513\WP00 - Model Selection Study\TECHNICAL\Drawings\GIS\MXD

	Name	Date
Fig5_Land Cover.mxd	BRT	Oct 08

Data Notes:

Site locations sourced from EnvironmentWaikato.

Background data sourced from Land Information New Zealand

1:350,000

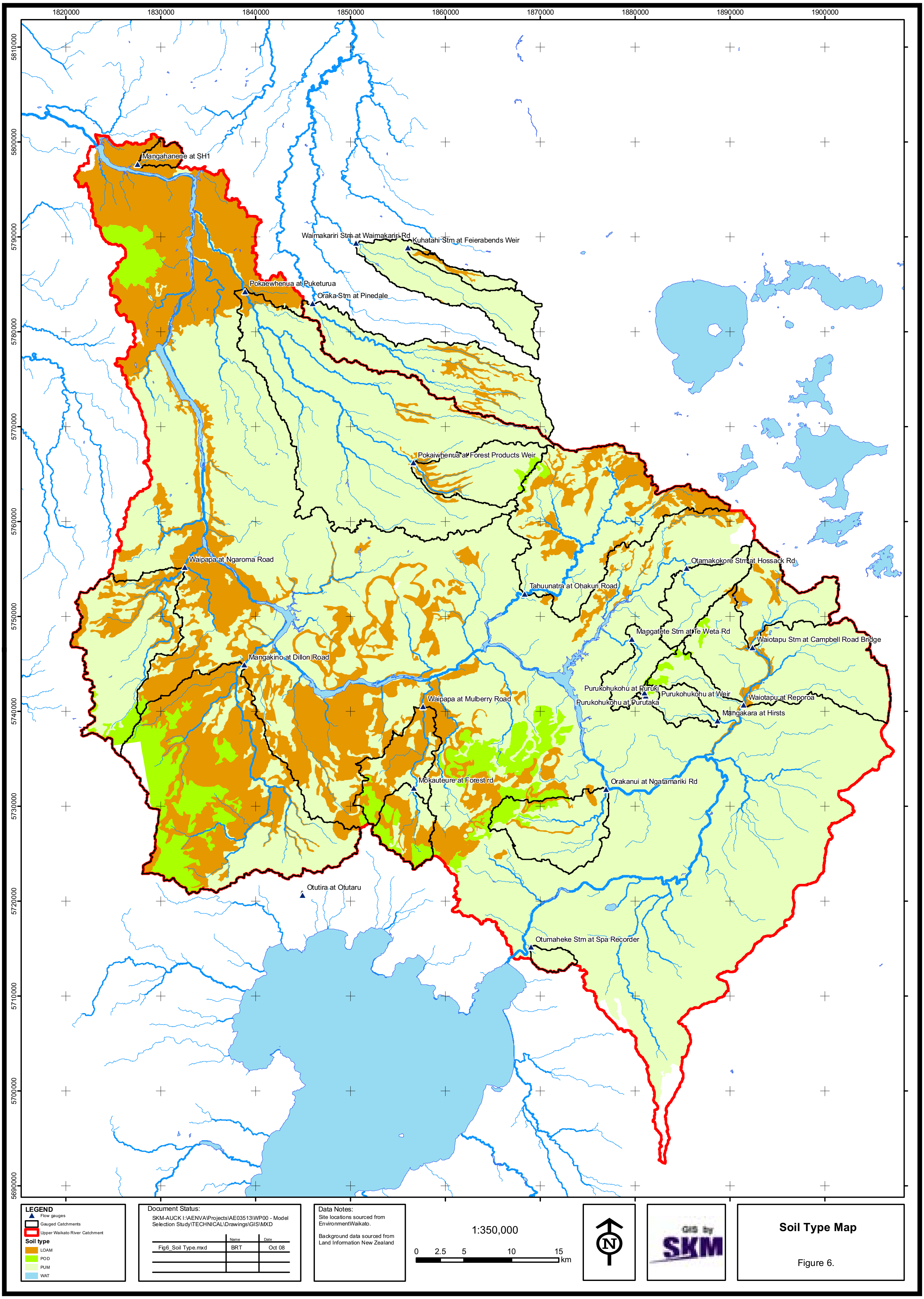
0 2.5 5 10 15 km

N

GIS by SKM

Generalised Land Cover Map

Figure 5.



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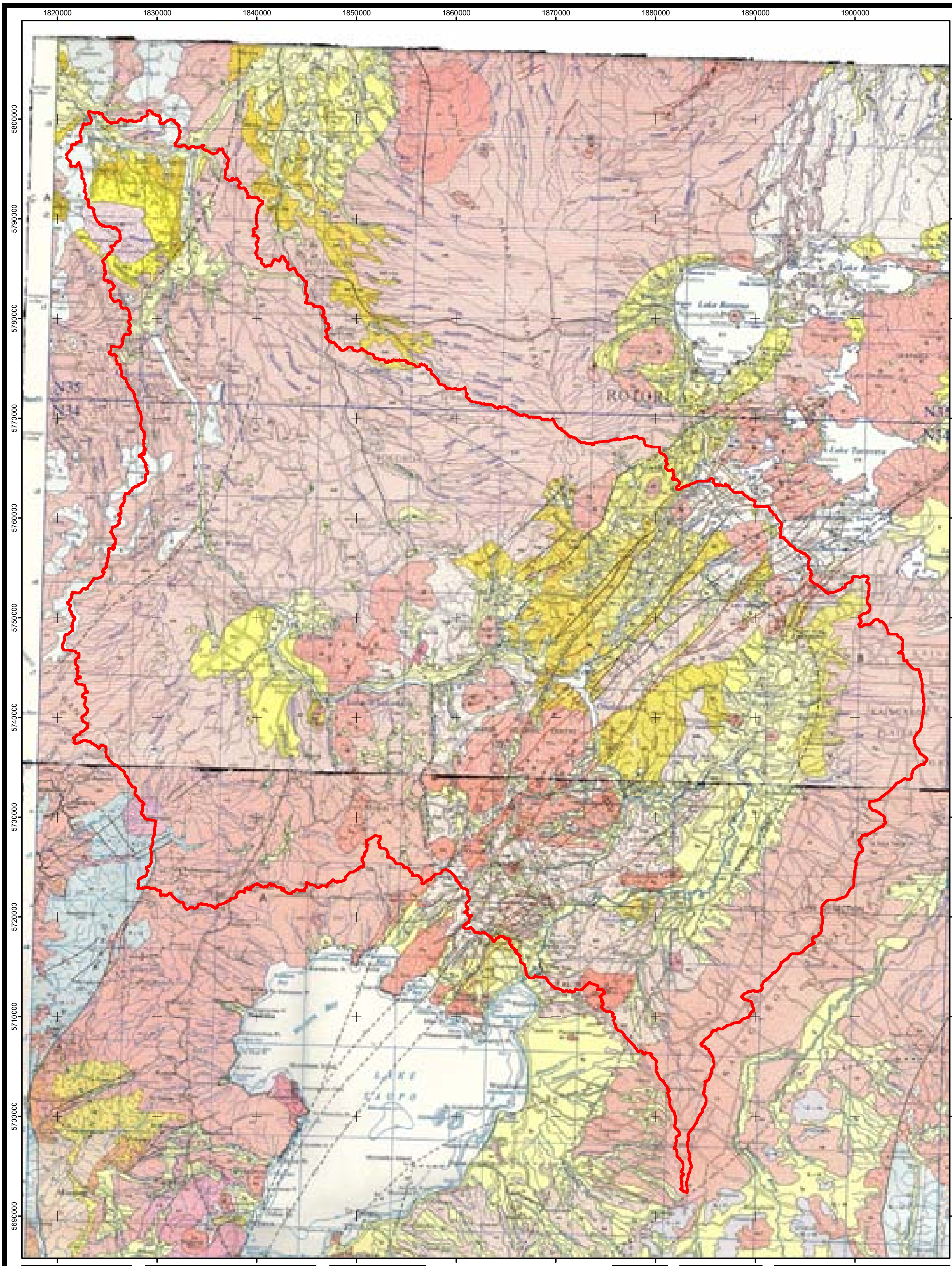
Mangahanene at SH1
Waimakariri Stm at Waimakariri Rd
Kuhatahi Stm at Feierabends Weir
Pokaewhenua at Puketurua
Oraka Stm at Pinedale
Pokaiwhenua at Forest Products Weir
Waipapa at Ngaroma Road
Tahuunatra at Ohakuri Road
Otamakokore Stm at Hossack Rd
Mangatete Stm at Te Weta Rd
Waiotapu Stm at Campbell Road Bridge
Mangakino at Dillon Road
Purukohukohu at Puruki
Purukohukohu at Weir
Purukohukohu at Purutaka
Waiotapu at Reporoa
Mangakara at Hirsts
Waipapa at Mulberry Road
Mokauteure at Forest rd
Orakanui at Ngatamariki Rd
Otutira at Otutaru
Otumaheke Stm at Spa Recorder
LEGEND
Flow gauges
Gauged Catchments
Upper Waikato River Catchment
Soil type
LOAM
POD
PUM
WAT
Document Status:
SKM-AUCK I:\AENVA\Projects\AE03513\WP00 - Model Selection Study\TECHNICAL\Drawings\GIS\MXD
Name
Date
Fig6_Soil Type.mxd
BRT
Oct 08
Data Notes:
Site locations sourced from EnvironmentWaikato.
Background data sourced from Land Information New Zealand
1:350,000
0
2.5
5
10
15
km
N
GIS by
SKM
Soil Type Map
Figure 6.



LEGEND

Upper Waikato River Catchment

Document Status:

SKM-AUCK I:\AENVA\Projects\AE03513\WP00 - Model Selection Study\TECHNICAL\Drawings\GIS\MXD

	Name	Date
Fig7_Geology.mxd	BRT	Oct 08

Data Notes:

Geology maps derived from NZ Geological Survey 1:250 000 Geology Maps 5 & 8 (Rotorua & Taupo)

Legend supplied as separate figure.

1:350,000

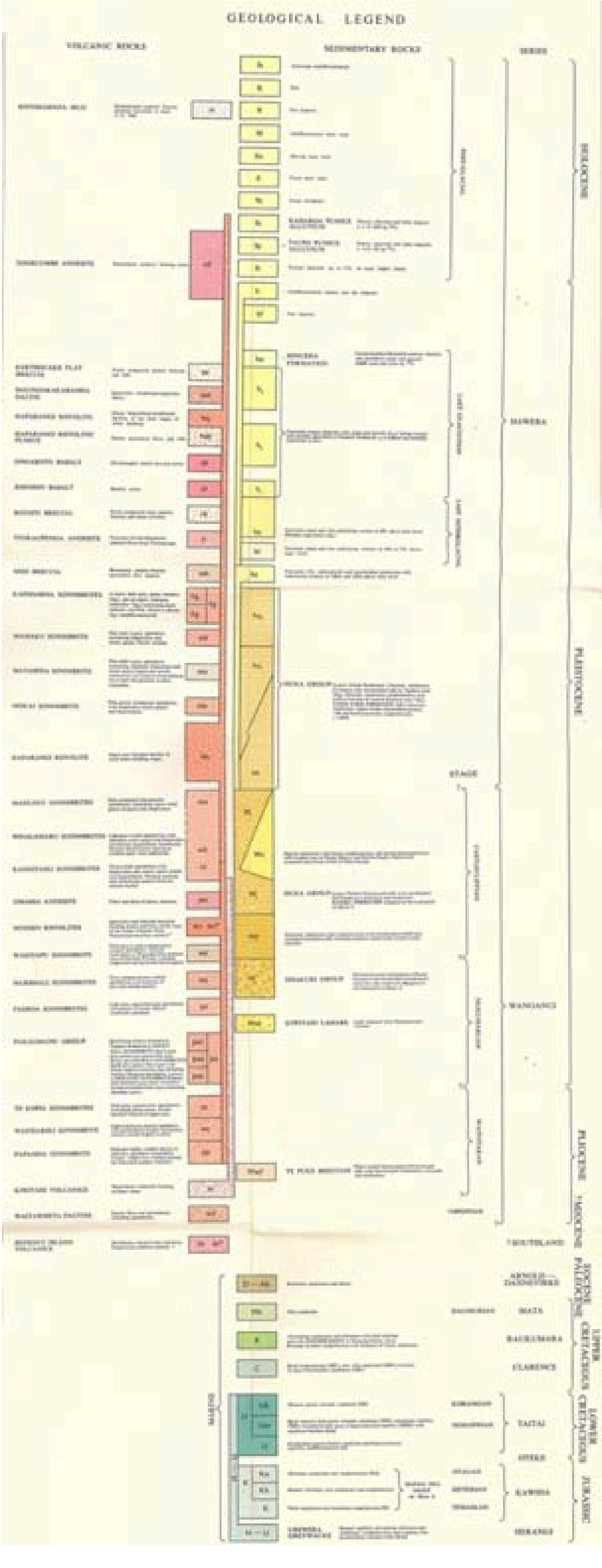
0 2.5 5 10 15 km

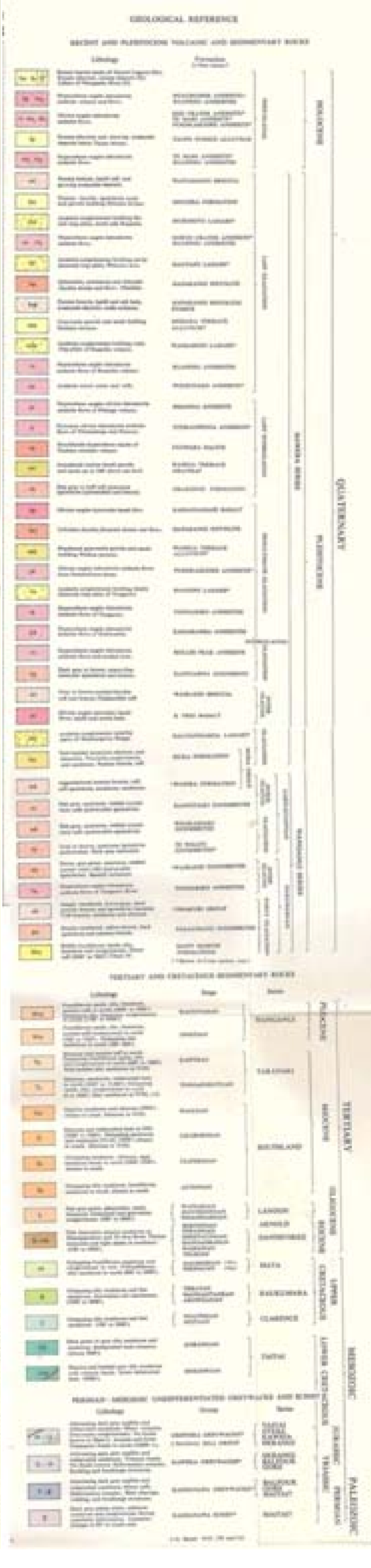
N

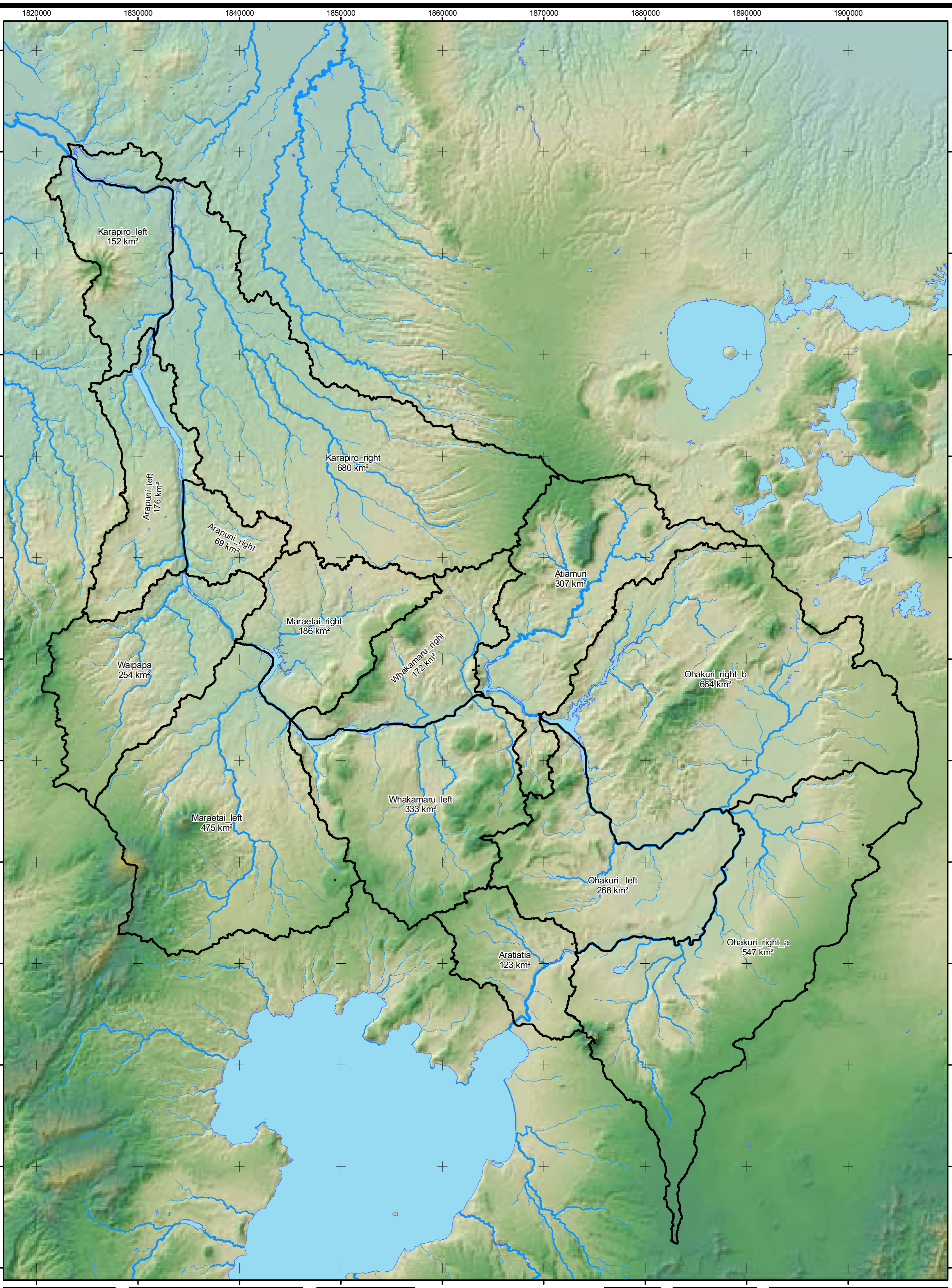
GIS by SKM

Geology Map

Figure 7.


GEOLOGICAL LEGEND
VOLCANIC ROCKS
SEDIMENTARY ROCKS
SERIES
HOLOCENE
HAWERA
PLEISTOCENE
STAGE
WANGANUI
PLIOCENE
MIOCENE
SOUTHLAND
ARNOLD-DANNEVIRKE
MATA
RAUKUMARA
CLARENCE
TAITAI
OTEKE
KAWHIA
HERANGI
UPPER CRETACEOUS
LOWER CRETACEOUS
JURASSIC


GEOLOGICAL REFERENCE
RECENT AND PLEISTOCENE VOLCANIC AND SEDIMENTARY ROCKS
HOLOCENE
PLEISTOCENE
QUATERNARY
TERTIARY AND CRETACEOUS SEDIMENTARY ROCKS
TERTIARY
MESOZOIC
TRIASSIC
PERMIAN
PALEOZOIC



LEGEND

Hydro lake basins

Document Status:

SKM-AUCK I:\AENVA\Projects\AE03513\WP00 - Model Selection Study\TECHNICAL\Drawings\GIS\MXD

	Name	Date
Fig18_Hydrobasins.mxd	BRT	Nov 08

Data Notes:

1:350,000

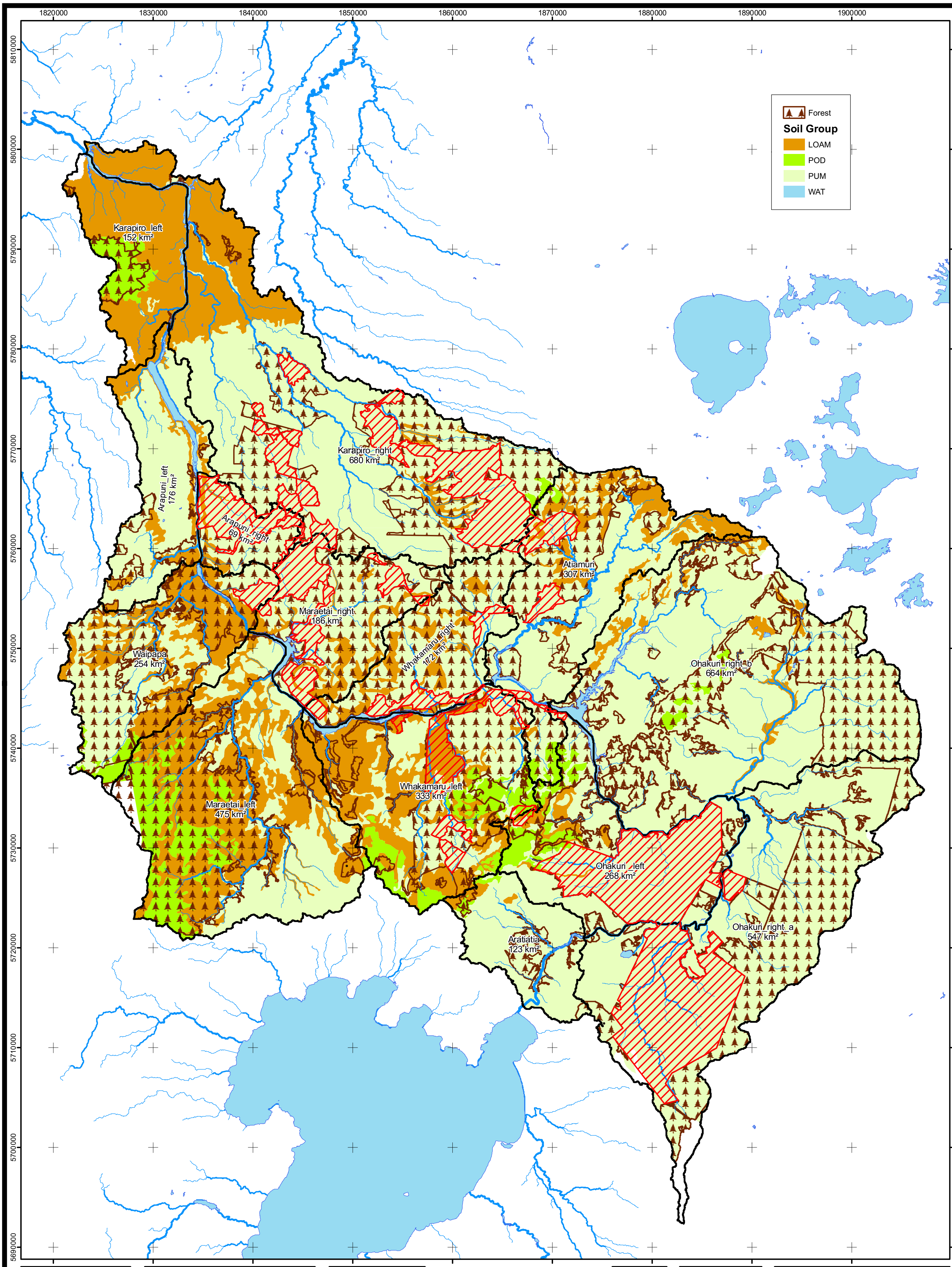
0 2.5 5 10 15 km

N

GIS by SKM

Hydro Lake Basin Map

Figure 18.



LEGEND

Hydro lake basins

Potential Deforestation

Document Status:

SKM-AUCK I:\AENVA\Projects\AE03513\WP00 - Model Selection Study\TECHNICAL\Drawings\GIS\MXD

	Name	Date
Fig24_Basins_LUCScenario.mxd	BRT	Nov 08

Data Notes:

1:350,000

0 2.5 5 10 15 km

N

GIS by SKM

Hydro Lake Basins (land use change scenario)

Figure 24.