Mangaroa River Flood Hazard Assessment

GREATER WELLINGTON REGIONAL COUNCIL

Mangaroa Hydraulic Modelling Report

AE04609 | Rev F

Mangaroa

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Mangaroa River Flood Hazard Assessment

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Document history and status

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A	29 Aug 2014	First Draft sent to Client	A Feek	D Grace	C Martell
B	29 Jan 2015	Revised draft incorporating Client comments	R Abbott	C Martell	C Martell
C	17 Mar 2015	Final	R Abbott	C Martell	C Martell
D		Final revised to address further Client comments	R Abbott	C Martell	C Martell
E	01 Oct 2015	Final to include Hazard Mapping	L Criste	P Kinley	R Rose
F	06 Nov 2015	Final to include additional calibration	R Eabry	P Kinley	P Kinley

Contents

Executive Summary

This report presents the flood hydrology and hydraulic model build for the 2014 Mangaroa River catchment model, which comprises an updated version of the 2007 model in direct response to peer review recommendations. The updates can be summarised as:

- Rethinking of the event selection for calibration and validation, and hence updated calibrations and validation;
- Increasing resolution of model bathymetry to 5 m grid cell size
- Incorporation of updated LiDAR data;
- Extension of the Black Creek watercourse within the model through addition of new survey;
- Refined channel alignment;
- Rainfall runoff modelling component based on SCS unit hydrograph method and included within hydraulic model as part of the recalibration;
- Predicted climate change impacts included in the design rainfall estimates;
- General update of minor model parameters to align them with current industry standards.

This updated model has been used to undertake hazard mapping of the Mangaroa. A series of sensitivity runs were carried out and the results combined to produce a peak hazard sensitivity output representing the worst case from each of the sensitivity runs over the catchment. An additional 300mm of freeboard has been added to the peak hazard, and hazard maps produced.

Conclusions

- The revised 2014 model achieved good calibration for the three events chosen, however the validation runs suggest that whilst the model performs well at predicting higher flow events, peak flow during lower flow events may be under-estimated by the model.
- The balanced storm approach, while conservative, was a considerably better match against the existing gauge record and recorded storm peaking than that achieved by using the Tomlinson storm distribution.
- A comparison of peak flows at the gauging station, both statistical and from the two model runs confirm that;
    1. The previous 2007 version of the model was overly conservative against the gauged record;
    2. The current 2014 model run falls into the expected range at the gauging station when mid-level climate change is taken into account;
    3. The 2014 model and the 2007 model have ended up with a similar peak flows due to the influence of climate change on the modelled peak flows.
    4.

Source	1% AEP	1% AEP with Climate Change
2007 Model	480 m^3/s	
2014 Model		475 m^3/s
Flood Frequency Analysis estimate	372 ± 57 m^3/s	450-515 m^3/s

undertaken in 2005		*(estimated by assuming 20% increase on the 1% AEP present day)*
Flood Frequency Analysis estimate undertaken in 2014 *(using full gauge record and EV1 (Gumbels) distribution)*	355 ± 73 m^3/s	426-515 m^3/s *(estimated by assuming 20% increase on the 1% AEP present day)*

- Modelled Top Water Levels differ from the 2007 modelling along much of the model. This is due to a range of factors including changes to the length of the open channel (which has altered chainages), additional survey of land around Black Creek, a new "in model" approach to the hydrology and calibration of storm events.

Recommendations

1. It is recommended that the 2014 model, using the balanced storm hydrograph, be adopted as the updated flood risk model for the Mangaroa River.
2. While through much of the lower river flood levels do not differ greatly from the previous assessment of flood risk, there are areas around Black Creek and in the upper catchment where differences are significant.
3. A combined Mangaroa and Hutt River model could be used to provide better calibration and better accuracy of the flooding near the confluence of the two rivers.
4. GWRC may want to consider a second gauging station on the Mangaroa River that is not affected by the Hutt River.
5. Continued development and maintenance of the model is recommended as additional data becomes available. The modelling should also be reviewed periodically as modelling software and best practice methodology continues to evolve.

Important note about your report

The sole purpose of this report and the associated services performed by Jacobs is to model flood hazard in the Mangaroa catchment in accordance with the scope of services set out in the contract between Jacobs and the Client. That scope of services, as described in this report, was developed with the Client.

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1. Introduction

In 2007, Jacobs (formally SKM) produced the Mangaroa river model (referred to as "the 2007 model" throughout this report) as part of the *Mangaroa Flood Hazard Assessment* study. A peer review of the 2007 model and report made suggestions to alter the hydrological approach used in the modelling and calibration on the basis of the peak flows in the design model being higher than those estimated from the gauging station record.

This report presents the 2014 model which comprises an updated version of the 2007 model in direct response to the peer review recommendations.

As well as addressing the peer review comments, in producing the updated 2014 model, other changes have been incorporated, thus the updates to the 2007 model can be summarised as:

- Rethinking of the event selection for calibration and validation, and hence updated calibrations and validation;
- Increasing resolution of model bathymetry to 5 m grid cell size
- Incorporation of updated LiDAR data;
- Extension of the Black Creek watercourse within the model through addition of new survey;
- Refined channel alignment;
- Rainfall runoff modelling component based on SCS unit hydrograph method and included within hydraulic model as part of the recalibration;
- Predicted climate change impacts included in the design rainfall estimates;
- General update of minor model parameters to align them with current industry standards.

This updated model has been used to undertake hazard mapping of the Mangaroa. A series of sensitivity runs were carried out and the results combined to produce a peak hazard sensitivity output representing the worst case from each of the sensitivity runs over the catchment. An additional 300mm of freeboard has been added to the peak hazard and hazard maps produced.

2. Review of Available Data

2.1 Review of Existing Data

The previous *Mangaroa Flood Hazard Assessment* report (SKM, 2007) was reviewed along with the associated flood model. As part of the data collection for this update it was noted that the Hutt River water levels are likely to be influencing the gauging of the Mangaroa River at Te Marua in some events. This tailwater will influence flood frequency analysis of the gauged discharge in the Mangaroa, but it is unclear to what extent. To account for this issue the event selection for calibration and validation was updated in an effort to address tailwater influence.

In addition, advances in technology and flood modelling practice over the past seven years allow for a finer resolution flood model than the one built in 2007. Refinements made to the model are discussed in Section 4.

2.1.1 **Hydrometric Data**

Streamflow

Instantaneous water level data for the Mangaroa River has been recorded by GWRC on a continuous basis at Te Marua (gauge number 29830) since May 1977. Data for the site was collected in accordance with the Resource Information Quality Procedures, which meet the ISO: 9002 Standard and is audited on an annual basis by TELARC registered auditor (Watts, 2005). This observed water level and rated discharge data was provided by GWRC for calibration and validation purposes.

The gauge for Mangaroa at Te Marua is located at the downstream end of the Mangaroa River (Figure 1). It is noted that the water levels in the receiving Hutt River influence the readings of this gauge at high flood flows and this is discussed further in Section 5.1 along with details of an upstream Hutt River gauge. While there is no level recorder at the confluence of the Mangaroa and Hutt Rivers, it is noted that GWRC maintain a MIKE-11 river model of the Hutt River.

Greater Wellington completed a thorough assessment of the gauged record ahead of the original report (Watts 2005) and developed flood frequency estimates at that time as shown in Table 1. This was a pooled estimate combining the preferred at site distribution (EV1) and the results of a rainfall runoff model developed by the Council.

Table 1: Flood Frequency estimates at Mangaroa River at Te Marua as derived by Greater Wellington in 2005 (taken from Tables 19 and 17, pages 26 and 27, in Watts (2005) *Flood Hydrology of the Mangaroa River*)

	Preferred at-site	Regional	Rainfall runoff model	Previous results (Pearson, 1990)	EV1 Annual maximum series
Q2	132	123	168	120	132
Q5	194	168	202	180	194
Q10	238	197	235	210	238
Q20	281	225	271	250	281
Q50	335	262	323	300	335
Q100	376	289	367	330	376
Q200	417	317	403	360	417
PMF	n/a	n/a	1864	n/a	n/a

We have also reassessed the current EV1 distribution, including data since 2005, as an update on the previous flood frequency analysis. The results of this updated analysis are provided in Table 2.

Table 2: Flood Frequency Estimation undertaken in 2014 using EV1 distribution

Return period	Gumbel (EV1) peak flood (m^3/s)
Q2	120
Q5	182
Q10	224
Q20	265
Q50	317
Q100	355
Q200	394

Rainfall

There are five rainfall gauges nearby the Mangaroa River catchment which record continuous sub-daily rainfall and all are still operating. These gauges and their period of record are summarised in Table 3 and their locations are shown in Figure 1. The Tasman Vaccine and Cemetery rain gauges were used exclusively for calibration and validation purposes due to their:

- Proximity to the Mangaroa River catchment;
- Suitable period of record;
- Suitable locations (i.e. less likely to be affecting by orographic affects which are not catchment representative).

Table 3: Summary of rain gauges

Gauge	Date Open	Comments
Mangaroa River at Tasman Vaccine Limited	July 1980	Within headwaters of catchment
Akatarawa River at Cemetery	March 1988	Near downstream end of catchment
Pakuratahi at Centre Ridge	April 1984	Outside (east) of the catchment boundary
Hutt River at Savage Park	July 2010	Poor data quality; Not open for events selected
Orongorongo at Orongo Swamp	October 1980	Outside (south) of the catchment boundary
Pinehaven Stream at Pinehaven Reservoir	August 2010	Not open for events selected
Wainuiomata at Skull Gully	July 1980	Outside (south) of the side of catchment boundary

These gauges have also been compared to the rainfall record kept by Mrs Berkett collected between 1980 and 2008 at two different sites within the valley. Comparative analysis was undertaken by Laura Keenan for Greater Wellington on this record (Watts, L., 2005. Flood Hydrology of the Mangaroa River, Greater Wellington City Council). Her comments were as follows.

Site 1 on "*the corner of Johnson's Valley Road is actually very close (about 1km) to our gauge at Tasman Vaccine Ltd. The storm rainfalls are therefore very similar - on average the difference was less than 4% over the duration of the storm, which is a very minor difference when considering measurement errors at both sites. The two sites fall within a band of equal rainfall for modelling purposes, and so the similar records are reassuring*."

Site 2 at "*1 Whitemans Valley Road is obviously in a slightly different part of the catchment, where we would expect rainfall to be lower. Comparison of the storm rainfalls at the Berkett gauge with our gauge at TVL shows the rainfall at 1 Whitemans Valley is generally 85-96% of what we recorded at TVL. The exception was the 5 January 2005 storm, when there was considerably more rainfall at 1 Whitemans Valley; this storm displayed a very strong W-E gradient.*"

While each gauge and storm will record varied results due to location and variable rainfall distributions in any given event these records align well with the assumptions made for rainfall in the updated model and are a useful comparator for existing rain gauges.

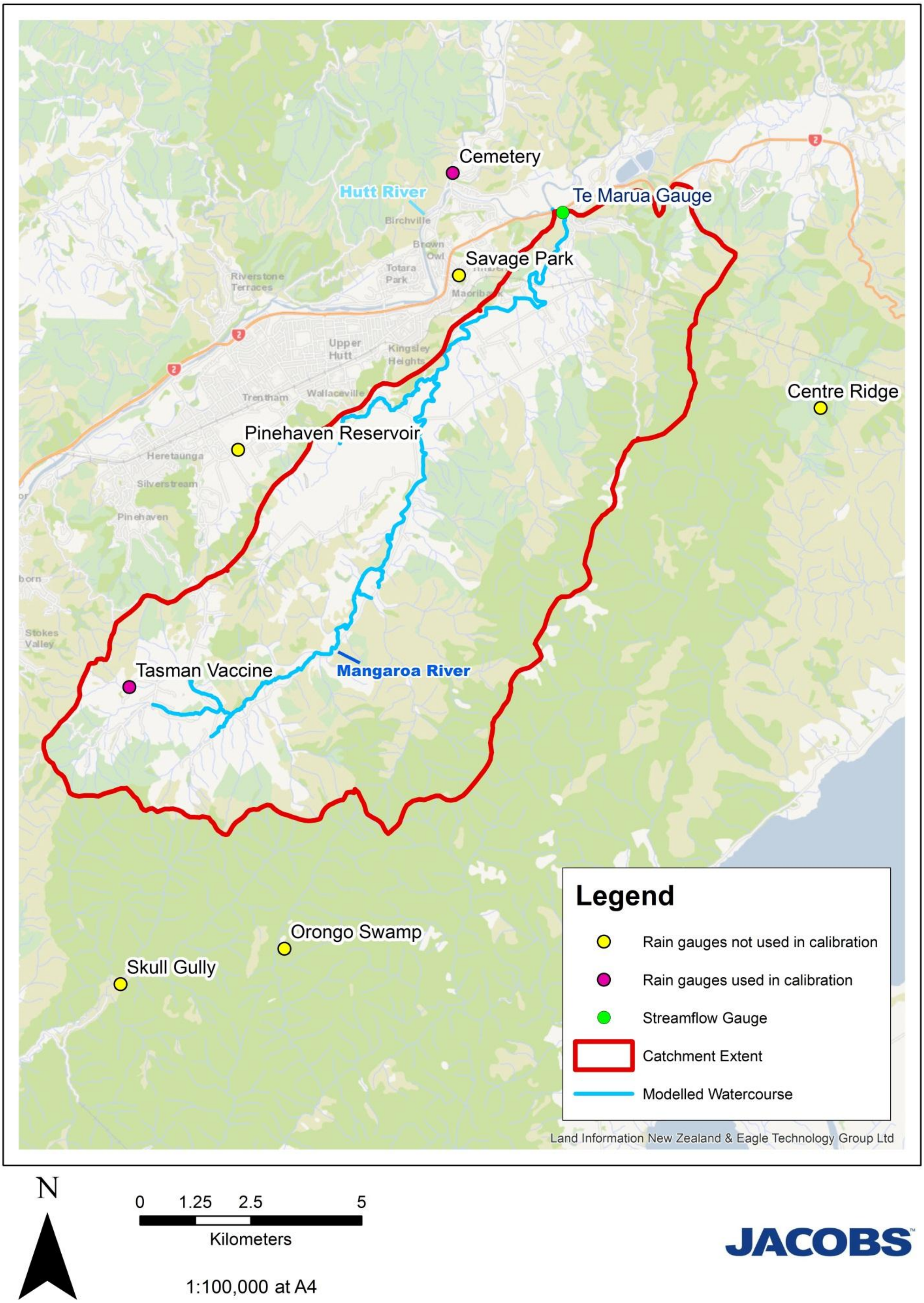

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Figure 1: Sources of Hydrometric Data within the vicinity of the study area

2.1.2 Topographical Data

LiDAR

The previous *Mangaroa Flood Hazard Assessment* (SKM, 2007) utilised LiDAR (Airborne laser scanning) survey of the Mangaroa floodplain commissioned in July 2004. This survey was used to create a Digital Elevation Model (DEM) of the floodplain that formed the basis of the MIKE-21 10 m bathymetry. Since that time, more recent LiDAR has been obtained which was deemed suitable for use. Section 4.2 details how the LiDAR was used to produce the model bathymetry.

Cross-sectional data and additional survey

In the previous study an engineering survey was undertaken for the channel cross-sections and hydraulic structures. Approximately 130 cross-sections were surveyed on the open channel of the Mangaroa River with a further 40 cross-sections covering the tributaries being Black Creek, Huia, and Narrow Neck Streams.

There was a concern that the potential secondary flow path and storage area between Mangaroa River and Black Creek was not adequately represented in the 2007 model. Therefore it was deemed appropriate to obtain additional cross-sectional channel survey further upstream in Black Creek and build this into the 2014 model (as shown on Figure 5 in Section 4).

3. Catchment Description

3.1 General Description

The Mangaroa River catchment has an area of 103 km^2 and is characterised by the cluster of small catchments and streams that contribute to the main river channel. These small catchments are very steep with falls of up to 500 m over 3 to 4 km. The catchment comprises approximately 15 – 20 % of alluvial floodplain (a small percentage is now active floodplain) with the balance in indigenous forest, regenerating scrub and exotic forest. The Mangaroa River is approximately 21 km long from Johnsons Road at its headwaters to the confluence with the Hutt River. The Mangaroa River has a typical slope of 6 m drop per 100 m length and a typical width of 30 m. An overview of the catchment area can be seen in Figure 2.

3.2 River Description

The Mangaroa River and floodplain is broadly characterised by three reaches, as described below and shown in Figure 2.

- The upper reach comprises the cluster of headwater catchments and small tributaries starting approximately near Russells Road, Johnsons Road and Blue Mountains Road. In their flatter sections, these smaller streams have been modified by channelisation and the construction of access-culverts and bridges.
- The middle reach of the Mangaroa runs through Whitemans Valley to the Mangaroa Valley Road Bridge. The floodplain is generally narrow and there are approximately 10 lateral tributary catchments north and south of the main Mangaroa River channel. The channel is relatively shallow and mobile through this reach.
- The lower reach begins close to the Mangaroa Valley Road Bridge and flows to the outlet to the Hutt River. The upstream section from the Mangaroa Valley Road Bridge down to a short gorge adjacent to Maymorn Road (approximately 8 km long) runs through alluvial floodplain and land-use is predominantly rural and pastoral. The Black Creek tributary (which drains the expansive swampy area behind Katherine Mansfield Drive) joins the Mangaroa River in this rural section. The lower 2 km of this reach, near Plateau Road, has outcropping rock features and parts of the adjacent residential development may be flood-prone.

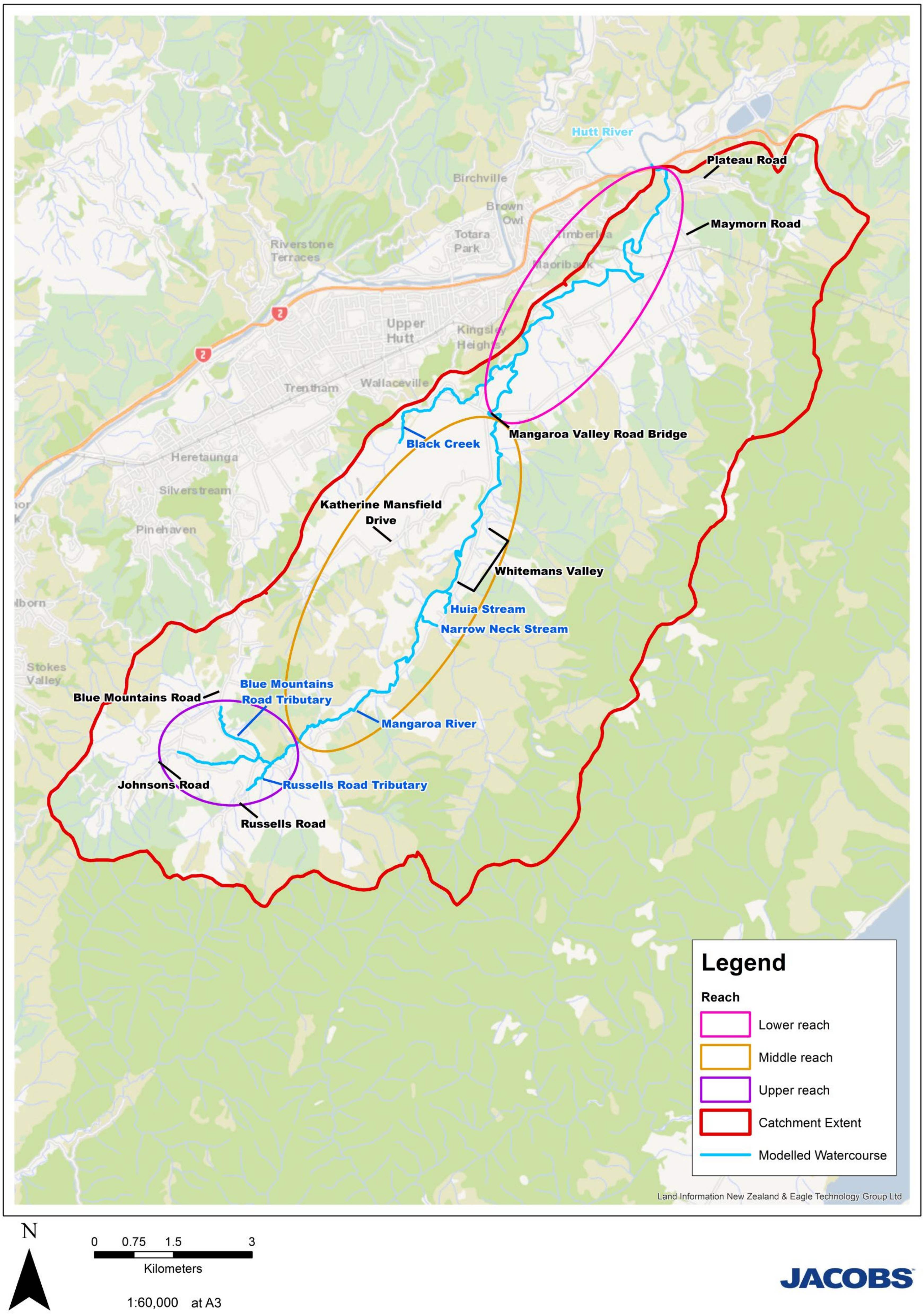


Figure 2: Study area location

3.3 Topography

The topography of the region surrounding the Mangaroa River mainly consists of a series of large ridgelines defining the total Mangaroa River catchment extent. Within the catchment the land consists of a large undulating area with steep ridgelines defining the sub catchments. These small catchments are very steep with falls of up to 500 m over 3 to 4 km.

3.4 Geology and Soils

The geological and soil makeup for the Mangaroa River catchment largely consists of alluvial and swamp deposits following the main river channel and a mixture of sandstone and mudstone for the upper reaches of the sub-catchments.

3.5 Land Use

The current land use for the Mangaroa River catchment is a mixture of exotic and native forest, farm land, rural development and a small area of urban development.

The land use was used to derive land roughness values. The land was split between rural, roads and forestry land (the three main predominate land uses within the catchment) and resistance values were assigned accordingly (with reference to Chow, 1959). Urban resistance was not considered due to the extremely small percentage of land covered by urban areas. Resistance was specified with the model area over which flooding occurs. The resistance layer can be seen in Figure 3 and the values are as below in Table 4. This resistance layer was based on data provided by the New Zealand Land Cover Database.

Table 4: Resistance layer values

Category	Hydraulic Roughness (Manning's *n*)
Rural Land (predominantly pasture)	0.03
Forestry Land	0.1
Roads	0.015

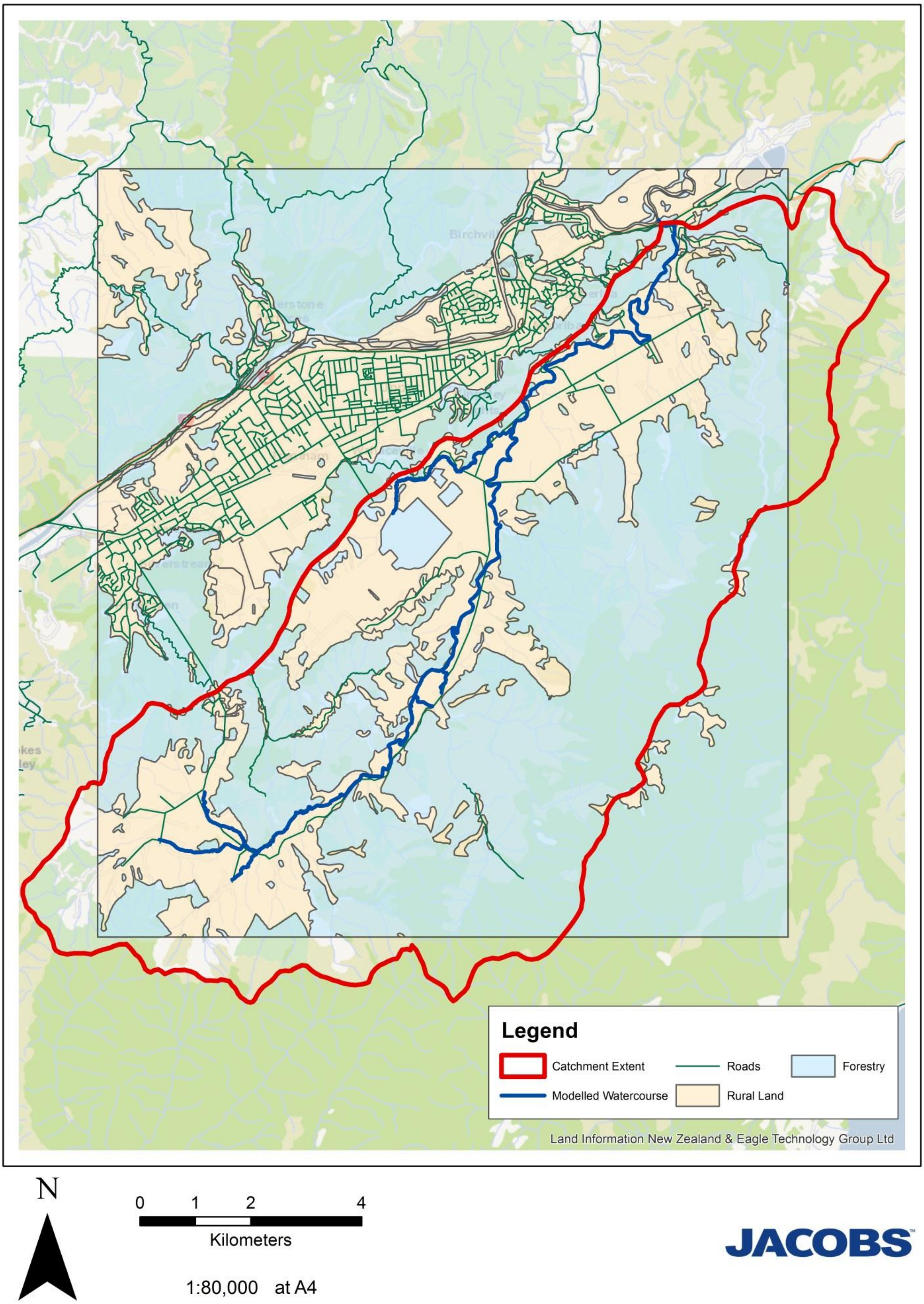


Figure 3: Landuse in the modelled area used to define resistance (Land categories attributed to: Landcare Research – LCDB-v3-land-cover-database)

3.6 Stormwater Drainage Systems

As there is very little urban development, there is only a very limited stormwater drainage system within the catchment. As such, the hydraulic model does not include an urban component as this was deemed unnecessary.

4. Model Build

4.1 Hydrological Model

The hydrology for the Mangaroa River catchment has been developed using the Soil Conservation Service (SCS) unit hydrograph method to estimate the conversion of catchment rainfall into runoff over time. It requires the delineation of suitable sub-catchments and the adoption of specific catchment characteristics for each sub-catchment.

4.1.1 **Catchments**

The catchments identified in the *Mangaroa River Flood Hazard Assessment* (SKM, 2007) were checked against recent LiDAR for the area and were determined to still be appropriate. The delineation of the sub-catchments can be seen in Figure 4.

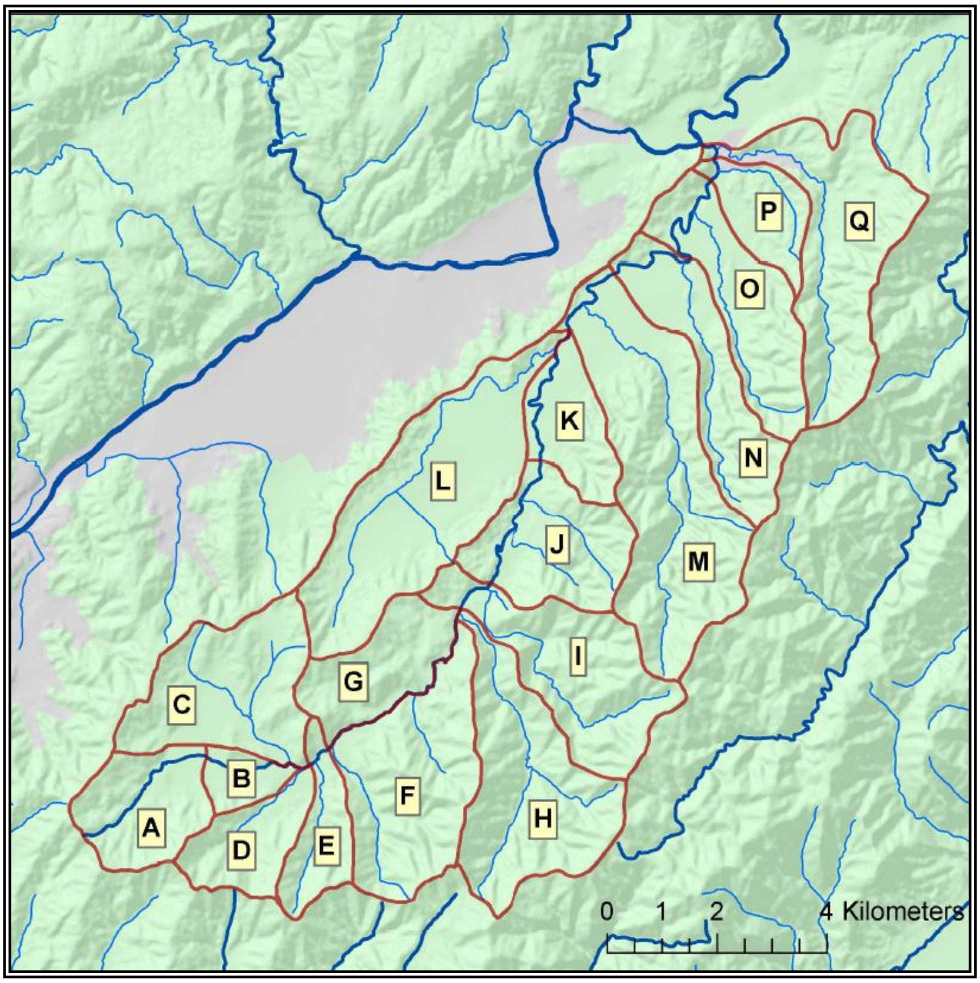


Figure 4: Sub-catchments used in development of the hydrology from Mangaroa River Flood Hazard Assessment (SKM, 2007)

4.1.2 Curve Number (CN)

The runoff curve number (CN) is used for predicting direct runoff from rainfall excess. Within the scope of this investigation the CN was based on the hydrologic soil group and land use (From the New Zealand Land Cover Database) of the sub-catchment. The CN for each soil group is derived by assessing the soil group type shown in Table 5 and the specific land cover type shown in Table 6. The final list of all types of soils present within the Mangaroa River catchment and their CN is shown in **Table 7**.

Table 5: Soil Groups from Hoggan, D.H, 1996. Floodplain Hydrology and Hydraulics. 2nd ed. McGraw-Hill.

Soil Groups	Type
Basalt	B
Gravel	B
Sandstone	C
Silt	D

Table 6: Landcover CN Numbers from Hoggan, D.H, 1996. Floodplain Hydrology and Hydraulics. 2nd ed. McGraw-Hill.

		CN		
Landcover*	**Type****	**B**	**C**	**D**
Manuka and/or Kanuka	Brush Good	48	65	73
Tall tussock grassland	Meadow	58	71	78
Broadleaved Indigenous Hardwoods	Brush Good	48	65	73
Exotic Forest	Woods Good	55	70	77
Forest - Harvested	Woods Fair	60	73	79
Gorse and/or Broom	Brush Good	48	65	73
Gravel or Rock	Pasture Good	61	74	80
High Producing Exotic Grassland	Pasture Good	61	74	80
Indigenous Forest	Brush Good	48	65	73
Lake or Pond	-	98	98	98
Low Producing Grassland	Brush Fair	56	70	77
Built-up Area (settlement)	Open Space Good	61	74	80

*** As defined attributed to: Landcare Research – LCDB-v3-land-cover-database**

**** Cover type from Hoggan, D.H, 1996. Floodplain Hydrology and Hydraulics. 2nd ed. McGraw-Hill.**

Table 7: Soil Grouping CN

Final Grouping	CN
High Producing Exotic Grassland gravel	61
High Producing Exotic Grassland sandstone	74
Exotic Forest gravel	55
Exotic Forest sandstone	70
Low Producing Grassland sandstone	70
Broadleaved Indigenous Hardwoods gravel	48
Broadleaved Indigenous Hardwoods sandstone	65
Indigenous Forest sandstone	65
Gorse and/or Broom sandstone	65
Built-up Area (settlement) gravel	61
Built-up Area (settlement) sandstone	74
Gravel or Rock sandstone	74
Gravel or Rock gravel	61
Gorse and/or Broom gravel	48
Manuka and/or Kanuka sandstone	65
Forest - Harvested sandstone	73
Manuka and/or Kanuka gravel	48
Indigenous Forest gravel	48
Tall Tussock Grassland sandstone	71
Forest - Harvested gravel	60
High Producing Exotic Grassland silt	80
Broadleaved Indigenous Hardwoods silt	73
Built-up Area (settlement) silt	80
Gorse and/or Broom silt	73
Exotic Forest silt	77
Manuka and/or Kanuka silt	73
Indigenous Forest silt	73
High Producing Exotic Grassland basalt	61
Broadleaved Indigenous Hardwoods basalt	48
Gorse and/or Broom basalt	48
Manuka and/or Kanuka basalt	48
Exotic Forest basalt	48
Lake or Pond sandstone	98
Lake or Pond gravel	98
Low Producing Grassland gravel	56

4.1.3 Connected Impervious Area (CIA)

The Connected Impervious Area (CIA) is effectively 0 for each sub-catchment due to the large difference in ratio between rural (largely pervious lands) to urban (largely impervious land) for each sub-catchment.

4.1.4 Initial Abstraction

The initial abstraction for each catchment was estimated to be a uniform 5 mm for each catchment. From experience with previous hydrological studies around the Greater Wellington region, this value is considered appropriate for areas with little to no urban development.

4.1.5 Time to Concentration

Time to concentration was calculated following the Bransby Williams formula. Using the equal area slope method, the average fall can be calculated for the basin.

$$TC = \left(\frac{L}{1.5 * D} * \left(\frac{M^2}{F}\right)^{0.2}\right) * 60$$

Where:
Tc is the time to concentration
L is the longest straight line distance that can be drawn from the basin mouth to any point in the basin (km)
D is the diameter of a circle equal in area to the basin area (km)
M is the Basin area(km^2)
F is the average fall of the main water course (m/100m)

4.1.6 Lag Time

Lag time is a factor of TC and is used within the MIKE-11 hydrology model. Lag time is estimated at 60% of the TC for the same sub-catchment as per Hoggan, D.H, 1996. Floodplain Hydrology and Hydraulics. 2nd ed. McGraw-Hill.

4.1.7 Summary of Hydrological Model Components

A summary of hydrological model components and sub catchment characteristics can be found in Table 8 and Table 9.

Table 8: Summary of hydrological model components

Hydrological Model Components	Values
Number of sub-catchments	17
Range of sub-catchment size (km^2)	1.4 - 12.7
Range of SCS curve numbers for pervious areas	70 - 83
SCS curve number for impervious area*	98
Initial loss for pervious area (mm)	5
Initial loss for impervious area (mm)	0

* A few small areas are ponds or lakes which are effectively impervious areas

Table 9: Sub Catchment Characteristics

Name	Area (km^2)	Initial Abstraction	CN	CIA	TC (hours)	Lag Time
A	4.3	5.0	64.6	0.0	0.4	0.3
B	1.4	5.0	64.5	0.0	0.1	0.1
C	7.1	5.0	66.6	0.0	0.5	0.3
D	3.2	5.0	65.0	0.0	0.3	0.2
E	2.6	5.0	64.8	0.0	0.3	0.2
F	8.2	5.0	66.6	0.0	0.5	0.3
G	4.1	5.0	65.8	0.0	0.3	0.2
H	8.7	5.0	71.4	0.0	0.8	0.5
I	7.4	5.0	65.4	0.0	0.4	0.2
J	5.7	5.0	68.2	0.0	0.2	0.1
K	3.3	5.0	65.5	0.0	0.2	0.1
L	11.4	5.0	65.2	0.0	1.5	0.9
M	12.7	5.0	65.1	0.0	0.9	0.6
N	5.7	5.0	66.4	0.0	0.6	0.3
O	5.9	5.0	66.1	0.0	0.4	0.2
P	2.7	5.0	70.0	0.0	0.4	0.3

4.2 Hydraulic Model

4.2.1 Modelling Software and overview

The model has been built and run using DHI software. MIKE FLOOD was used to couple the two model components MIKE-11 and MIKE-21. The software used was version 2012, and included Service Packs and Hotfixes released by DHI prior to February 2014.

A coupled 1D-2D hydraulic model (MIKE FLOOD) was chosen to simulate the flooding in the river. MIKE FLOOD links two model components together: the one-dimensional channel model (MIKE-11) and the two-dimensional floodplain (MIKE-21). During the simulation of flood flows, water overtops the channel banks modelled in MIKE-11 and flows onto the floodplain modelled in MIKE-21.

The updated hydraulic model was based on the model completed for the previous study by SKM in 2007. The following sections detail the updates made to the model.

4.2.2 MIKE-11

The updated MIKE-11 model was based on the previous MIKE-11 model completed for the previous study. The channel alignment and chainages were updated to more closely follow the true river alignment, resulting in an overall increase in modelled watercourse length of approximately 2.5 km. In addition, Black Creek was extended upstream to better capture the overland flow interaction in the floodplain upstream of Mangaroa Valley Road. The updated 1D model network is shown in Figure 5.

The channel roughness was set to either a Manning's n of 0.035 or 0.04 as per the previous report.

Rainfall MIKE11 Inputs

Rainfall runoff was inputted into the MIKE11 river system using either point or distributed sources based on the each sub-catchment.

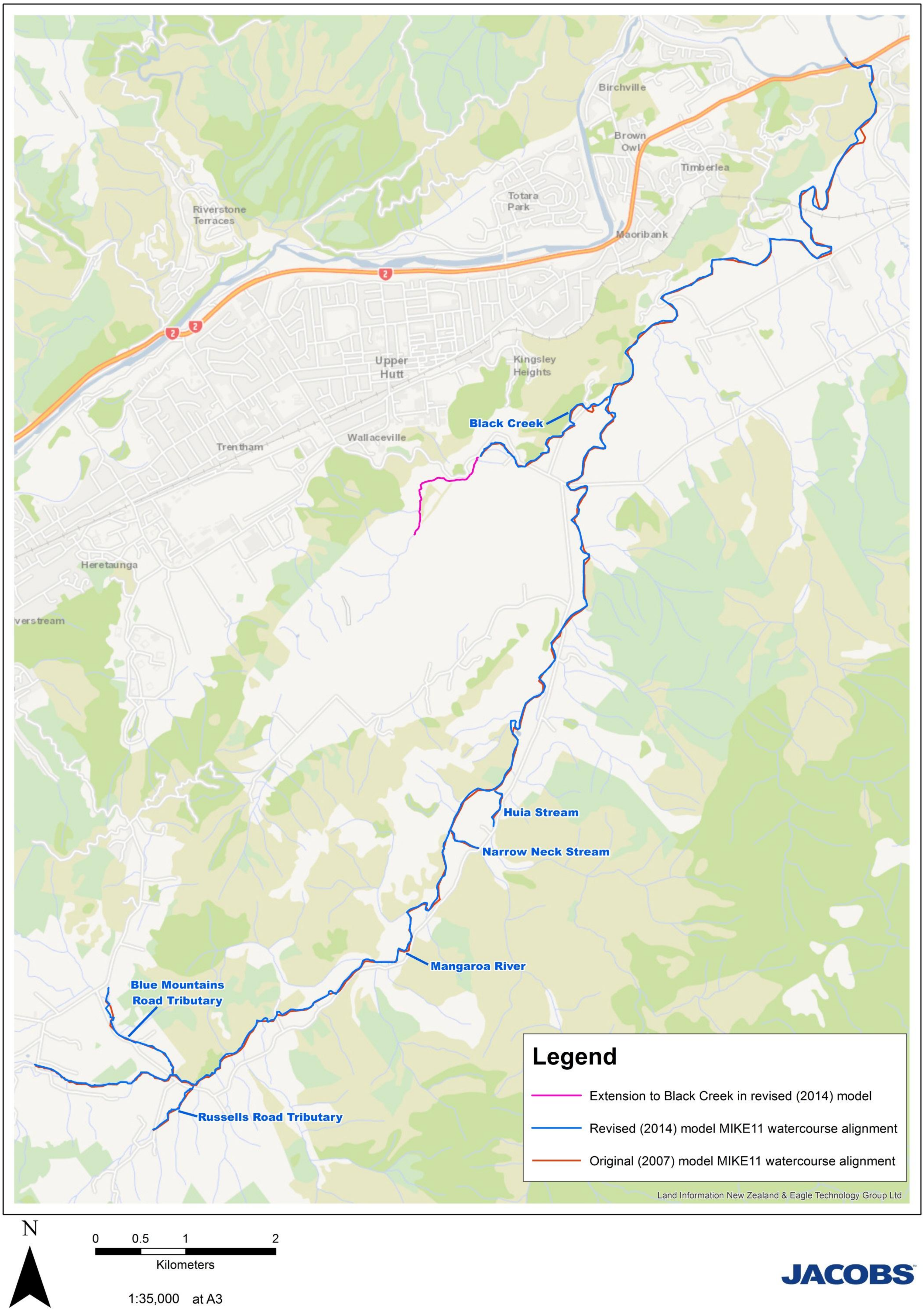


Figure 5: Realignment of watercourse and Black Creek extension within the revised model

4.2.3 MIKE-21

Bathymetry

The MIKE-21 bathymetry was based on a 5 m DEM grid (Figure 6) which was created from the 1 m gridded LiDAR-derived DEM provided by Greater Wellington Regional Council. It was noted that in a key floodplain area upstream of Mangaroa Valley Road (see Figure 7), some of the vegetated areas, including thick gorse and tree wind breaks, appeared to have erroneous elevation data. This error was also present in the outdated July 2004 LiDAR, possibly resulting in an underestimation of the potential flood storage volume and extent in this part of the catchment. These sections of land were manually edited through smoothing.

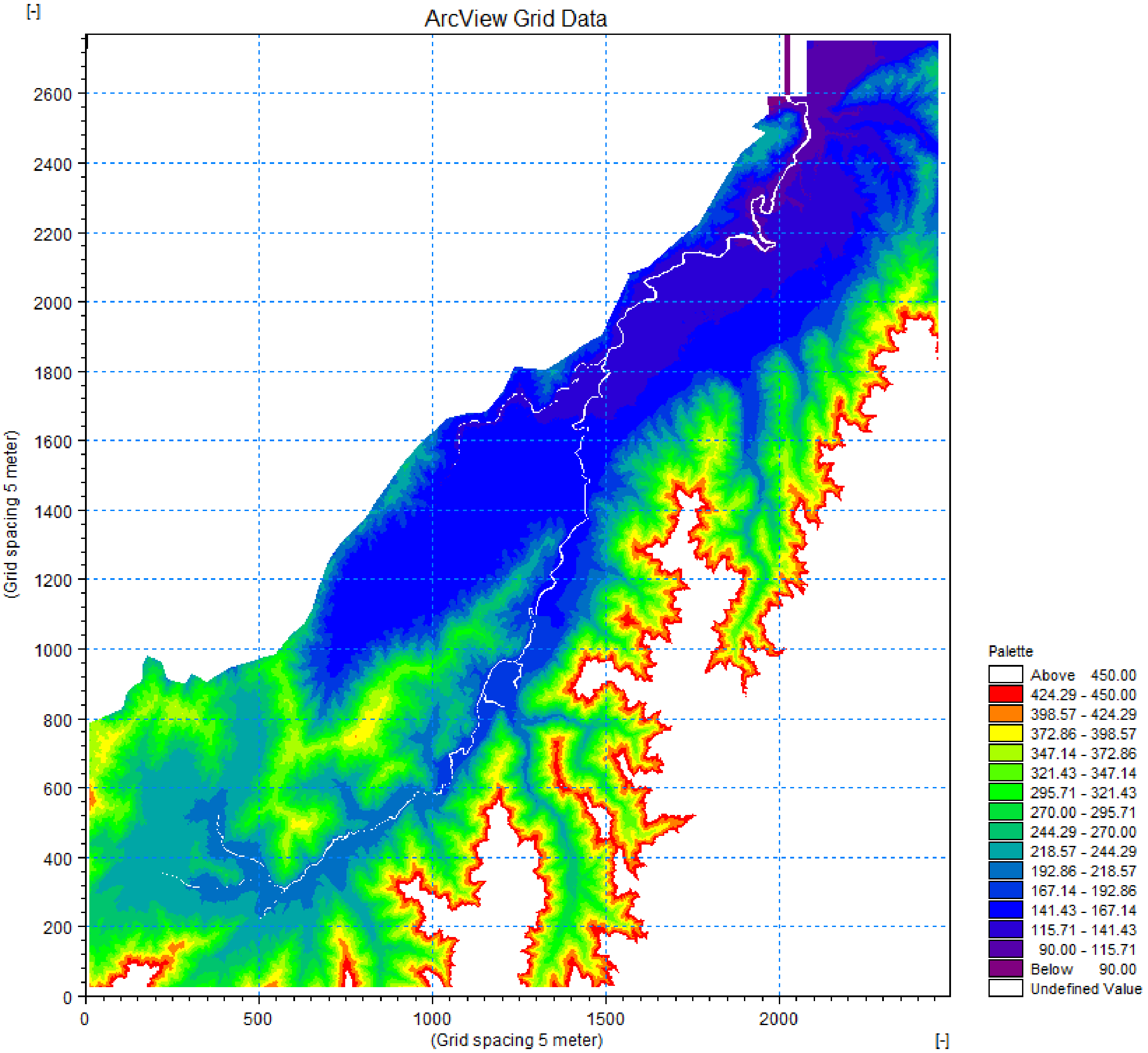


Figure 6: MIKE-21 bathymetry

Roughness

The resistance layer has been generated in GIS from the land use layers provided by Great Wellington Regional Council (Figure 3) and checked against aerial imagery. The roughness for the area of erroneous data shown in

Figure 7 was changed to reflect actual land use (i.e. forestry land) and assigned a Manning's n of 0.1 accordingly.

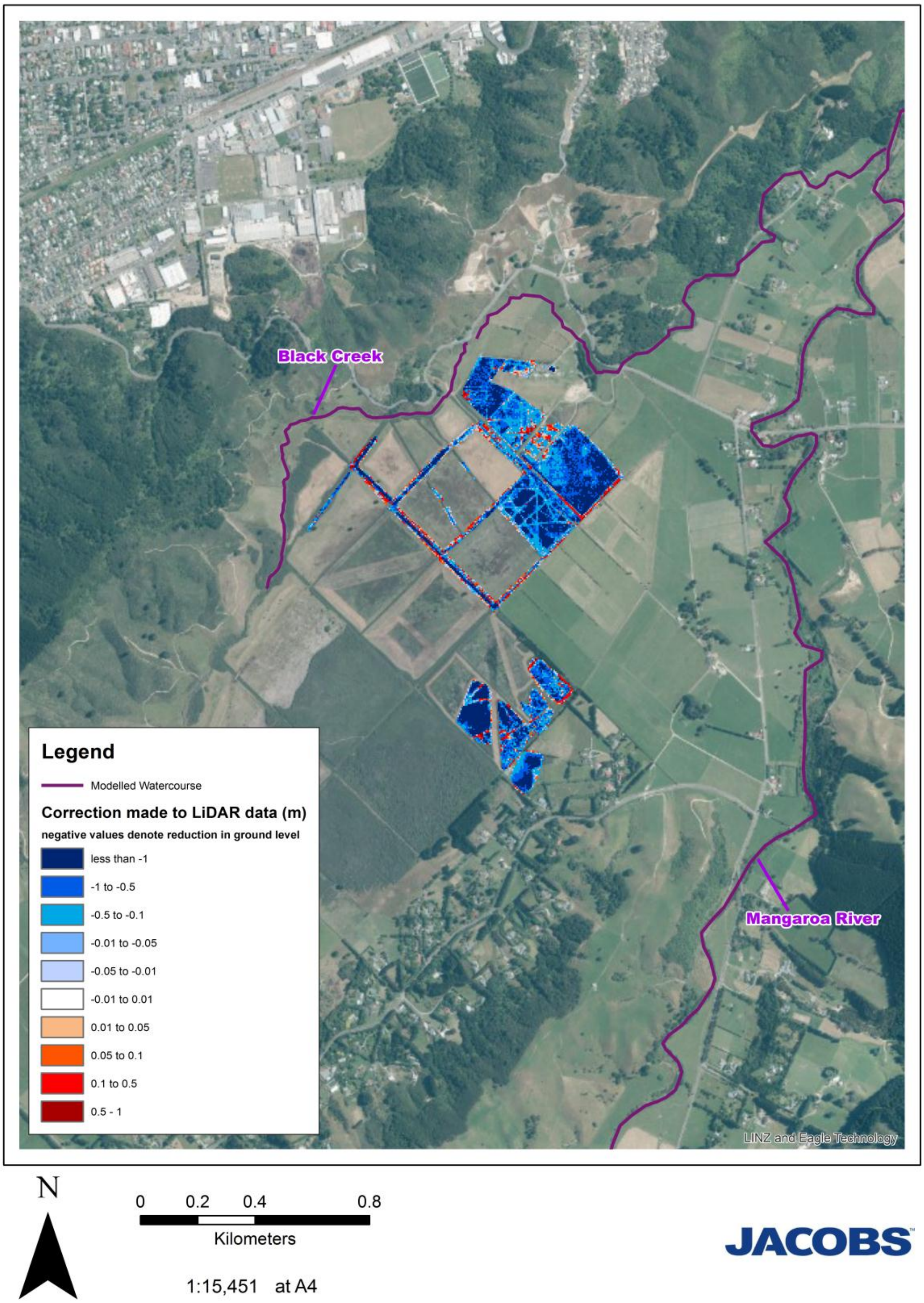


Figure 7: Area of erroneous LIDAR data that has been corrected in the model bathymetry

4.2.4 Model downstream boundary and linkages

The Hutt River confluence is the downstream boundary for the Mangaroa River hydraulic model. The 1D MIKE-11 component was extended to just upstream of the confluence and then linked to the MIKE-21 grid via a standard link. The grid was manually altered to smoothly drain water to the north before exiting the model as a M21 boundary condition. The model at this location is not intended as an accurate physical representation of the surrounds and is not within the study area. The boundary set-up lends stability to the model at its downstream end without influencing model performance (and results) upstream within the study area. The influence of the model downstream boundary does not extend upstream of the SH2 bridge over the Mangaroa.

Both the left and right banks of the river in MIKE-11 were laterally linked to MIKE-21 using the 'HGH method'. This method selects the higher value of either the bank height or the corresponding grid cell height to assess any flow breakouts. Gaps were set in the lateral links around the culverts and bridges. The linkages were amended from the previous model to reflect the adjustments that were made to the channel alignment (see Section 4.2).

The dx value (minimum interpolated chainage between cross sections) was set at 20 m which is acceptable when laterally linked to a 5 m grid as it allows transfer of flows between the M11 and M21 model components at a sufficient accuracy to capture the flow mechanisms in the system whilst maintaining appropriate calculation (model run length) times.

5. Model Calibration and Validation

The model was calibrated by comparing the modelled results with observed gauge readings at the Te Marua gauging station.

5.1 Effect of Downstream Tailwater Level

It was noted in the previous Mangaroa Flood Hazard Assessment (SKM, 2007) that the gauging station at Te Marua is likely to be influenced by the water levels in the Hutt River at the confluence particularly in high flow events in the Hutt River. No observed data is available for use at the confluence of the two rivers; however an analysis of simulated concurrent design events in both the Mangaroa River and the Hutt River was assessed as part of the previous report (Figure 8). Hutt River water levels influence the gauging station across the full range of design flow events with the impact becoming less as the size of the Mangaroa design event increases.

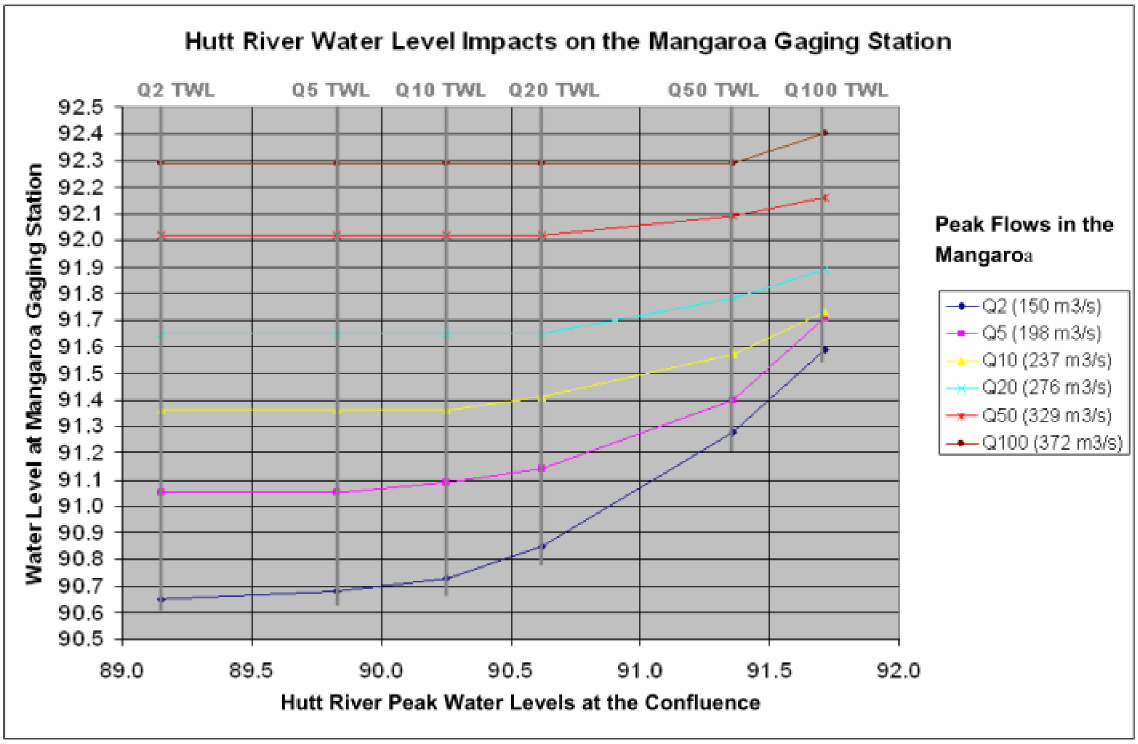


Figure 8: Hutt River impacts on Mangaroa gauging station (source: SKM, 2007 pg9)

To try and avoid using inappropriate discharges for calibration and validation purposes (whilst maintaining an adequate number of events available for use), it was decided to remove all events from the calibration/ validation selection process when the Hutt River was in excess of a 10% AEP flow.

To determine whether the Hutt River was in excess of the 10% AEP flow, gauged records from Hutt River at Te Marua gauge were obtained. This gauge is approximately 3.3 km upstream of the Mangaroa confluence with no major tributaries in between. The record was used to undertake a partial series flood frequency analysis to obtain an approximate 10% AEP flow estimate.

The 10% AEP flow was estimated at 500 m^3/s. As such a cut-off of 500 m^3/s was used. That is, any event in the Mangaroa River which coincides with the Hutt River having a peak flow greater than 500 m^3/s at the Hutt at Te Marua gauge will be considered not suitable for calibration or validation purposes.

Greater Wellington may wish to consider assessing an alternative site for long term gauging of the Mangaroa River.

5.2 Event selection

The largest flow events on record are summarised in Table 10. Six events were selected for calibrating and validating the model.

Table 10: Summary of Storm Events

Storm Event	Mangaroa River Gauge Record Peak Discharge (m^3/s)	Hutt River Gauge Record Peak Discharge (m^3/s)	Calibration, Validation or Discarded
Feb 2004	252	**395**	**Calibration**
Jan 2005	250	580	Most likely influenced by Hutt River
May 1981	245	No Hutt River gauged record available	**Validation**
Oct 1998	240	583	Most likely influenced by Hutt River
Oct 2003	231	**377**	**Calibration**
Oct 1997	226	**493**	**Calibration**
Jan 1980	202	No Hutt River gauged record available	No rain data available
Nov 1994	193.7	No Hutt River gauged record available	**Validation**
Dec 1982	192	No Hutt River gauged record available	No rain data available
Oct 2000	189	531	Most likely influenced by Hutt River
Aug 1985	182	No Hutt River gauged record available	Most likely influenced by Hutt River
Oct 1984	161	No Hutt River gauged record available	No rain data available
Aug 1991	156	**353**	**Validation**

5.3 Calibration

There are a few model parameters that can be altered for the calibration process. The rainfall-runoff parameters (hydrology) determine the total volume of runoff generated by a storm and the temporal runoff distribution (i.e. 'shape') to be applied within the hydraulic model.

Consideration was given to the use of the two gauged rainfall datasets (Section 2.1). As part of the calibration and validation process the rainfall at each gauge is extrapolated to the entire catchment and can often be a source of over-prediction or under-prediction of runoff. Hence the allocation of gauged rainfall for certain time-periods and to appropriate sub-catchments was used to aid calibration. The rainfall spatial distribution across catchment varies between the different events and this is reflected in the hydrological approach whereby distribution of rainfall over the model sub-catchments varied between the three events (Table 11).

Initial flow conditions in the model were matched to the gauged flow at the beginning of the calibration event and the initial abstraction was left at 5 mm as the model duration captured the antecedent rainfall.

The hydraulic model can further influence this combined hydrograph 'shape' which affects the timing and peak discharge in the model. The hydraulic model can impact this via channel and floodplain roughness, flowpaths and storage capacity of the floodplain and/or behind structures.

In the previous version of this model the hydrology was calibrated separate to the hydraulic model and provided to the modellers as an input. In this version of the model the calibration has been undertaken within the model proper to ensure the hydrology can be altered in such a way ("calibrated") to ensure the hydraulic model matches as far as possible recorded peaks at the downstream gauging station.

This is done by taking each of the chosen events and after fixing rainfall calibrating them individually by altering the catchment characteristics CN and Lag Time. These parameters which are specific to each sub-catchment were altered *en masse* by a consistent multiplier. This kept the number of variables to a minimum and also to some degree retained the relative characteristics for each sub-catchment. Once this process is complete average calibration values are used to the test other storm events of a similar magnitude to see if they provide an adequate representation of catchment response.

Hydraulic model parameters (i.e. Manning's n, inclusion of floodplain storage areas and appropriate model schematisation) were held constant for each calibration event.

Based on assessment of the upstream flows in the Hutt River, all events were run with a constant tailwater level of 89.2 m which corresponds to a 2 year Average Recurrence Interval (ARI) flow in the Hutt River (Figure 8). The one exception to this was the October 1997 event whereby the tailwater level was set to 89.7 m which corresponds to a 5 year ARI flow in the Hutt River (Figure 8).

It is important to recognise that it is a normal process for the calibration parameters to differ across storms. This is widely understood as covered in Australian Rainfall & runoff;

"The values and parameters of a model determined from different floods will generally be different to some extent, even when the one fitting criterion is used. There are several reasons for this:

1. *All models are only approximations to reality with inadequacies always present: in the model structure; in the manner in which the catchment storage is represented; and in the form of nonlinearity utilised;*
2. *Errors which are always present in the recorded rainfall and streamflow, particularly for floods;*
3. *Errors in the estimation of losses from rainfall and separation of baseflow; and*
4. *Spatial variations of rainfall which are not sufficiently identified or even detected by the available raingauges." (ARR,1997)*

5.4 Calibration results

The multipliers which resulted in the best calibrations for the three selected events are shown in Table 11. The actual CN values and lag times for each sub-catchment for each calibration event can be found in Appendix A.

Comparisons of modelled discharge and gauged discharge for the calibration events can be seen in Figure 9, Figure 10 and Figure 11. Comparison of modelled versus gauged water levels was hampered due to a lack of verified information relating to the relative level of the gauged depths. Also, the gauge appears to be located within a reasonably steep reach which may result in level discrepancies if the modelled levels were extracted slightly up- or downstream from the actual gauge location. Depth comparisons are not appropriate due to the varying channel bed profile between surveyed cross-sections. A brief analysis was undertaken and the calibrated levels matched well for both timing and magnitude, similar to the flows.

Table 11: Calibrated CN and Lag Time Values

Storm Event	Calibration Run Final Results		
	Calibrated CN Multiplier	Calibrated Lag Time Multiplier	Rainfall Used
February 2004	0.9 CN	5 Lag	Tasman Vaccine rain applied to all sub-catchments.
October 1997	1.0 CN	4 lag	Tasman Vaccine and Cemetery rain applied to closest sub-catchments.
October 2003	1.2 CN	2 Lag	Tasman Vaccine rain applied to all

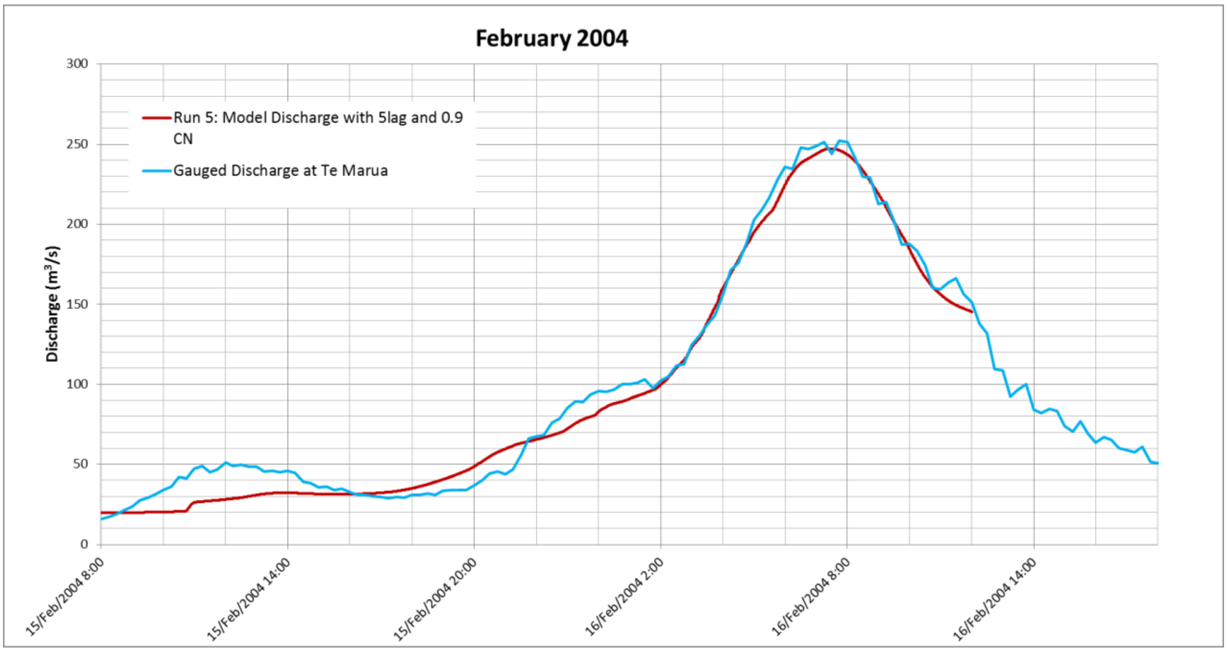


Figure 9: Calibration - February 2004. Modelled peak flow = 247 m^3/s. Gauged peak flow = 252 m^3/s

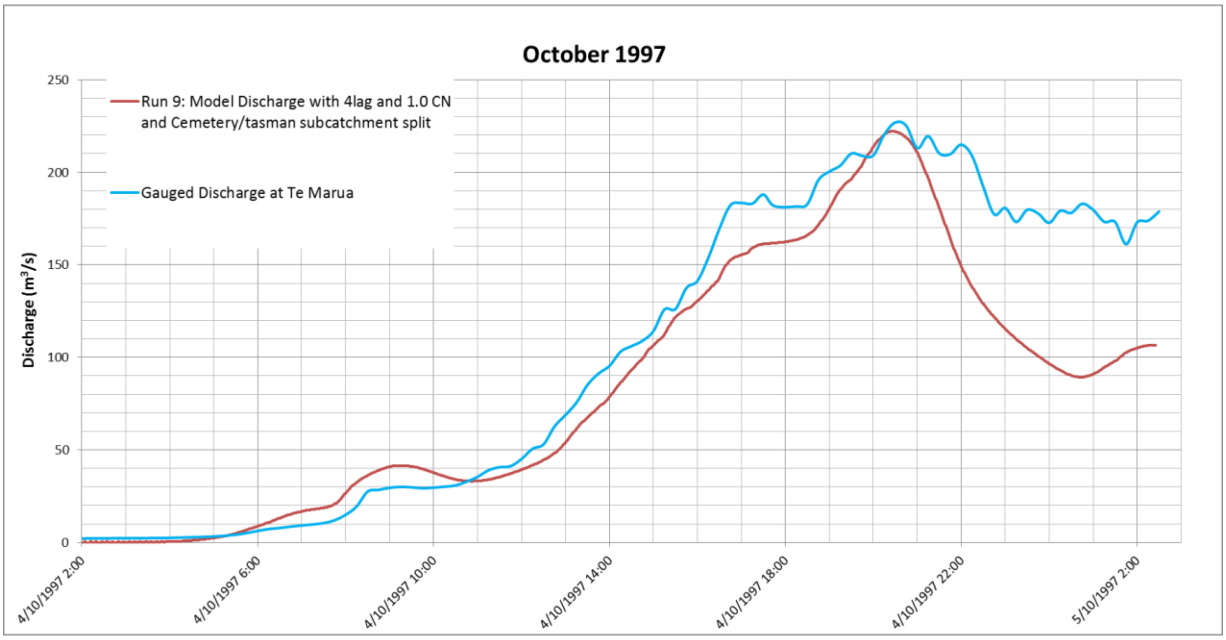


Figure 10: Calibration - October 1997. Modelled peak flow = 222 m^3/s. Gauged peak flow = 227 m^3/s

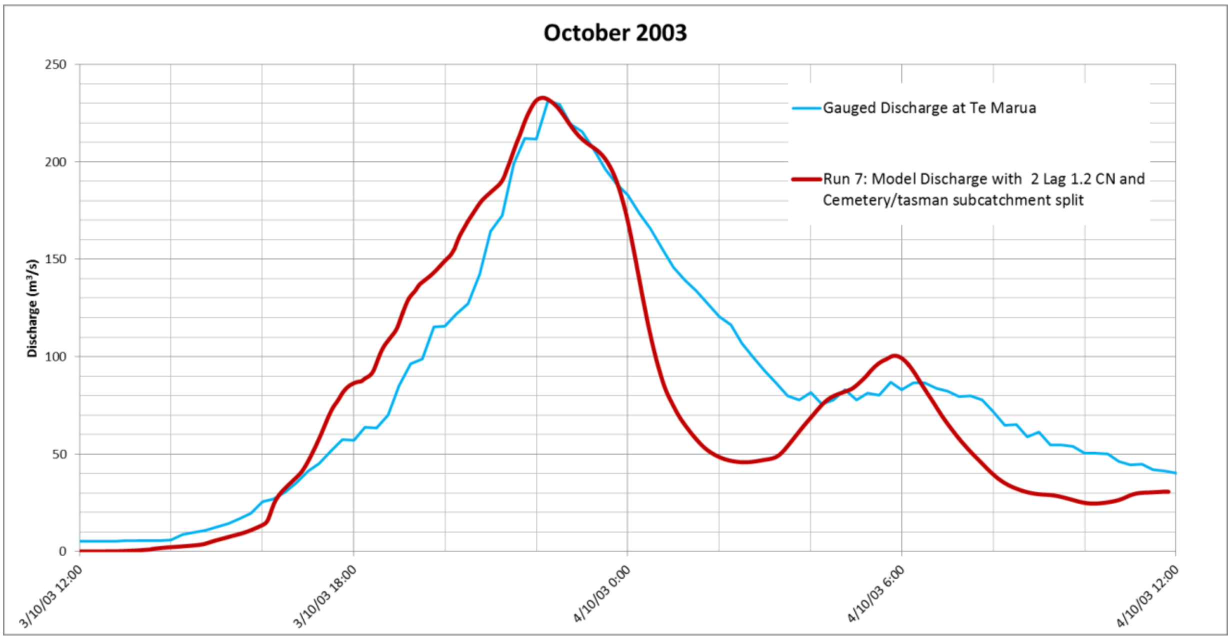


Figure 11: Calibration - October 2003. Modelled peak flow = 233 m³/s. Gauged peak flow = 231 m³/s

5.5 Parameter Selection and Validation

A single set of parameters was required for use for the three validation events. Multipliers of 1.0 for CN and 4 for lag time were selected based on the fitted parameters for the three calibration events (Table 11). These were considered median values and suitable for a range of events. Modelled sub-catchments were attributed rainfall from the closest operating rain gauge. The comparison plots are shown in Figure 12, Figure 13 and Figure 14.

The modelled discharge for the November 1994 event under-predicts peak discharge by approximately 60 m^3/s. The time to peak and general slope however are of reasonable match, although the initial gauged discharge peak was not fully captured. The modelled discharge for the May 1981 event over-predicts peak discharge by approximately 40 m^3/s but has reasonable hydrograph shape. The modelled discharge for the August 1991 event under-predicts peak discharge by approximately 45 m^3/s but has reasonable hydrograph shape.

The model was also run for the October 2003 and February 2004 calibration events using the multipliers of 1.0 for CN and 4 for lag time, the results are shown in Figure 15 and Figure 16. The modelled discharge for the October 2003 event under-predicts peak discharge by approximately 75 m^3/s but the hydrograph shape is a reasonable match. For the larger February 2004 event the model over-predicts the peak discharge by approximately 35 m^3/s and has a good match with the hydrographs shape.

Given the large discrepancies with the peak discharges for modelled and recorded flows, another parameter set was trialled. A multiplier of 1.2 for CN and 2 for lag time were trialled as these matched well with the October 2003 calibration. The comparison plots for these can be found in Appendix B. As expected, these gave much better matches for November 1994 and August 1991 (although the lag time is noticeably too short) but an overestimate of peak discharge of 150 m^3/s for May 1981.

As the focus of this study is the calibration of the larger events, the multipliers of 1.0 for CN and 4 for lag time were selected for the design parameters as these seem to better match the larger flood flows.

This validation highlights the variability of catchment rainfall-runoff response.

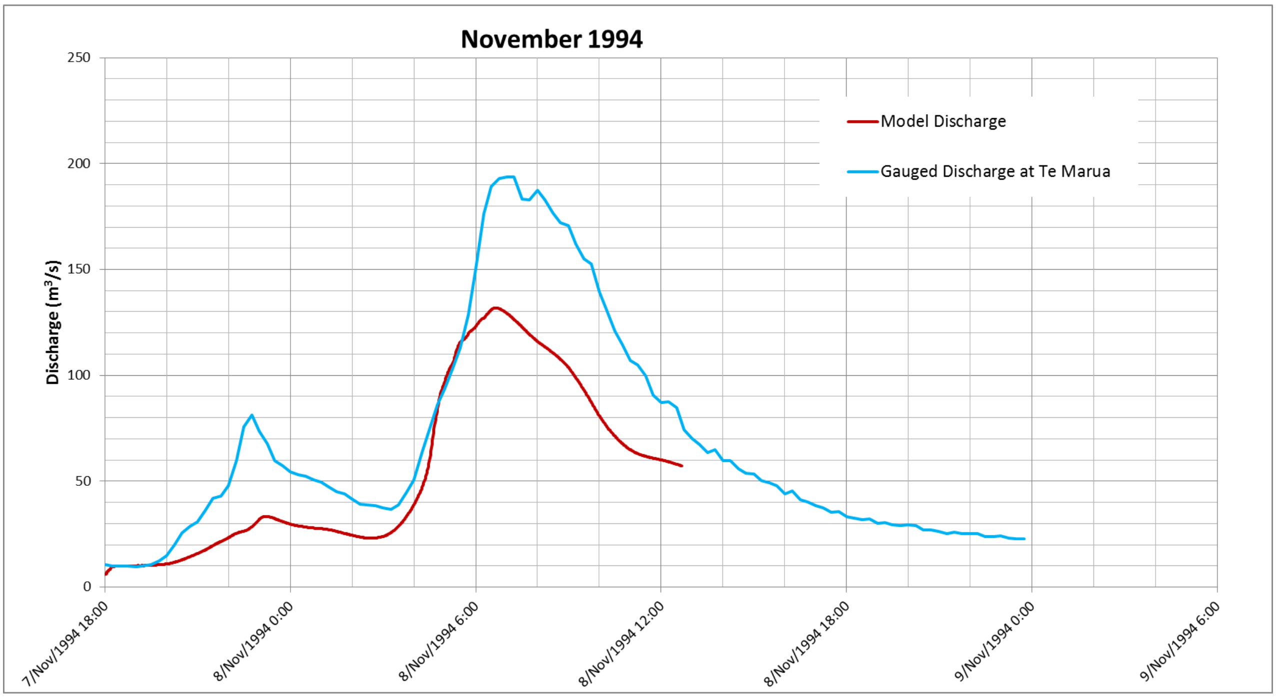


Figure 12: Validation Run 1 November 1994. Modelled peak flow = 132 m³/s. Gauged peak flow = 194 m³/s

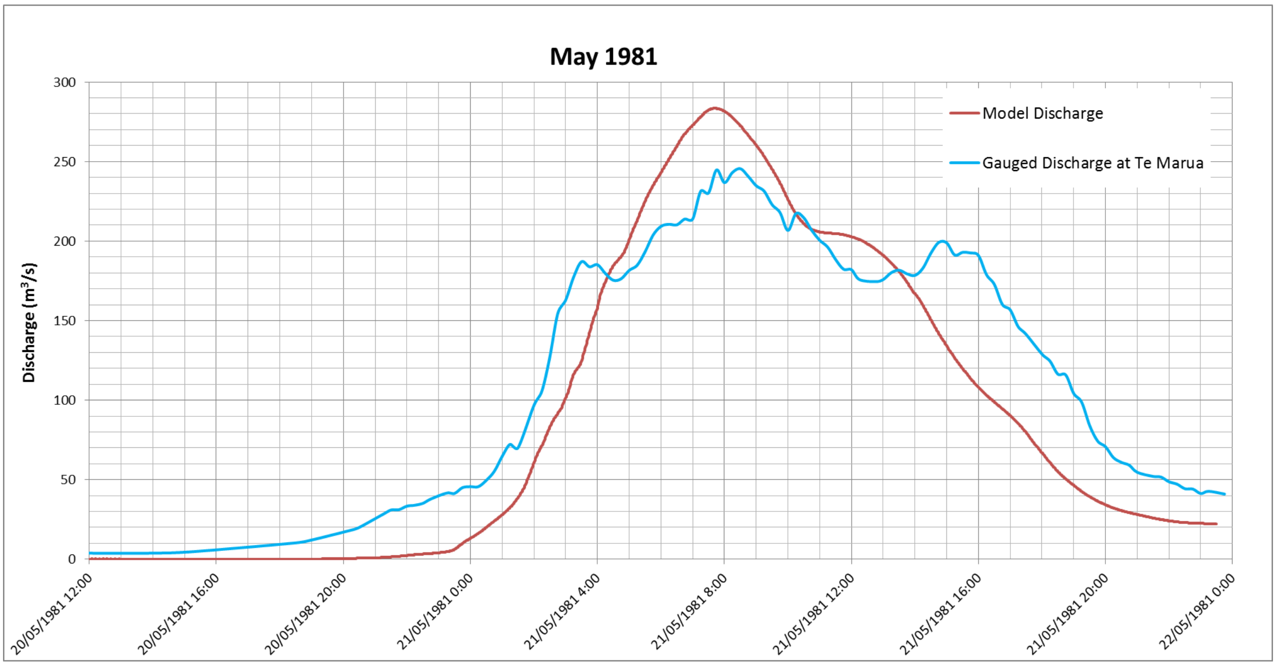


Figure 13: Validation Run 1 May 1981. Modelled peak flow = 283 m³/s. Gauged peak flow = 246 m³/s

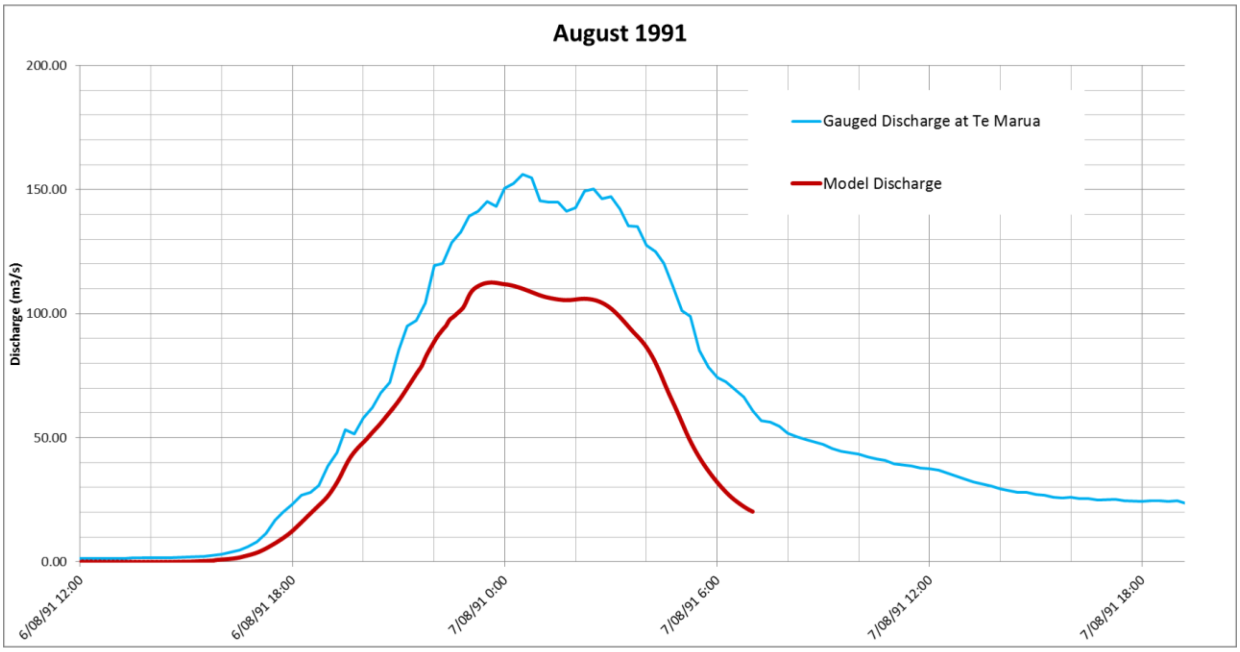


Figure 14: Validation Run 1 August 1991. Modelled peak flow = 113 m³/s. Gauged peak flow = 156 m³/s

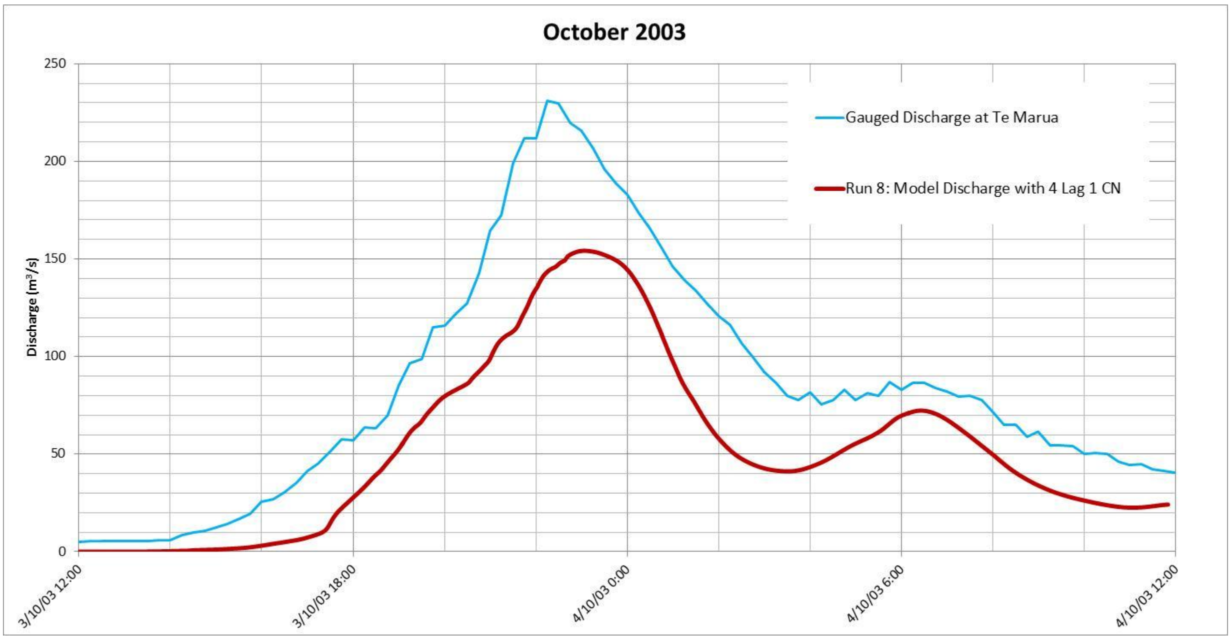


Figure 15: Calibration - October 2003. Modelled peak flow = 154 m³/s. Gauged peak flow = 231 m³/s

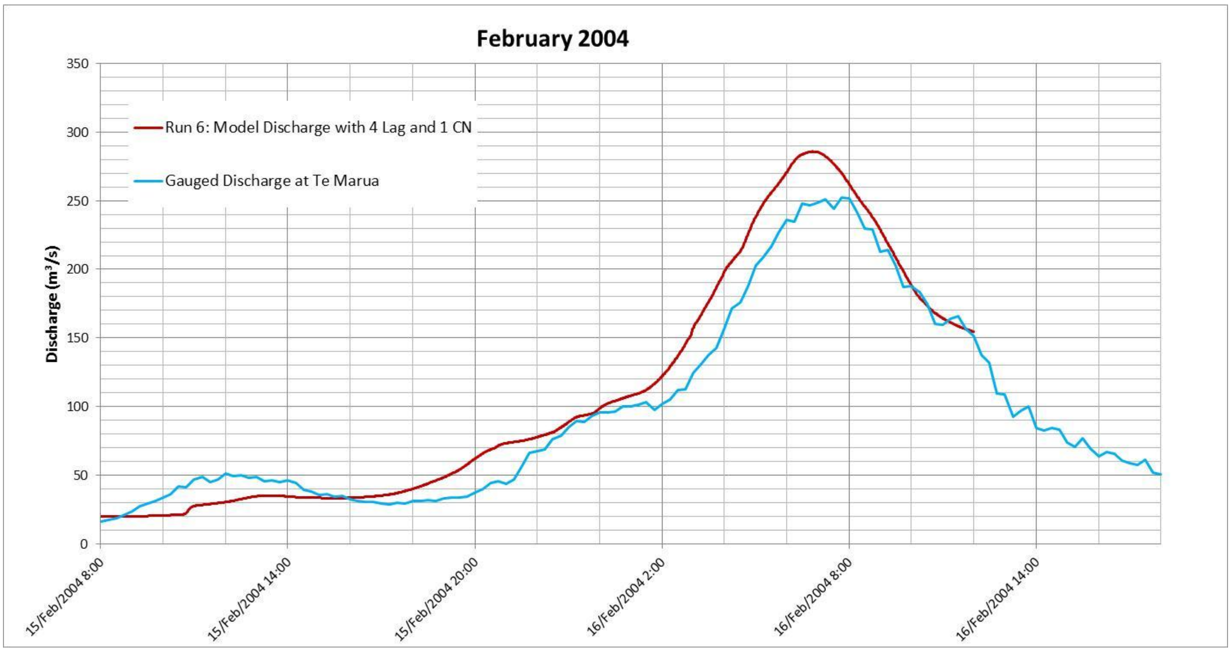


Figure 16: Calibration – February 2004 . Modelled peak flow = 286 m^3/s. Gauged peak flow = 252 m^3/s

6. Design Runs

6.1 Hydrological Approach

The hydrological approach adopted in the design runs modelling uses a nested storm distribution based on rainfall depths derived from the High Intensity Rainfall System (HIRDS) v3. Values were obtained using the catchment centroid. A predicted increase in temperature of 2.1^{o} C for the period 2080-99 was adopted to account for climate change was applied as per the Ministry for the Environment guidelines for the Wellington region (Ministry of Environment, 2008). Areal Reduction Factors (ARFs) were appropriately applied to each duration within the nested design storm based on the ARF values for a 100 km^2 catchment from Table 5.2 in the Regional Stormwater Hydraulic Modelling Specifications V3 (Capacity, 2013). Ten and twenty minute duration ARFs were derived by log-linear extrapolated. The rainfall depths used in the design runs modelling are shown in Table 12. These rainfall depths were compiled into 24 hour nested storms to cover all design rainfall intensities within the same storm.

Table 12: Design rainfall depths

Duration (mins)	Design Rainfall Depth with no ARF (mm)		Design Rainfall Depth with ARF applied (mm)		ARF
	2% AEP	1% AEP	2% AEP	1% AEP	
10	17.9	20.6	11.1	12.8	0.62
20	25.7	29.7	18.0	20.8	0.7
30	31.8	36.7	23.5	27.2	0.74
60	45.7	52.7	36.6	42.2	0.8
120	65.4	75.2	55.6	63.9	0.85
360	115.7	132.3	104.1	119.1	0.9
720	166	189	154.4	175.8	0.93
1440	237.9	269.9	223.6	253.7	0.94

The approach described above is considered likely to be conservative for small duration events as they are modelled to occur in the midst of a rare long-duration event (i.e. saturated antecedent catchment conditions).

6.1.1 Design hyetographs

The design hyetographs used in the design runs modelling are shown Figure 17 and Figure 18.

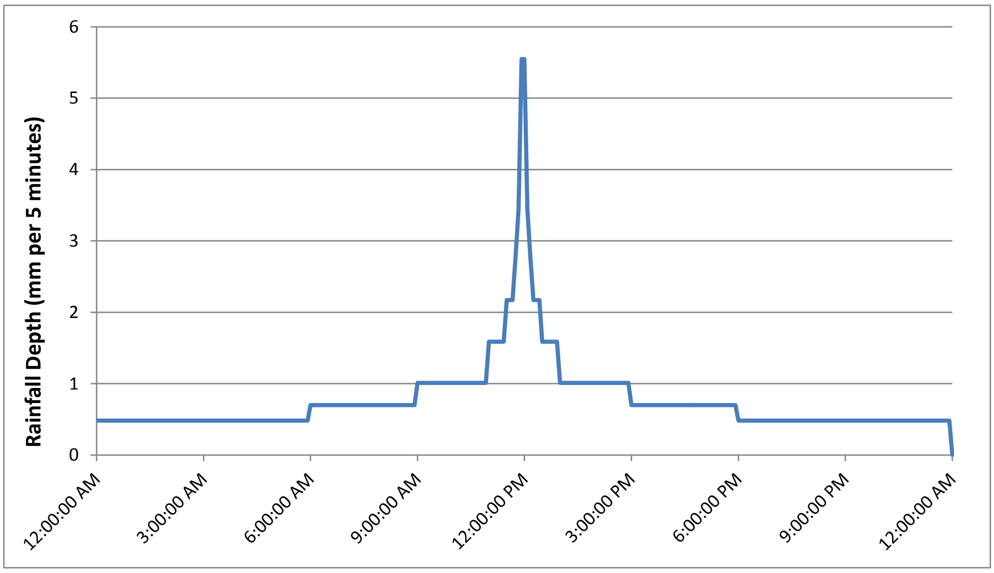


Figure 17: Design hyetograph for 2% AEP flood event (nested storm)

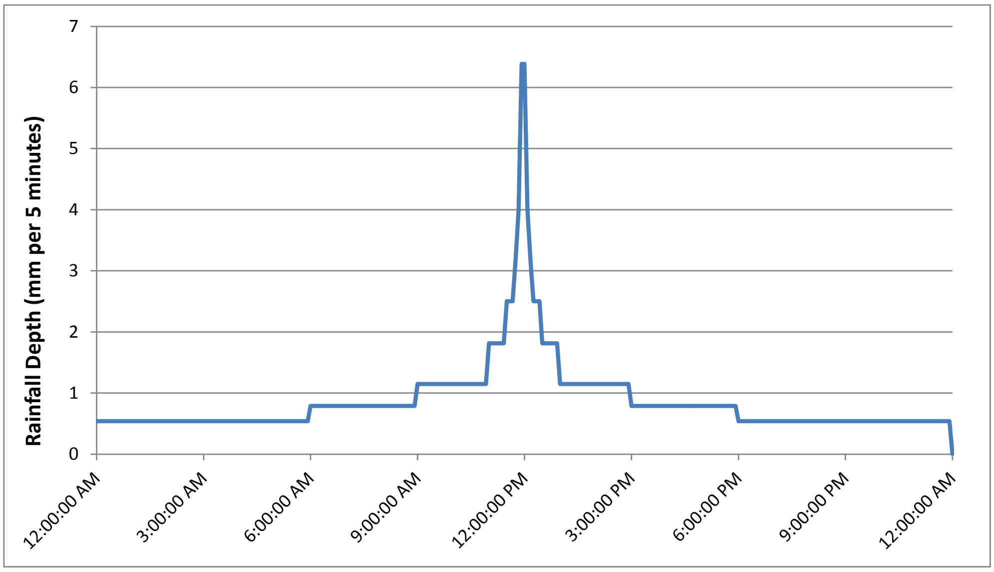


Figure 18: Design hyetograph for 1% AEP flood event (nested storm)

The balanced storm approach is used widely throughout the country and has shown itself to be a useful empirical distribution for both peak flow and volume estimation. A sensitivity test was undertaken using Tomlinsons distribution. This produced hydrographs with a muted peak flow response that did not match well with recorded storm hydrographs, and was set aside on this basis.

6.2 Model Results

At the Te Marua gauge location the updated model predicts a peak flow of 385 m^3/s for the 2% AEP flood event and a flow of 475 m^3/s for the 1% AEP with Climate Change event. The resultant hydrographs based on the design storms are shown in Figure 19 and Figure 20 below.

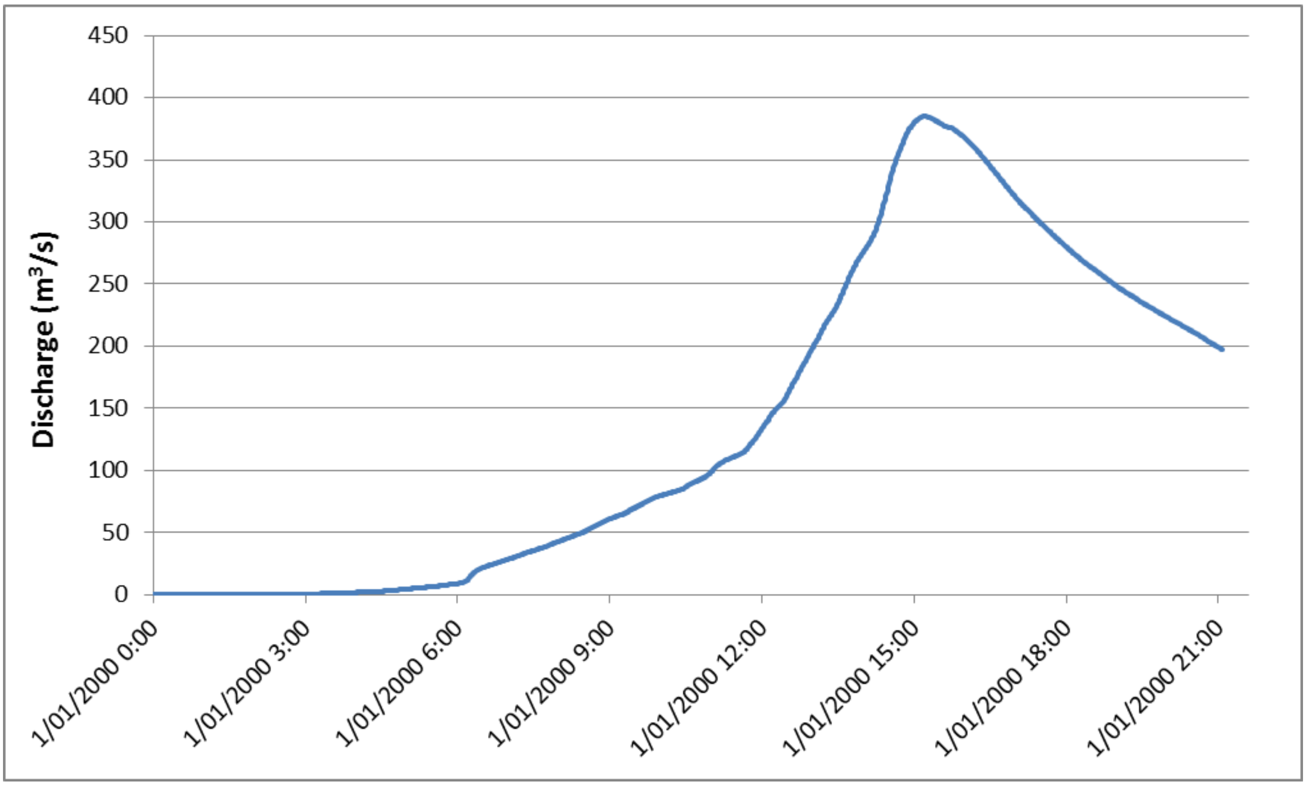


Figure 19: Resultant 2% AEP hydrograph for Mangaroa River at Te Marua

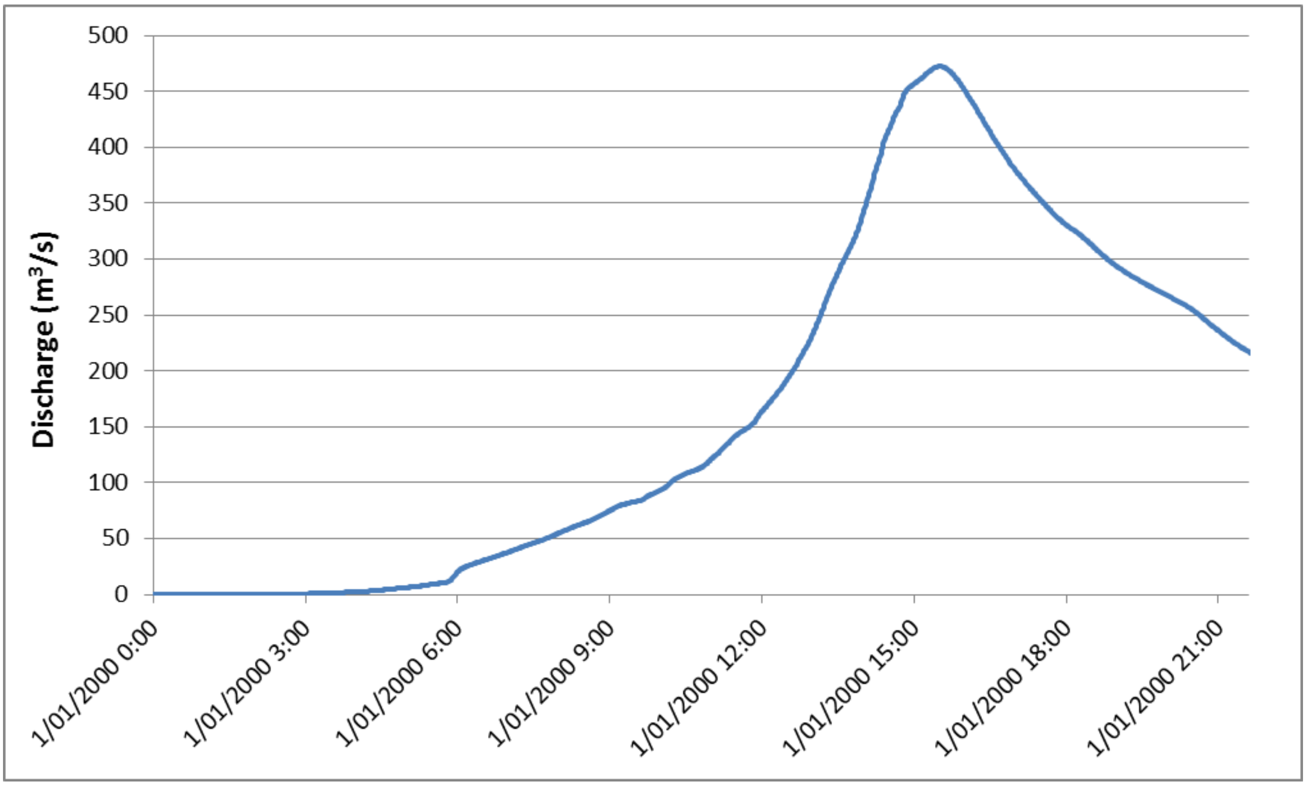


Figure 20: Resultant 1% AEP hydrograph for Mangaroa River at Te Marua

6.3 Results Context

The Mangaroa has been subject to hydraulic modelling studies since the mid-2000s. Over this period, three main sets of distinct results have been produced, as follows:

- “The 2007 model”: Initial build and run of the Mangaroa River Model.
- “The 2014 model”: The 2007 model was updated and calibrated in accordance with the Peer Review recommendations, as described within this report. Design runs use HIRDS v3 rainfall depths and a nested storm distribution approach.
- “The Tomlinson’s Sensitivity model”: The 2014 model was run using Tomlinson’s curve distribution, as described within this report.

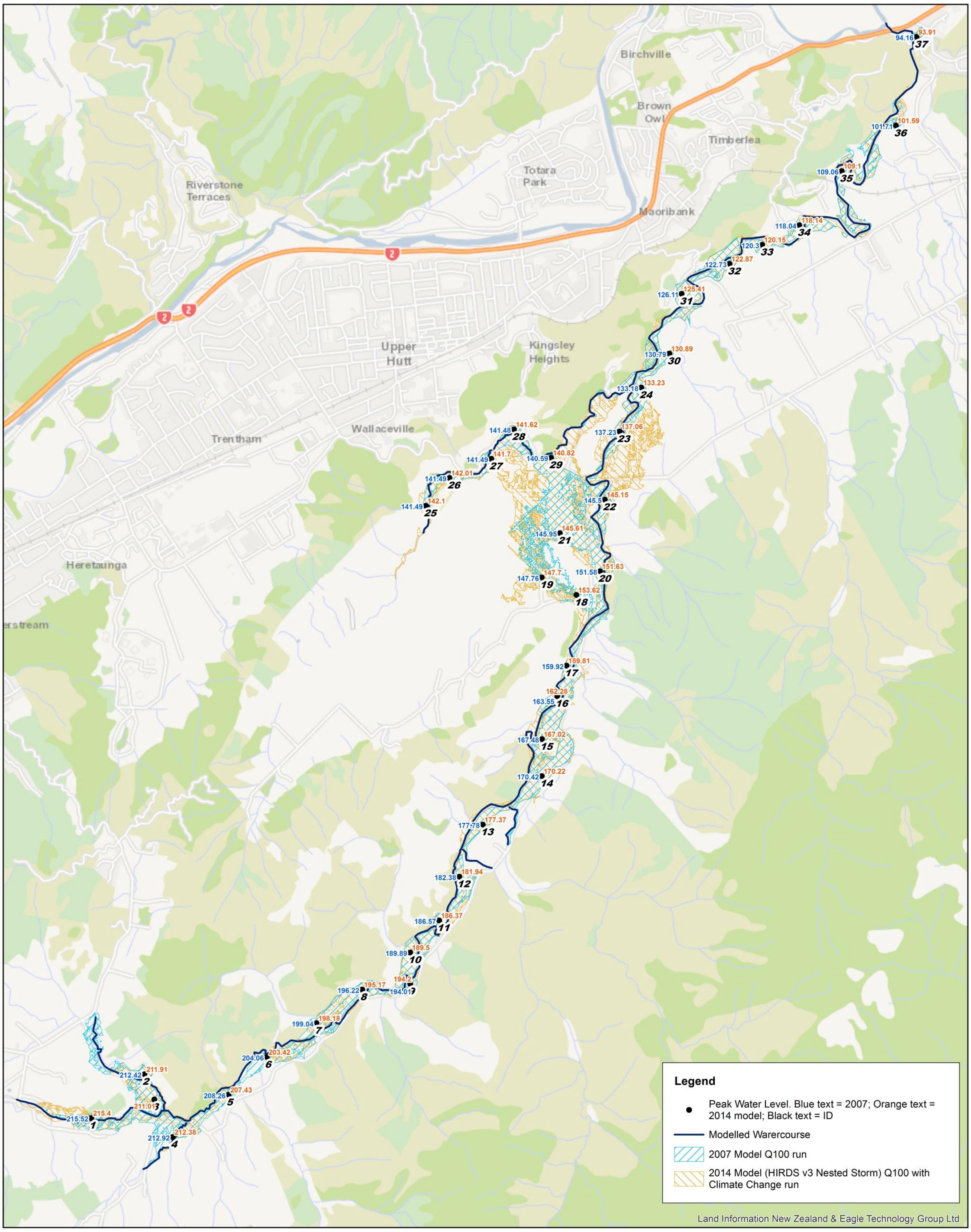
Figure 21 shows the modelled flood extents and peak water levels derived from the 2007 and 2014 models. The difference in levels at various points throughout the catchment floodplain are tabulated in Table 13. In general, the largest differences in peak level are occurring in the upper reaches – upstream of Whitemans Valley (locations ID 1 to 16 in Table 13) - where the average difference in flood levels is approximately 500 mm. Analysis of the model set up suggests that the primary reason for these changes is the altered hydrology, which results in a reduced prediction of flows in the upper catchment. However it is worth noting that while depths have decreased, the extents are similar. The largest differences seen in Table 13 (e.g. ID 8 and 16), are also reflective of localised changes to the channel alignment within the model.

In the lower reaches (ID 17 to 37) the difference in peak level are generally smaller with average difference of approximately 200 mm. It should be noted that the differences in the peak water levels reflects not only the different hydrological approaches adopted in the two models, but also the other updates included in the 2014 model, including revised channel alignment, increased resolution, and adjustment of the LiDAR (see section 4.2).

Reference to Figure 21 shows that there is spatial variation in the difference in flood extents produced by the two models. In the downstream reaches of the catchment, on the reach of the Mangoroa River downstream of its confluence with the Black Creek River, the extents are broadly similar; the 2014 flood extent is generally marginally larger, but the magnitude of increase is minimal and does not introduce significant new areas or vulnerabilities of landuse into the floodplain.

A similar pattern is also apparent within the uppermost reaches, in the area immediately downstream of the headwaters of the river system at Johnson’s Road.

The part of the catchment in which the most marked difference in flood extent is apparent is within the vicinity of the confluence of the Mangaroa River and the Black Creek River. In this area the floodplain derived from the revised 2014 model is more extensive than that derived from the original 2007 model. The floodplain flowpath between the two watercourses extends over a larger area. On both the Mangaroa River and the Black Creek River immediately upstream of the confluence, the floodplain in the 2007 model is in bank or confined to an immediate narrow (approximately 50m wide) corridor adjacent to the channel; in the 2014 model, flows spill out of bank over a longer reach and extend over a larger area (approximately 300m wide) beyond the immediate vicinity of the channel.



Disclaimer

The flood information contained within these plans has been derived from information and techniques available at the time of the study. It is provided as an indication of potential flood hazard in the area.

Localised flood levels may vary in a vicinity of buildings, fences and other structures not represented in the model.

These maps do not include freeboard which is essential in the development of flood planning maps. The agencies and individuals involved in the assessment of the flood hazard assume no responsibility for any action by any agency or individual that is based on the information provided.

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Figure 21: Comparison of peak water level results (as derived from the 2007 and 2014 models) at locations throughout the catchment

Table 13: Comparison of peak water level results (as derived from the 2007 and 2014 models) at locations throughout the catchment

ID (cross reference to Figure 19)	2007 Model Q100 run Peak WL	2014 Q100 with Climate Change run Peak WL	Difference (-ve numbers indicate 2007 model results are lower than 2014 model results)
1	215.52	215.40	0.12
2	212.42	211.91	0.51
3	211.60	211.01	0.59
4	212.92	212.38	0.54
5	208.26	207.43	0.83
6	204.06	203.42	0.64
7	199.04	198.18	0.86
8	196.22	195.17	1.05
9	194.01	194.20	-0.19
10	189.89	189.50	0.39
11	186.57	186.37	0.20
12	182.38	181.94	0.44
13	177.78	177.37	0.41
14	170.42	170.22	0.20
15	167.48	167.02	0.47
16	163.55	162.28	1.27
17	159.92	159.81	0.11
18	153.83	153.62	0.21
19	147.76	147.70	0.06
20	151.58	151.63	-0.05
21	145.95	145.61	0.34
22	145.50	145.15	0.35
23	137.23	137.06	0.17
24	133.18	133.23	-0.05
25	141.49	142.10	-0.61
26	141.49	142.01	-0.52
27	141.49	141.70	-0.21
28	141.48	141.62	-0.14
29	140.59	140.82	-0.23
30	130.79	130.89	-0.10
31	126.11	125.41	0.70
32	122.73	122.87	-0.14
33	120.30	120.15	0.15
34	118.04	118.14	-0.10
35	109.06	109.10	-0.04
36	101.71	101.59	0.12
37	94.16	93.91	0.25

The flow at the Te Marua gauge on the Mangaroa River (cross section 21426 in the model) from the three different model runs described above is presented in Table 14 alongside the estimated flow at the gauge derived from a Flood Frequency Analysis.

Table 14: Comparison of flows at Te Marua gauge from different modelling sources

Source	1% AEP	1% AEP with Climate Change
2007 Model	480 m^3/s	
2014 Model		475 m^3/s
Tomlinson's Sensitivity Model		365 m^3/s
Flood Frequency Analysis estimate undertaken in 2005	372 ± 57 m^3/s	450 m^3/s *(estimated by assuming 20% increase on the 1% AEP present day)*
Flood Frequency Analysis estimate undertaken in 2014 *(using full gauge record and EV1 (Gumbels) distribution)*	355 ± 73 m^3/s	426 m^3/s *(estimated by assuming 20% increase on the 1% AEP present day)*
Source	**2% AEP**	**2% AEP with Climate Change**
2007 Model	440 m^3/s	
2014 Model		385 m^3/s

The Tomlinson's distribution model run does not appear to reflect the peakiness of the catchment. The distribution has a much longer storm peak than those recorded at the gauging station, and lower peaks than what would be expected given the statistical record. Therefore, whilst providing a useful sensitivity run and a low end result to compare against other model runs and previous sensitivity work, the Tomlinson's distribution model is not considered appropriate for flood hazard mapping purposes as it is likely to underestimate the level of risk. The 2014 and 2007 models appear to be a better choice for this purpose as they are closer to the statistical record.

It is recommended that the results of the modelling undertaken to date as presented above are considered in terms of their relative appropriateness for the development of updated Flood Hazard Plans. When such plans are to be produced, an agreement on the assumed freeboard to be used in each location of the catchment should be sought.

7. Sensitivity Runs

7.1 Purpose of Sensitivity Analysis

The purpose of the sensitivity analysis is to assess the sensitivity of the design run results to the factors outlined in Section 7.2. This assessment will also allow identification of the peak water levels and hazard in each cell of the catchment, by combining the effects of adjusting the sensitivity factors.

7.2 Parameter and adjustments

Ten sensitivity runs were undertaken on the 100 year Climate Change event. Five of these runs were undertaken to incorporate an additional 300 mm of freeboard to the first five runs. Table 15 outlines the factors, their magnitude of allowance for incorporation in the sensitivity run, and the reasoning behind the choice of magnitude value.

Table 15 : Sensitivity Runs Factors

Name	Factor	Magnitude of allowance for incorporation in Sensitivity Run	Reasoning behind choice of magnitude value
Sensitivity 1	Blockage	As per *Appendix C* Culverts and bridges blocked between 20% and 90% Plus blockage in Black Creek downstream of Wallaceville Road.	The proportion of blockage allocated for each of the structures represents an engineering judgement on the likely behaviour of the system in a large flood event. This judgement has been informed by the type and size (shape/height/length) of structure. A greater proportion of blockage expected at culverts compared to large bridges. The Mangaroa catchment is rural and the channel is heavily vegetated along many of the reaches, The potential for mobilisation of this vegetation (and subsequent structure blockage) in a large flood event is therefore a significant hazard in this catchment.
Sensitivity 2	Manning's 'n'	Increase floodplain and in-channel Manning's n value by 25%	Due to lack of good calibration of the model against flows/levels throughout the catchment, +25% is appropriate for capturing the level of uncertainty associated with the choice of Manning's 'n' value in this particular model. 25% is slightly more conservative than the often-used 20%.
Sensitivity 3	Hydrology	Increases hydrology by 21%	As stated in the Mangaroa Hydraulic Modelling Report, the Flood Frequency Analysis undertaken in on the Te Marua gauge data (using full gauge record and EV1 Gumbels distribution) suggests 1% AEP flood event discharge (and associated uncertainty) of 355 ± 73 m3/s. The proposed increase of 21% is of a similar magnitude to the IPPC High scenario allowance (an additional 24%)
Sensitivity 4	Downstream boundary	100 year flow on the Hutt River coinciding with 100 year flow in Mangaroa.	This is a conservative approach which reflects the current uncertainty in understanding the probability/timing of a large flood on both rivers and associated tailwater effect on the lower reaches of the Mangaroa.

Name	Factor	Magnitude of allowance for incorporation in Sensitivity Run	Reasoning behind choice of magnitude value
Sensitivity 5	Combination run	Blockage as above PLUS +10% hydrology PLUS +10% Manning's n	In reality, these factors may coincide and have inter-related effects.
Sensitivity 6	Sensitivity 1+Freeboard	Add 300mm freeboard onto model using an initial water level	Whilst landslide/aggradation are known potential hazards that could be subject to inclusion in a Sensitivity Run, it has been determined that such runs will not be undertaken as part of the Mangaroa Hazard Mapping as their effect will be accounted for in the blockage Sensitivity Run.
Sensitivity 7	Sensitivity 2+ Freeboard	Add 300mm freeboard onto model using an initial water level	Based on discussion in the Workshop and subsequent research a freeboard of 300 mm is appropriate.
Sensitivity 8	Sensitivity 3+ Freeboard	Add 300mm freeboard onto model using an initial water level	Based on discussion in the Workshop and subsequent research a freeboard of 300 mm is appropriate.
Sensitivity 9	Sensitivity 4+ Freeboard	Add 300mm freeboard onto model using an initial water level	Based on discussion in the Workshop and subsequent research a freeboard of 300 mm is appropriate.
Sensitivity 10	Sensitivity 5+ Freeboard	Add 300mm freeboard onto model using an initial water level	Based on discussion in the Workshop and subsequent research a freeboard of 300 mm is appropriate.

7.3 Methodology

Sensitivity runs 1 to 5 applied changes were as described in section 7.2. For sensitivity runs 6 to 10, the peak water level results for its corresponding sensitivity run without freeboard (e.g. Sensitivity 1 peak results were used for Sensitivity 6) were used as an initial water level in MIKE 21 and MIKE 11 with an additional 300 mm as freeboard. The time step was also reduced to 0.5 seconds and the model ran for 2 hours.

To capture the effect of these hazard factors on the flood risk, the sensitivity runs 1 to 5 were combined to identify and produce a Peak Hazard Sensitivity Output to represent the worst case from each of the Sensitivity Runs over the catchment. The same process was conducted for sensitivity runs 6 to 10 which were for scenarios with 300 mm freeboard. The freeboard was applied in accordance with the methodology agreed at the workshop held on 20 May 2015.

7.4 Model Results

Figure 20 shows the modelled flood extents derived from the 2014 base model, and the Peak Hazard Sensitivity Output from sensitivity runs 1 to 5, and from sensitivity runs 6 to 10.

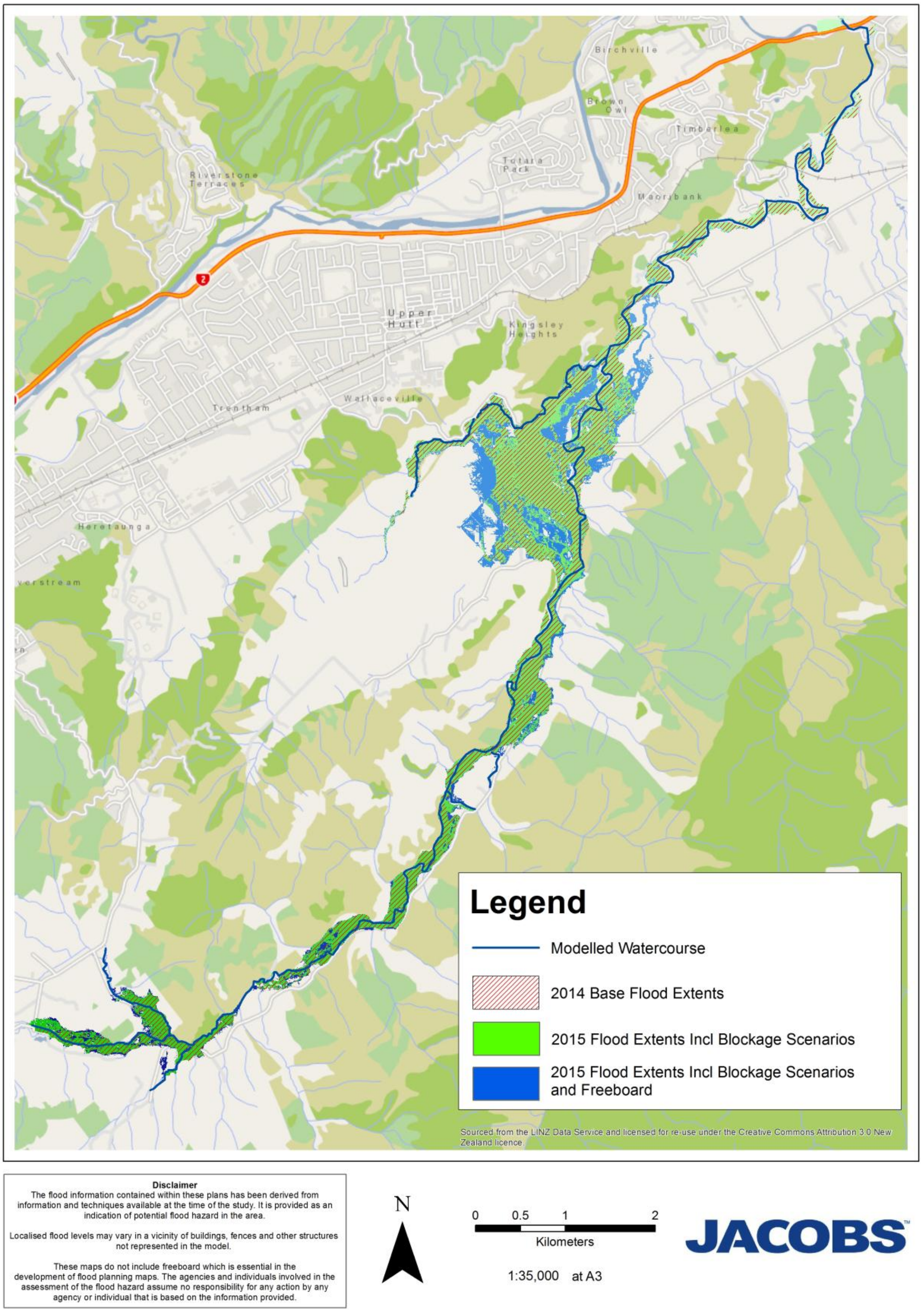

Figure 20: Modelled flood extents derived from the 2014 and the Peak Hazard Sensitivity Output from sensitivity runs 1 to 5 and from sensitivity runs 6 to 10

7.5 Results Context

Figure 20 shows that there is a spatial variation in the difference in the flood extents produced by the three models. The largest differences in spatial extent occur between the middle and lower reach, from near the intersection of Whitemans Valley Road and Katherine Mansfield Drive to the confluence of Black Creek and the Mangaroa River.

The difference between the extents produced by the 2014 base model compared to sensitivity analysis runs 1 to 5 is generally minimal, with the main increase in extent occurring immediately to the north of the intersection of Whitemans Valley Road and Katherine Mansfield Drive.

The difference between the extents from sensitivity analysis runs 6 to 10 is noticeably greater than the other runs, with the floodplain extending several hundred metres west between Katherine Mansfield Drive and Black Creek, additional flooded area upstream of the confluence of Black Creek and the Mangaroa River, as well as a break-out flowpath to the east of the Mangaroa River which bypasses the confluence with Black Creek.

8. Model Limitations

The modelled flood breakouts are largely dependent on the model bathymetry which was derived from the LiDAR data. Clear errors are present for some densely vegetation regions in the LiDAR data which may impact floodplain storage and secondary flowpaths.

The model has been calibrated against the three highest recorded flows on record where the Hutt River has been shown to not influence the observed Mangaroa gauged readings. The model validation only yielded adequate results. However, it should be noted that the two events with poor validation are thought to have an annual exceedance probability of greater than 10% which may not be representative of catchment conditions for larger flows. A much better validation was achieved for the larger event which is preferable, given that the purpose of this study is to develop a model for producing flood maps for extreme events.

The Mangaroa gauge is known to be influenced by the Hutt River water levels. Although this study attempts to exclude such events from the analysis, this does present a source of uncertainty throughout the flood study. In addition, it means that a legitimate flood frequency analysis cannot be undertaken for the gauged data and hence legitimate estimates for flood frequency quantiles cannot be derived. Uncertainty in the modelling will be taken into consideration through an appropriate choice of freeboard when undertaking the hazard mapping.

Should a significantly larger flow event occur within the Mangaroa River catchment, consideration should be given to comparing the flood model results against the observed data.

9. Conclusions and Recommendations

9.1 Model Build Summary

The updates to the revised flood model can be summarised as the following:

- A 5 m grid bathymetry based on updated LiDAR data;
- Identification and manual removal of topographical errors in LiDAR data based on gorse thickets (thus opening up more floodplain storage);
- New survey added to the model to extend Black Creek upstream;
- Refined channel alignment and hence new chainage numbers for model components;
- Rainfall runoff modelling component based on SCS unit hydrograph method and included within hydraulic model;
- Rethinking of the event selection for calibration and validation, and hence updated calibrations and validation;
- General update of minor model parameters to align them with current industry standards.

Conclusions

- The revised 2014 model achieved good calibration for the three events chosen, however the validation runs suggest that whilst the model performs well at predicting higher flow events, peak flow during lower flow events may be under-estimated by the model.

- The balanced storm approach, while conservative, was a considerably better match against the existing gauge record and recorded storm peaking than that achieved by using the Tomlinson storm distribution.

- A comparison of peak flows at the gauging station, both statistical and from the two model runs confirm that;
  - The previous 2007 version of the model was overly conservative against the Gauged record;
  - The current 2014 model run falls into the expected range at the gauging station when mid-level climate change is taken into account;
  - The 2014 model and the 2007 model have ended up with a similar peak flows due to the influence of climate change on the modelled peak flows.

Source	1% AEP	1% AEP with Climate Change
2007 Model	480 m^3/s	
2014 Model		475 m^3/s
Flood Frequency Analysis estimate undertaken in 2005	372 ± 57 m^3/s	450-515 m^3/s *(estimated by assuming 20% increase on the 1% AEP present day)*
Flood Frequency Analysis estimate undertaken in 2014 *(using full gauge record and EV1 (Gumbels) distribution)*	355 ± 73 m^3/s	426-515 m^3/s *(estimated by assuming 20% increase on the 1% AEP present day)*

- Modelled Top Water Levels differ from the 2007 along much of the model. This is due to a range of factors including changes to the length of the open channel (which has altered chainages), additional survey of land around Black Creek, a new “in model” approach to the hydrology and calibration of storm events.

Recommendations

1. It is recommended that the 2014 model, using the balanced storm hydrograph, be adopted as the updated flood risk model for the Mangaroa River.

2. While through much of the lower river flood levels do not differ greatly from the previous assessment of flood risk, there are areas around Black Creek and in the upper catchment where differences are significant.

3. A combined Mangaroa and Hutt River model could be used to provide better calibration and better accuracy of the flooding near the confluence of the two rivers. Explicitly capturing the interaction of the two rivers within the model would address some of limitations mentioned earlier on in the report associated with deriving a ‘Hutt River representative’ downstream model boundary for the Mangaroa.

4. GWRC may want to consider a second gauging station on the Mangaroa River that is not affected by the Hutt River.

5. Continued development and maintenance of the model is recommended as additional data becomes available. The modelling should also be reviewed periodically as modelling software and best practice methodology continues to evolve.

10. References

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Chow, V.T., 1959 *Open-channel hydraulics*, New York, McGraw- Hill Book Co.

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Watts, L., 2005. *Flood Hydrology of the Mangaroa River*, Greater Wellington City Council

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Appendix A. CN and Lag Values for all model runs

Sub-Catchment	February 2004		October 2003		October 1997	
	CN	Lag (hrs)	CN	Lag (hrs)	CN	Lag (hrs)
A	60	1.4	80	0.6	67	1.1
B	58	0.8	78	0.3	65	0.7
C	59	1.8	78	0.7	65	1.4
D	62	1.4	83	0.6	69	1.1
E	63	1.5	84	0.6	70	1.2
F	60	1.5	79	0.6	66	1.2
G	60	1.4	80	0.6	66	1.1
H	59	2.5	78	1.0	65	2.0
I	59	1.8	79	0.7	65	1.4
J	61	1.6	82	0.7	68	1.3
K	59	1.1	78	0.4	65	0.9
L	64	5.9	86	2.4	71	4.7
M	58	3.3	78	1.3	65	2.7
N	58	2.3	78	0.9	65	1.8
O	58	1.9	77	0.8	65	1.5
P	60	1.4	80	0.6	67	1.2
Q	59	2.4	79	1.0	66	1.9

Appendix B. Validations Runs with Discarded Alternate Parameters

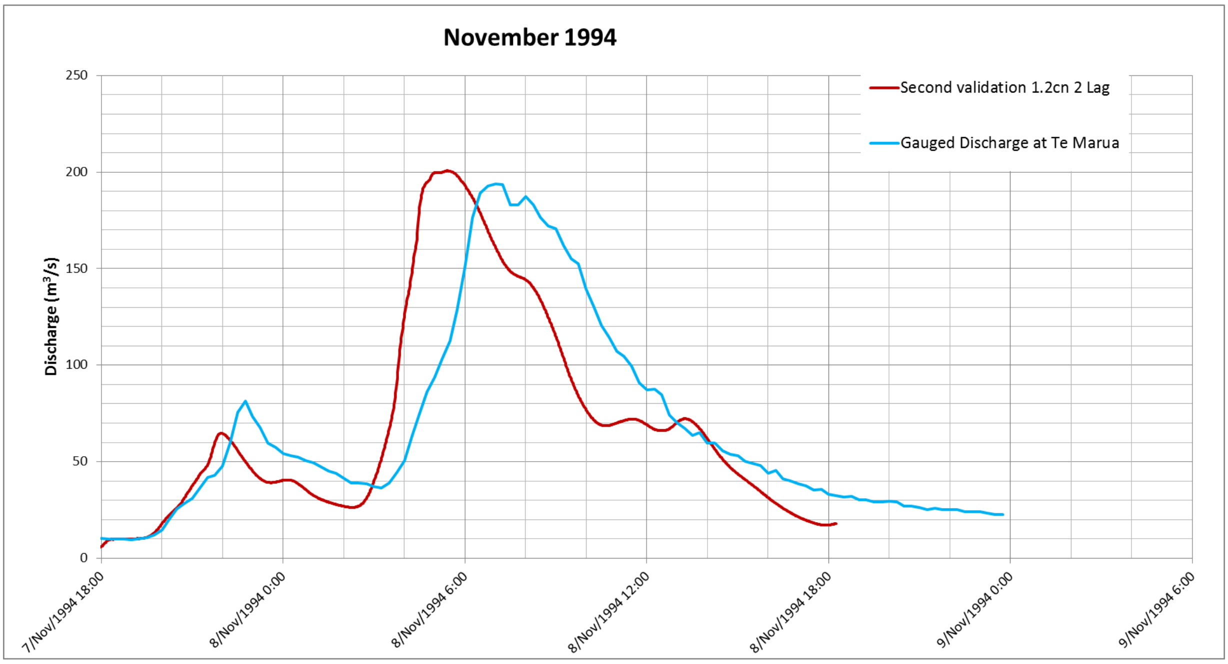


Figure A1: Validation Run for November 1994

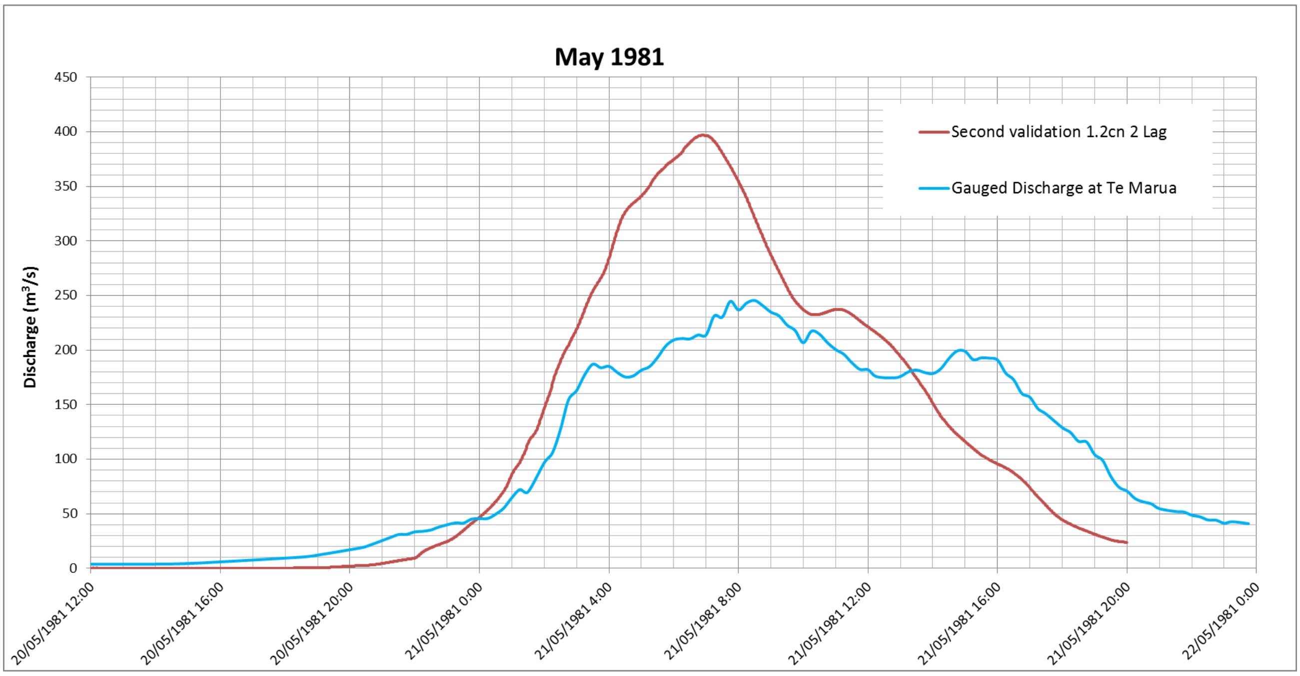


Figure A2: Validation Run for May 1981

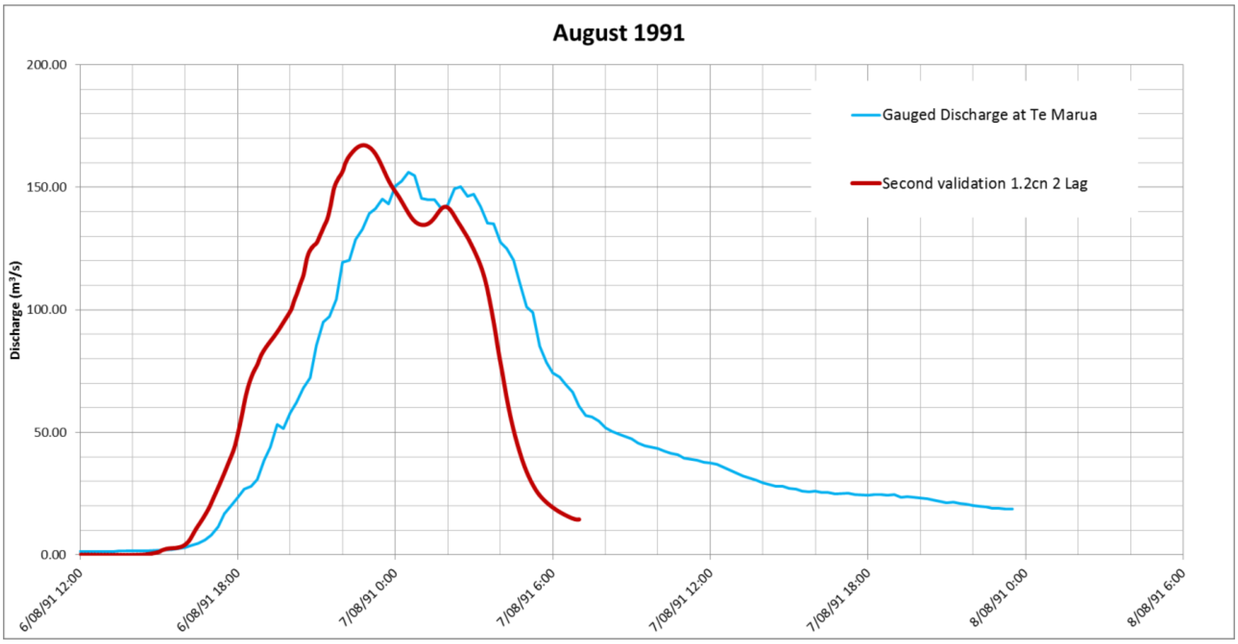


Figure A3: Validation Run for August 1991

Appendix C.

ID	Structure name	Proportion blocked in Blockage Sensitivity Run	Photo
1	Bridge 913 Whitemans Valley Road	20%	
2	Whitemans Valley Road Bridge	50%	

3	#13 Russel Road	90%	

4	Whitemans Valley Trib Stream Bridge	90%	

5	Bridge 750 Whitemans Valley Road	20%	
6	Bridge 408 Whitemans Valley Road	20%	

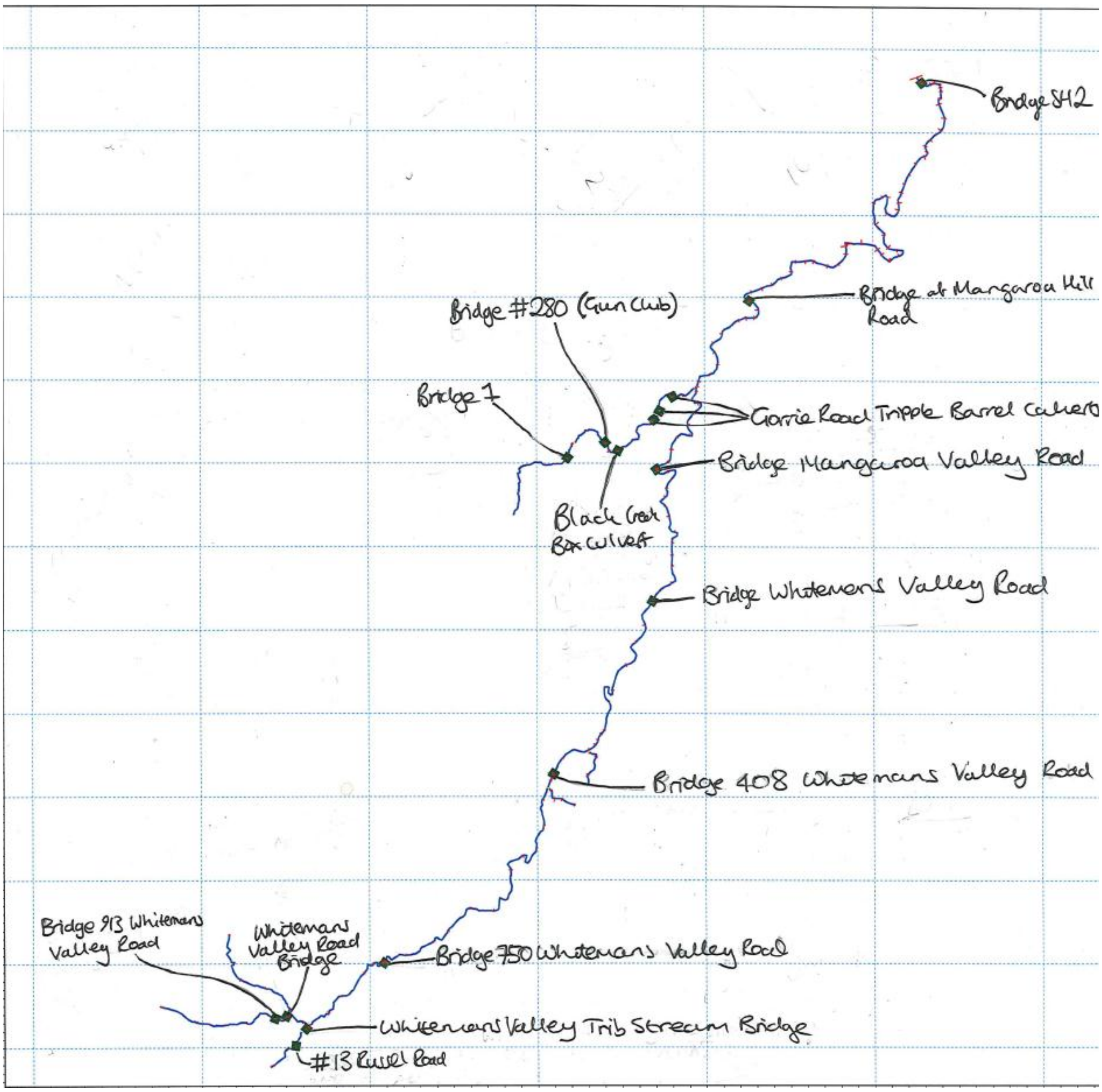
7	Bridge Whitemans Valley Road	20%	
8	Bridge Mangaroa Valey Road	20%	
9	Bridge 1	50%	

10	Bridge #280 (Gun Club)	50%		
11	Black Creek Box culvert	50%		

12	Gorrie Road triple barrel culvert 1	90%	
13	Gorrie Road triple barrel culvert 2	90%	

14	Gorrie Road triple barrel culvert 2 (# 85)	90%	
15	Bridge at Mangaroa Hill Road	20%	

16	Bridge SH2	20%	



Bridge SH2
Bridge at Mangaroa Hill Road
Bridge #280 (Gun Club)
Bridge 7
Garrie Road Tripple Barrel Culverts
Bridge Mangaroa Valley Road
Black Creek Box Culvert
Bridge Whitemans Valley Road
Bridge 408 Whitemans Valley Road
Bridge 913 Whitemans Valley Road
Whitemans Valley Road Bridge
Bridge 750 Whitemans Valley Road
Whitemans Valley Trib Stream Bridge
#13 Russel Road