

Tutaenui Stream

Floodplain Hazard Assessment

Hydraulic Modelling and Mapping



Tutaenui Stream Floodplain Hazard Assessment

Hydraulic Modelling and Mapping

PO Box 300-705
Albany
New Zealand

Tel: +64 9 912 9638
Fax: +64 9 912 9639
e-mail: dhi@dhihroup.com
Web: www.dhi.co.nz

Client Horizons Regional Council	Client's representative Jeff Watson
---	--

Project Tutaenui Stream: Flood Plain Hazard Assessment: Hydraulic Modelling & Mapping	Project No 50130
---	-------------------------

Authors G. Whyte T. van Kalken A. Taylor	Date 6 October 2008
	Approved by G. Whyte

Revision	Description	By	Checked	Approved	Date
02	Final report	GMW	TVK	GMW	06/10/08
01	Draft report	GMW	TVK	GMW	29/08/08

Key words Floodplain, detention basins, flood mapping, MIKE Flood, Tutaenui, Marton, Bulls	Classification <input type="checkbox"/> Open <input type="checkbox"/> Internal <input checked="" type="checkbox"/> Proprietary
---	---

Distribution	No of copies
Horizons Regional Council: Jeff Watson	3
DHI Auckland: Library	1
DHI Christchurch: Greg Whyte	1



© DHI Water and Environment Limited 2008

The information contained in this document produced DHI Water and Environment Ltd is solely for the use of the Client identified on the cover sheet for the purpose for which it has been prepared and DHI Water and Environment Ltd undertakes no duty to or accepts any responsibility to any third party who may rely upon this document.

All rights reserved. No section or element of this document may be removed from this document, reproduced, electronically stored or transmitted in any form without the written permission of DHI Water and Environment Ltd.

All hard copies of this document are "UNCONTROLLED DOCUMENTS". The "CONTROLLED" document is held in electronic form by DHI Water and Environment Ltd.



CONTENTS

1	INTRODUCTION	1-1
1.1	Background.....	1-1
1.2	Physical Setting	1-1
1.3	Existing Flood Control Infrastructure	1-1
1.4	Approach	1-1
1.5	Projections and datum	1-2
2	HYDROLOGICAL ASSESSMENT	2-1
2.1	Catchment Description	2-1
2.2	Methodology	2-1
2.3	Hydrometric Data Availability	2-2
2.3.1	Streamflow	2-2
2.3.2	Rainfall.....	2-2
2.4	Frequency Analysis	2-3
2.4.1	Rainfall.....	2-3
2.4.2	Discharge.....	2-5
2.5	Hydrological Model Development and Calibration.....	2-6
2.5.1	Catchment Delineation	2-6
2.5.2	Model Development.....	2-7
2.5.3	Hydrological Model Calibration	2-7
2.6	Design Event Generation.....	2-13
2.6.1	Catchment Design Rainfall	2-13
2.6.2	Validation against Flood Frequency Analysis	2-13
3	HYDRAULIC MODEL DEVELOPMENT AND VALIDATION	3-2
3.1	Model Description	3-2
3.2	Data availability.....	3-2
3.2.1	Land Level Data.....	3-2
3.2.2	GIS Data	3-2
3.2.3	Cross Sections and Topography	3-2
3.2.4	Structures	3-3
3.2.5	Detention Dams	3-5
3.2.6	Water Supply Dams.....	3-5
3.2.7	Flood Levels and Extents	3-5
3.3	Model Extent and Development.....	3-6
3.3.1	Model Extent.....	3-6
3.3.2	1D MIKE 11 Model.....	3-7
3.3.3	2D MIKE 21 Model.....	3-7
3.4	MIKE Flood Model Build	3-9
3.4.1	Linkages	3-9
3.4.2	Model simulations	3-10
3.5	MIKE Flood Model Validation	3-10
3.5.1	Validation	3-10
4	FLOOD RISK ASSESSMENT	4-1
4.1	Water Supply and Detention Dam Performance.....	4-2



5	CONCLUSIONS AND RECOMMENDATIONS.....	5-1
5.1	Summary	5-1
5.2	Recommendations.....	5-2
6	REFERENCES	6-3

DRAWINGS

1	Study Area – Marton
2	Study Area - Bulls
3	Hydrology – Gauge Locations
4	Hydrology – Dams and Catchments
5	Structures and Cross Section Surveys – Marton Area
6	Structures and Cross Section Surveys – Bulls Area
7	February 2004 Flood Event Extent – Marton Area
8	February 2004 Flood Event Extent – Between Marton and Bulls
9	February 2004 Flood Event Extent – Bulls Area
10	100 year ARI Event Water Level Depth, Water Supply Dam Full – Marton Area
11	100 year ARI Event Water Level Depth, Water Supply Dam Full – Between Marton and Bulls
12	100 year ARI Event Water Level Depth, Water Supply Dam Full – Bulls Area
13	100 year ARI Event Velocity, Water Supply Dam Full – Marton Area
14	100 year ARI Event Velocity, Water Supply Dam Full – Between Marton and Bulls
15	100 year ARI Event Velocity, Water Supply Dam Full – Bulls Area
16	100 year ARI Event Flood Hazard, Water Supply Dam Full – Marton Area
17	100 year ARI Event Flood Hazard, Water Supply Dam Full – Between Marton and Bulls
18	100 year ARI Event Flood Hazard, Water Supply Dam Full – Bulls Area
19	200 year ARI Event Water Level Depth, Water Supply Dam Full – Marton Area
20	200 year ARI Event Water Level Depth, Water Supply Dam Full – Between Marton and Bulls
21	200 year ARI Event Water Level Depth, Water Supply Dam Full – Bulls Area
22	200 year ARI Event Velocity, Water Supply Dam Full – Marton Area
23	200 year ARI Event Velocity, Water Supply Dam Full – Between Marton and Bulls
24	200 year ARI Event Velocity, Water Supply Dam Full – Bulls Area
25	200 year ARI Event Flood Hazard, Water Supply Dam Full – Marton Area
26	200 year ARI Event Flood Hazard, Water Supply Dam Full – Between Marton and Bulls
27	200 year ARI Event Flood Hazard, Water Supply Dam Full – Bulls Area
28	100 year ARI Event Water Level Depth, Water Supply Dam Full – Upstream of Mar- ton (No LiDAR Area)
29	200 year ARI Event Water Level Depth, Water Supply Dam Full – Upstream of Mar- ton (No LiDAR Area)
30	2004 year ARI Event Water Level Depth, Water Supply Dam Full – Upstream of Marton (No LiDAR Area)

APPENDICES

A	Depth Duration Frequency Rainfall Tables
---	--



1 INTRODUCTION

1.1 Background

Horizons Regional Council (HRC) requires information regarding the extent and depth of flood inundation occurring from floods in the Tutaenui Stream and in particular the urbanised areas of Marton and Bulls. This report details the work undertaken to develop hydrological and hydraulic models of the catchments and the subsequent flood risk assessment to identify the 100 and 200 year ARI flood event extents.

1.2 Physical Setting

The Tutaenui Stream catchment is a tributary catchment of the Rangitikei River which joins with the River three kilometres below the township of Bulls. Both State Highways 1 (SH1) and 3 (SH3) cross the catchment.

The upper catchment extends to approximately 12 kilometres north of Marton. The catchment is 27 kilometres long with an average width of 5 kilometres. Marton is located centrally in the catchment while Bulls is located towards the downstream end of the catchment. The catchment has a mean annual rainfall of 1040mm-1140mm¹.

Drawing 1 shows the study area.

1.3 Existing Flood Control Infrastructure

The Tutaenui Catchment Control Scheme (TCCS) was constructed between 1977 and 1985 to control flooding from the Tutaenui Stream and to manage some of the Tutaenui tributaries within the catchment (John Philpot and Associates, 2006). The scheme involved the construction of 15 detention dams of varying sizes, which supplemented three existing dams built on the outskirts of Marton between 1962 and 1965. The fifteen TCCS dams were constructed in the mid to upper sub-catchments and were designed to offer protection from the 1 in 20 year return period flood event. The SH3 crossing of the Tutaenui Stream upstream of Bulls was also upgraded over this period. This consisted of a bypass channel and second culvert crossing to improve the conveyance of larger flood events downstream.

1.4 Approach

DHI have developed hydrological and hydraulic models to aid the assessment of the flood hazard. The hydrological model has been calibrated against recorded historical flood events and is used to generate inflows to the hydraulic model. This comprises a dynamically linked 1D-2D model (MIKE FLOOD), which is used to both route the catchment runoff downstream of the headwaters and at the same time map the flood spread and depth. Details of the model development and calibration are provided in the following sections.

¹ Source:wrenz.niwa.co.nz



1.5 Projections and datum

The map projection adopted of the study is NZ Map Grid (NZMG) and the flood levels are referred to Wellington datum.



2 HYDROLOGICAL ASSESSMENT

The hydrological assessment of the Tutaenui Stream was undertaken through a combination of model development and calibration, supported by a separate regional flood frequency analysis.

2.1 Catchment Description

The Tutaenui catchment rises from an elevation of 40 metres at the Rangitikei River confluence to over 300 metres above the Marton water supply dams. Land use in the catchment is predominately rural with the main urban areas being the townships of Marton and Bulls. Drawings 1 and 2 show the catchment topography.

The Tutaenui Stream forms the main drainage channel in the catchment. From the water supply dams which are located approximately 8 km upstream of Marton, the stream falls 200 metres in a well defined channel through rural land to the outskirts of the town. Through Marton township, the stream is deeply incised, and is crossed by a large number of local roads. Downstream of Marton the stream is generally well contained down to Curls Bridge

Flooding in Marton township occurs when the Tutaenui Stream spills floodwater at Calico Line at the north end of Marton. This occurs due to a number of small tributaries that join the Tutaenui at this point, overwhelming the local channel capacity. Folly Stream and Painui Stream, which join at the southern end of Marton, are also both flood prone.

The Marton water supply dams are located at the headwaters of the catchment 8 km upstream of the town, see Drawing 3. Two dams, connected in series (known as Dam B and Dam C) provide some flood storage capability, although they are not operated with a flood control objective. The 15 TCCS flood detention dams are designed to provide protection against a 1 in 20 year event. These are supplemented by three additional dams on the outskirts of Marton. During lesser events, the flood detention dams are designed to throttle the flow in each of the contributing catchments, whereas above this event threshold much larger outflows will occur once the dam storages reach capacity and flows occur over each dam spillway.

2.2 Methodology

A hydrological assessment of the Tutaenui subcatchments has been developed in order to provide inflow hydrographs to the hydraulic model.

DHI's rainfall runoff Model B has been applied for this study. This incorporates a simple initial and continuing loss model together with a kinematic routing component. Input parameters comprise catchment slope and hydraulic length, as well as initial and continuing infiltration loss values for the various types of contributing catchments (pervious and impervious, of differing slopes).



2.3 Hydrometric Data Availability

HRC have provided hydrological and topographical data as shown in Table 2-1. Drawing 4 shows the gauge locations.

Table 2-1 Hydrological data available for the study

Data	Availability	Comments
Rainfall		
Ohakea	January 1986-June 1993	15 minute data & hourly data, gap half of December 1992
Tutaenui at Smiths Road	February 1983-November 1986	1 minute-240 minutes, gap 1 week in August 1986
Tutaenui at Mill Street	January 1962-March 2007	Daily record, gaps first half 1963 and first 2/3 2002, 2005
Mangaone Valley Rd	March 1987-present	6-15 minute data, daily in 1988 event
Makino at Cheltenham	December 1989-present	6 minute data
Discharge		
Hammond Street	March 1968-August 2007	Gaps mid 1971-mid 1991, mid 1998-end 2006

2.3.1 Streamflow

Streamflow data is available on the Tutaenui Stream at Hammond Street in Marton. Data is available between 1968-1987, 1991-1998 and from the end of 2006. Table 2-2 shows maximum annual flows recorded at this location. The largest flow on record at the Hammond Street gauge is 45.9m³/s, recorded in July 1991. The 2004 event was not recorded by the gauge but the peak flow was estimated from debris levels in the vicinity of the gauge to be 67.4m³/s. A further 20-30m³/s was estimated to have bypassed the gauge at the flood peak.

2.3.2 Rainfall

Recorded rainfall data suitable for a detailed hydrological assessment is not available within the catchment. The closest recording gauges are located at Ohakea Aerodrome, Valley Road and Cheltenham. The only gauge located within the catchment is Mill Street in Marton, which records on a daily basis, which is not sufficient for high resolution data required for historical storm analysis and subsequent hydrological model input.

DHI's Temporal Analyst package was used to synthesize an hourly record at Mill Street by disaggregating the daily record using the hourly data from the closest automatic station at Ohakea. The limitation of this technique is that the correlation between the Mill Street and Ohakea sites is sometimes poor. In some cases a rainfall event recorded in one location may not be reflected in the other. Generally rainfall for the Tutaenui catchment represented by the Mill Street gauge is slightly lower than recorded rainfall at the Ohakea site. The highest daily rainfall recorded at Tutaenui Mill Street was on 14th February 2004, when a daily total of 122mm was recorded. The 2004 event, which resulted in the highest flood on record at Hammond Street, was not captured at all at the Ohakea site as the gauge was not operational.



The second largest recorded rainfall event at Mill Street was on the 3rd February 1967 when 90mm of rainfall was recorded in the 24 hour period.

Table 2-2 Maximum Annual flows recorded on the Tutaenui Stream at Hammond Street.

Date and Year	Max. Annual Discharge (m ³ /s)	Date and Year	Max. Annual Discharge (m ³ /s)
31-Aug-68	14.5	15-Jul-84	9.4
27-Jun-69	9.0	27-Jul-85	2.8
1-Jul-70	23.1	24-Aug-86	18.5
22-Oct-71	29.4	30-Jun-87	21.0
17-Jul-72	19.2	26-Jul-91	45.9
17-Sep-73	12.7	16-Aug-92	23.4
4-Jul-74	20.4	22-Nov-93	9.8
28-Aug-75	16.2	16-Nov-94	27.1
29-Jun-76	42.3	18-Sep-95	19.9
24-Jul-77	12.7	13-Oct-96	11.5
20-Jul-78	19.7	15-Oct-97	14.6
25-Aug-79	28.8	15-Jul-98	20.5
19-Oct-80	33.4	16-Feb-04	67.4 ²
4-Jul-81	18.8	21-Dec-06	0.8
21-Jul-82	10.6	7-Aug-07	12.1
20-May-83	14.9		

2.4 Frequency Analysis

2.4.1 Rainfall

A frequency analysis of the daily rainfall at Mill Street and Ohakea was undertaken using DHI's Extreme Value Analysis (EVA) module. EVA extracts an annual extreme value series from an observed record to which a range of probability distributions can be fitted to select a "best fit". Both Extreme Value Type 1 (EV1) and Log-Pearson III distributions have been tested. Table 2-3 shows the results from the daily rainfall frequency analysis and Figure 2-1 and Figure 2-2 shows the results plotted with a 95% confidence interval.

Table 2-3: EVA 24 hour Rainfall Depths at Tutaenui Mill Street and Ohakea

Rainfall Site	Best Fit Distribution	100 year ARI (mm)	200 year ARI (mm)
Mill St	Adj EV1	123	135
Ohakea	Adj EV1	126	139

² Estimated value from peak flood level. A further 20-30m³/s was estimated to have bypassed the gauge at the event peak.

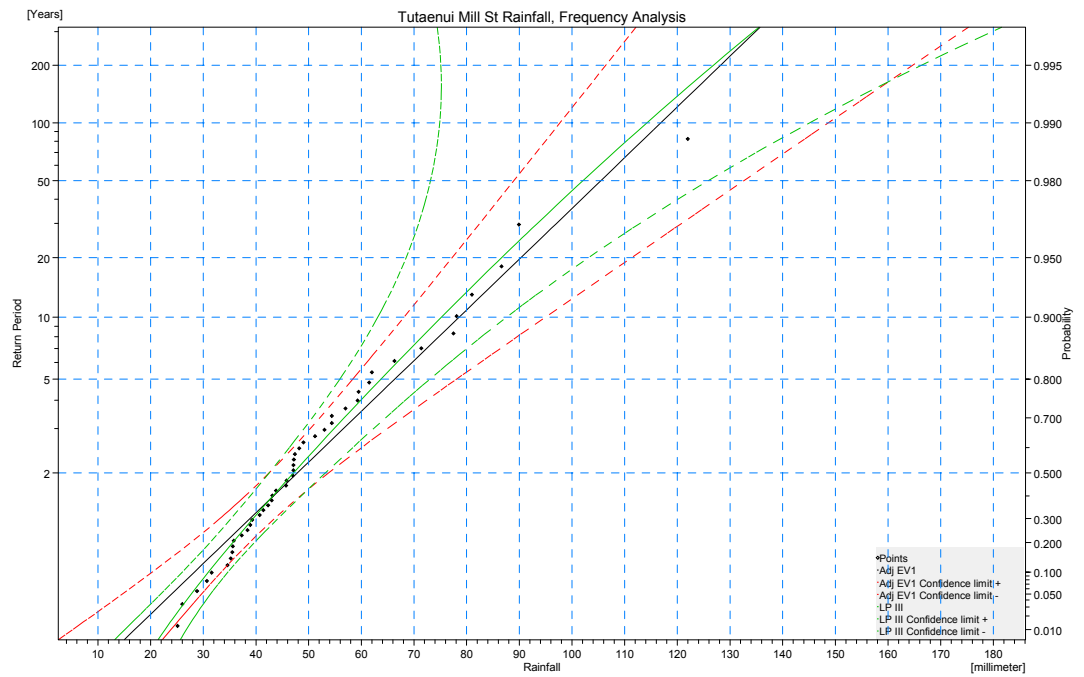


Figure 2-1 EVA Rainfall Depths at Tutaenui Mill Street

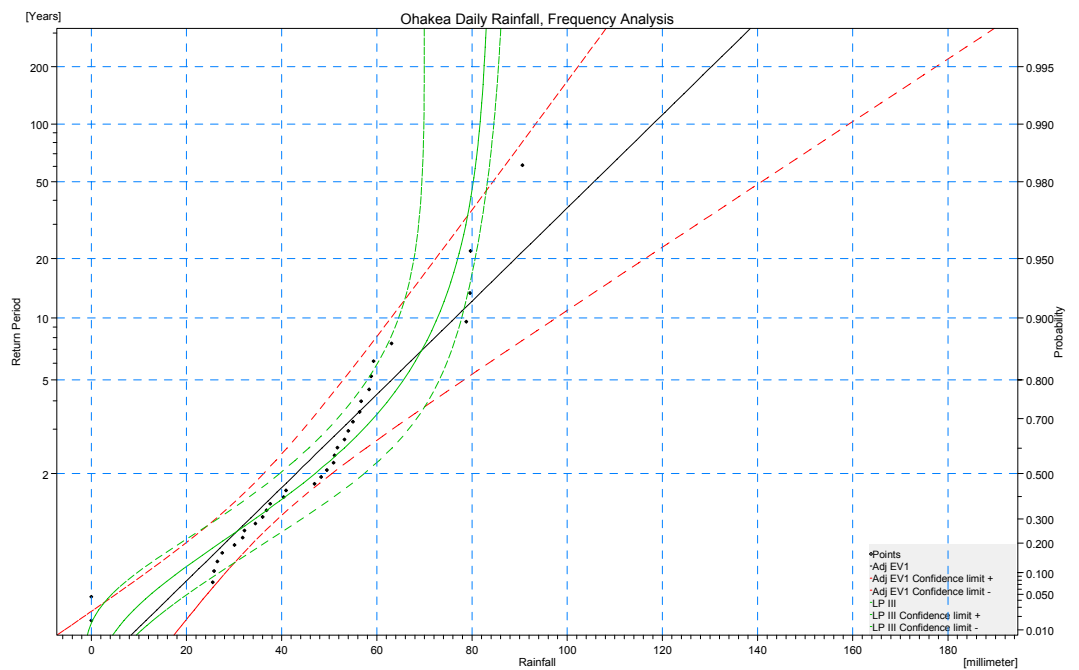


Figure 2-2 EVA Rainfall Depths at Ohakea



HIRDS was used as a comparison and the results in Table 2-4 were obtained. Two sites were investigated, one in Marton and one at the top of the catchment near the water supply dams. Appendix A details the full HIRDS analysis.

Table 2-4 HIRDS 24 hour Rainfall Depths at Tutaenui Mill Street and Water Supply Dams

HIRDS Site	100 year ARI (mm)	200 year ARI (mm)
Mill St	123	145
Water Supply Dams	127	150

Table 2-3 shows that there is only a small difference between predicted daily rainfall totals for Tutaenui Mill Street and Ohakea. Rainfall total differ by less than 3mm (2%) for the 100 year ARI rainfall event and 4mm (3%) for the 200 year ARI rainfall event.

From Table 2-4 the variation of daily rainfall between catchment headwaters near the water supply dams and in Marton is also quite small. HIRDS predicts an approximate 3% increase in daily rainfall in the catchment headwaters compared to Marton. When comparing the predicted daily rainfall total at Marton using EVA and HIRDS for a 100 year ARI rainfall event the results are exactly the same, whereas the 200 year ARI rainfall event using HIRDS is 10mm (7%) larger than the EVA estimate. Based on this analysis it has been decided to adopt the HIRDS values as these are slightly more conservative for the 200 year ARI event.

2.4.2 Discharge

The Hammond Street flow gauge provides a basis for a flood frequency analysis of catchment flows to this location. Gauging commenced in 1968, but was discontinued between 1988-1990 and 1999-2003. The statistical analysis of gauge flows is complicated by these gaps in the data, in addition to the fact that the catchment characteristics changed considerably after 1976 once the TCCS flood detention dam construction was completed. The dams are designed to mitigate against the 1 in 20 year flood event and therefore flood events of this magnitude will be attenuated at the gauge. Prior to the construction of the TCCS, the Marton Water Supply dams and three smaller flood detention dams would also have provided a mitigation effect, but these effects would be present in the entire flow record from 1968.

Two analyses have been undertaken:

- a. The entire record from 1968, including the 2004 flood event
- b. A reduced record from 1968-1976, plus the 2004 flood event

The first analysis therefore includes the flood record which after 1976 is modified by the effects of the flood detention dams. From Table 2-2, it can be seen that after 1976 only two significant flood events occurred, in 1991 and 2004. Without knowing the recurrence interval of the other events in this period it is reasonable to assume that due to their smaller magnitudes, significant flood attenuation would have taken place due to the presence of the flood detention dams.

By excluding these smaller events from the analysis after 1976, it is expected this will provide a more consistent basis for the estimation of a flood frequency distribution, al-



though greater uncertainties are introduced due to the shorter length of observed flow data that is used.

In both cases it is assumed the 2004 flood event represents the highest flow in the 40 years since records commenced in 1968, following Kuczera (1999). In addition an allowance has been made for the by-passing flows in February 2004, estimated by HRC to have been between 20-30m³/s (J. Watson, pers. comm.). The gauged flow was 67.4m³/s, and therefore allowing approximately 25m³/s as the bypass flow, the total 2004 peak discharge is assumed to be 93m³/s. Table 2-5 shows the results of the flood frequency analyses. An EVI analysis was applied as recommended by McKerchar and Pearson (1989).

Table 2-5 Design Discharges at Hammond Street (90% confidence limits in brackets)

Analysis	100 year ARI (m ³ /s)	200 year ARI (m ³ /s)
A; 1968-2007, incl 2004	59 (50-71)	65 (55-79)
B; 1968-1976 plus 2004	76 (55-106)	85 (61-119)

In analysis “A”, the 2004 event lies outside the 90% confidence limits. This is understandable as the data are likely to be skewed due to the inclusion of the smaller flood events which are reduced in magnitude due to the detention dams. The confidence limits for analysis “B” are higher than analysis “A” due to the smaller record considered.

A regional estimate (following McKerchar and Pearson, 1989) assuming no data at the gauge was also undertaken to cross check the at-sire estimates and the results are shown in Table 2-6. These are very similar to the “A” analysis undertaken above.

Table 2-6 Flood Frequency of New Zealand Design Discharges at Hammond Street

Site	100 year ARI (m ³ /s)	200 year ARI (m ³ /s)
Tutaenui Hammond St	59	64

An accurate determination of the flood statistics at Hammond Street is not straightforward as the lower end of the frequency distribution is affected by the presence of the flood detention dams. Ignoring the dams (ie the record after 1976) increases the uncertainty in the estimate. The above figures therefore should be regarded as indicative estimates of the likely flood magnitudes.

2.5 Hydrological Model Development and Calibration

2.5.1 Catchment Delineation

The study area has been delineated into 30 sub-catchments, with areas ranging from 0.3km² to 18.3 km². The delineated catchments are shown in Drawing 3. Catchment delineation was based on LiDAR land level data where available and 20m contours outside the LiDAR coverage area. Sub-catchments were defined for all detention dams and the two water supply dams, along with all other parts of the Tutaenui catchment area. Table 2-7 shows the properties derived for each sub-catchment.



2.5.2 Model Development

The drainage path of each catchment was determined from the land level data from which the hydraulic length and slope have been calculated. It has been assumed that the rural sub-catchments are 5% impervious. The impervious component takes account of roads and possible other impervious components of a typical rural environment. Sub-catchments that contain urbanised areas have been approximately assessed from topographical maps to determine the extent of the impervious fraction.

Table 2-7 Sub-Catchment Physical Properties

Catchment Name	Area (km ²)	Length (m)	Slope (m/km)
1	8.87	6859	15
2	1.10	2243	19
3	1.56	2303	15
4	1.64	3492	26
5	0.89	1858	23
6	1.46	2847	17
7	1.17	2506	8
8	4.62	6734	11
9	1.75	3022	12
10	0.93	1995	14
11	1.20	2419	10
12	8.27	10035	10
13	2.40	4136	7
14	1.63	3425	8
15	6.03	7711	8
16	2.01	3663	10
17	0.96	2093	7
18	0.27	831	16
19	0.31	1437	16
20	3.72	6001	14
21	5.67	6247	5
22	8.74	12681	10
23	18.32	11475	5
24	16.60	9731	6
25	9.45	9453	6
26	2.96	3736	7
27	2.13	3394	4
28	11.32	7729	8
29	7.60	4928	7
30	4.56	6328	13

2.5.3 Hydrological Model Calibration

The runoff from the catchments has been routed to the Hammond Street gauge in Marton where a comparison between simulated and observed flows can be undertaken. The routing utilizes a MIKE 11 hydraulic model of the upper catchment, which is essentially



the same model that has been developed for the full MIKE FLOOD catchment model, but which terminates about a kilometre downstream of the Hammond Street gauge. In addition the MIKE 11 routing model contains only the dams that existed at the time the calibration events occurred (1974-76). These comprise dams W3 and W4 as well as the two water supply dams.

The hydrological model calibration has focussed on adjustments of the pervious areas, where appropriate, and the infiltration losses, in particular the final loss rates.

Historical events for use in calibration have been selected from the gauge record between the period 1966-1976. This represents the period prior to the construction of the TCCS and has been selected as it was felt the presence of the dams in later years would affect the hydrological response of the catchment and therefore complicate the calibration. It was also important to select calibration events that are reflected both in the rainfall records at Tutaenui Mill Street and Ohakea as well as in the flow record at Hammond Street. Based on these criteria, three calibration events have been selected as described in Table 2-8. All of these events have been recorded at the two rainfall sites, Mill Street, Ohakea and at the flow gauge site.

Table 2-8 Selected Calibration Events

Event	Peak Flow, m ³ /s	Event Size from Flood Frequency Analysis, ARI
October 1974	19.6	< 2yr
August 1975	16.2	<2yr
June 1976	42.3	10-15yr

As described in Section 2.3.2 a synthesised hourly record at Mill Street was used to provide rainfall input for the calibration events.

The main calibration hydrological calibration parameter used was the infiltration rates. This figure was initially set to 2mm/hr but was reduced to 0.5mm/hr through an iterative process to achieve the overall best calibration possible for the three events.

The hydrological model calibration results are shown in Figure 2-3, Figure 2-4 and Figure 2-5. The results indicate a reasonable correlation to flow peak and volume in 1974 and 1975, but with a significant phase lag of between 10-17 hours. In addition the volume for the 1976 event is oversimulated.

The correlation coefficient, which is a measure of the degree of intensity of association between the data and model, is very low for all three calibration events. Peak discharges for the 1974 and 1975 events are within 9% of the recorded value. But for the 1976 event the model overestimates the peak flow by 57%. Discharge volumes are under predicted by 17% for the 1975 event and over predicted by 35% and 97% for the 1974 and 1976 events respectively. The very poor calibration is mainly due to the need to use a synthesised rainfall record for the catchment, and a lack on information on rainfall variability across the catchment.

As can be seen Figure 2-3, Figure 2-4 and Figure 2-5 the data versus the modelled flows tend to lag by 10-17 hours. This may be due to a different timing of the storm over the catchment compared to the Ohakea gauge which is used to synthesise the rainfall temporal pattern, or more likely an error in the timing of the Ohakea and/or Hammond



Street gauges themselves. In the latter case, time shifting the observed data would significantly improve the correlation coefficient.

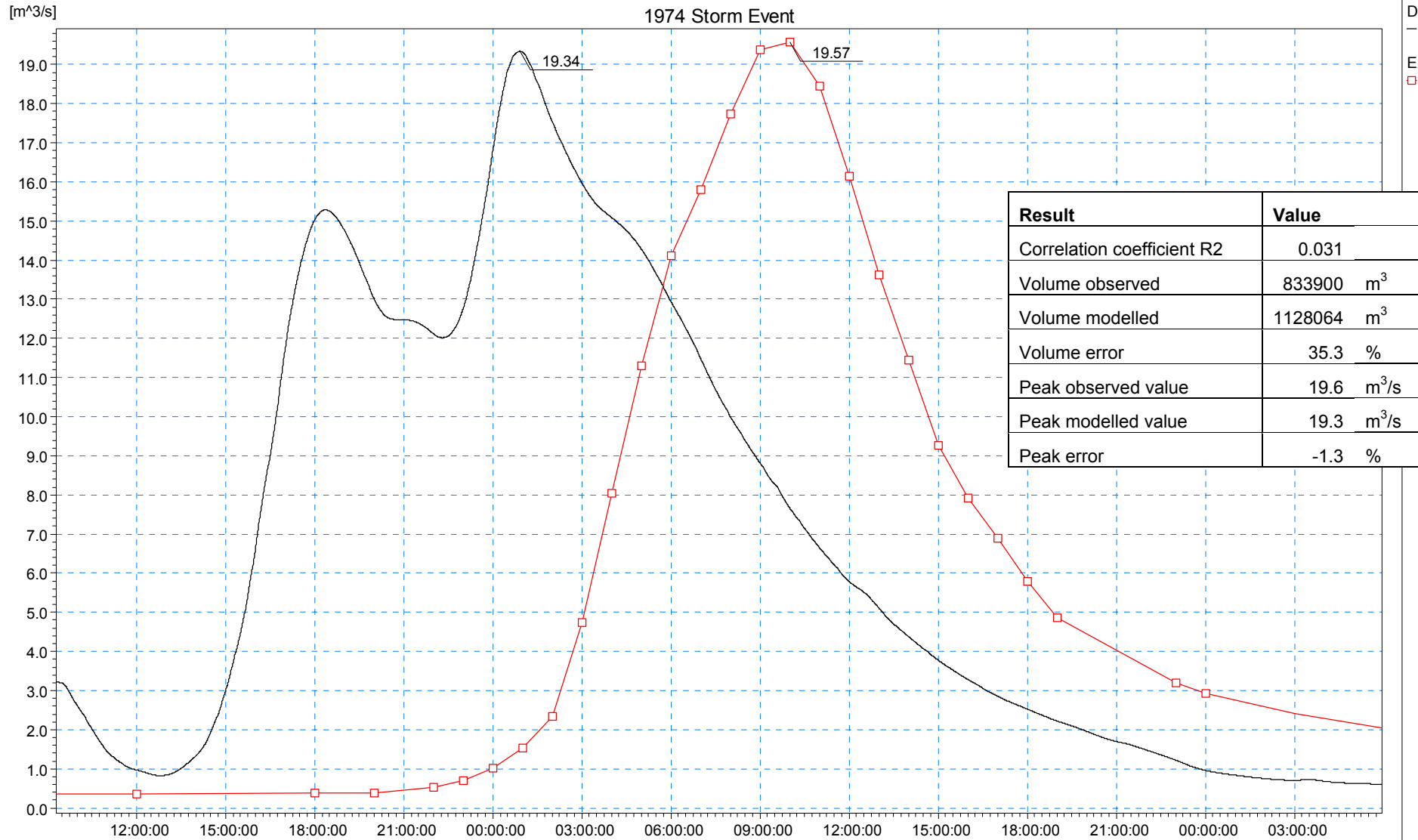


Figure 2-3 1974 Event – Calibration

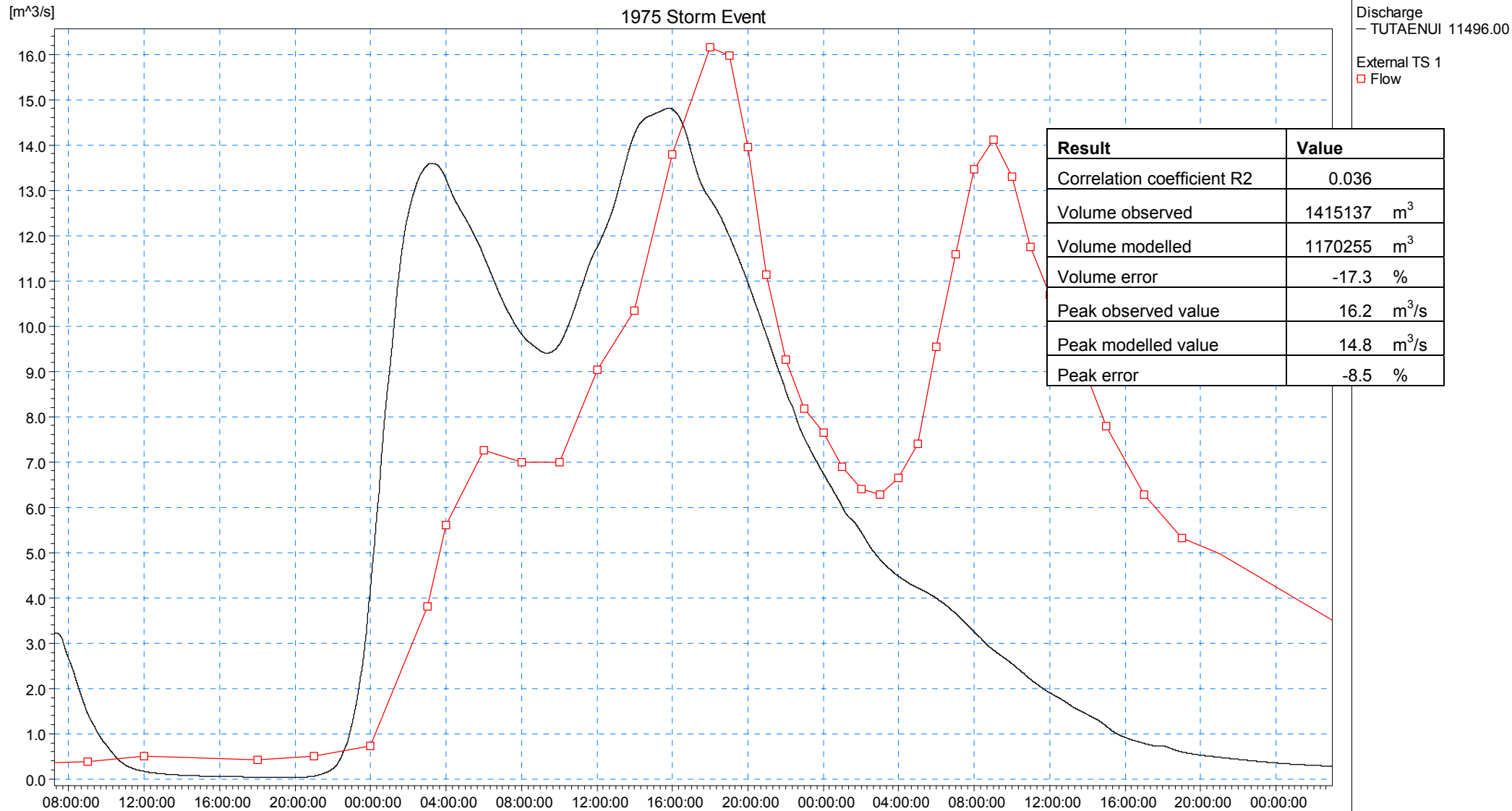


Figure 2-4 1975 Event - Calibration

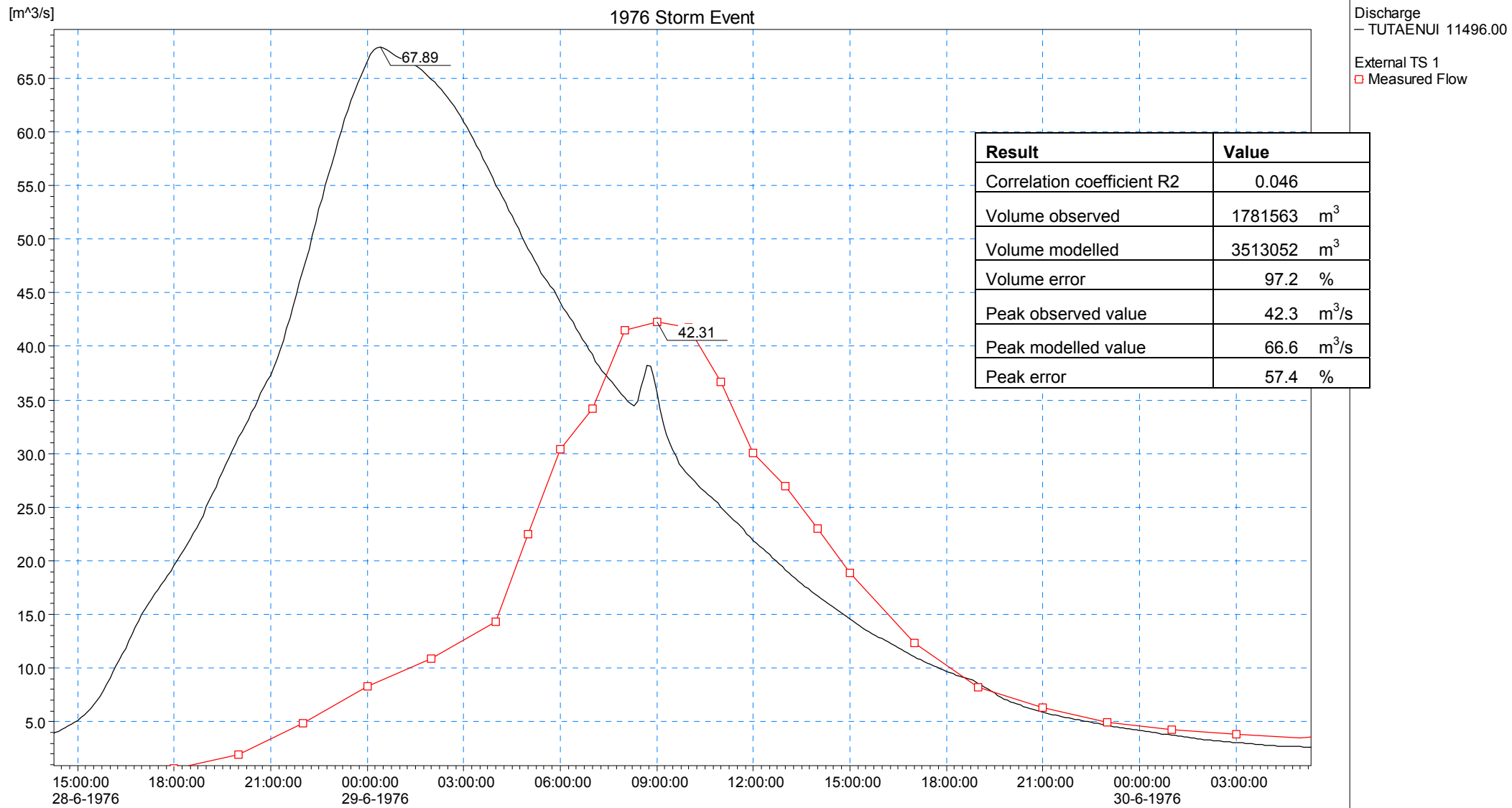


Figure 2-5 1976 Event - Calibration



2.6 Design Event Generation

2.6.1 Catchment Design Rainfall

The HIRDS data at Marton has been used and treated as being representative of rainfall across the catchment. The variation of rainfall between Marton and the top of the catchment based on the analysis in Section 2.4.1 was shown to be small, so HIRDS data at Marton has been used for design storm purposes. A Chicago type nested design storm approach has been used for this study. It has been assumed that the critical storm duration for the Tutaenui catchment will be less than 24 hours. The Chicago nested storm approach produces a symmetrical storm that covers all critical storm durations up to, in this case, 24 hours. Rainfall depths for the 100 year and 200 year ARI design storm events have been synthesised from the HIRDS rainfall depths and design storms produced. These are shown in Figure 2-6 and Figure 2-7.

2.6.2 Validation against Flood Frequency Analysis

The 100 year and 200 year ARI rainfall events were used as input to the calibrated rainfall runoff model, and routed to the Hammond Street gauge using the MIKE 11 routing model. The 100 year ARI rainfall was found to produce a discharge at the gauge of $86.9\text{m}^3/\text{s}$. This compares to the site based estimate of $59\text{-}76\text{ m}^3/\text{s}$, and lies within the confidence limits of the gauged based flood frequency analysis ($55\text{-}106\text{ m}^3/\text{s}$) where post TCCS events (i.e. post 1976) events have been ignored.

The 200 year flow at Hammond Street is simulated as $112.8\text{m}^3/\text{s}$, compared to the site based estimates of $65\text{-}85\text{m}^3/\text{s}$. This also lies within the confidence limits of the pre-TCCS gauge analysis ($61\text{-}119\text{m}^3/\text{s}$).

Given the uncertainty of both the gauge based analysis and the design rainfall, it is felt the rainfall-runoff based flood peak provides a reasonable, if slightly conservative estimate of the 100 and 200 year flood flows at Hammond Street

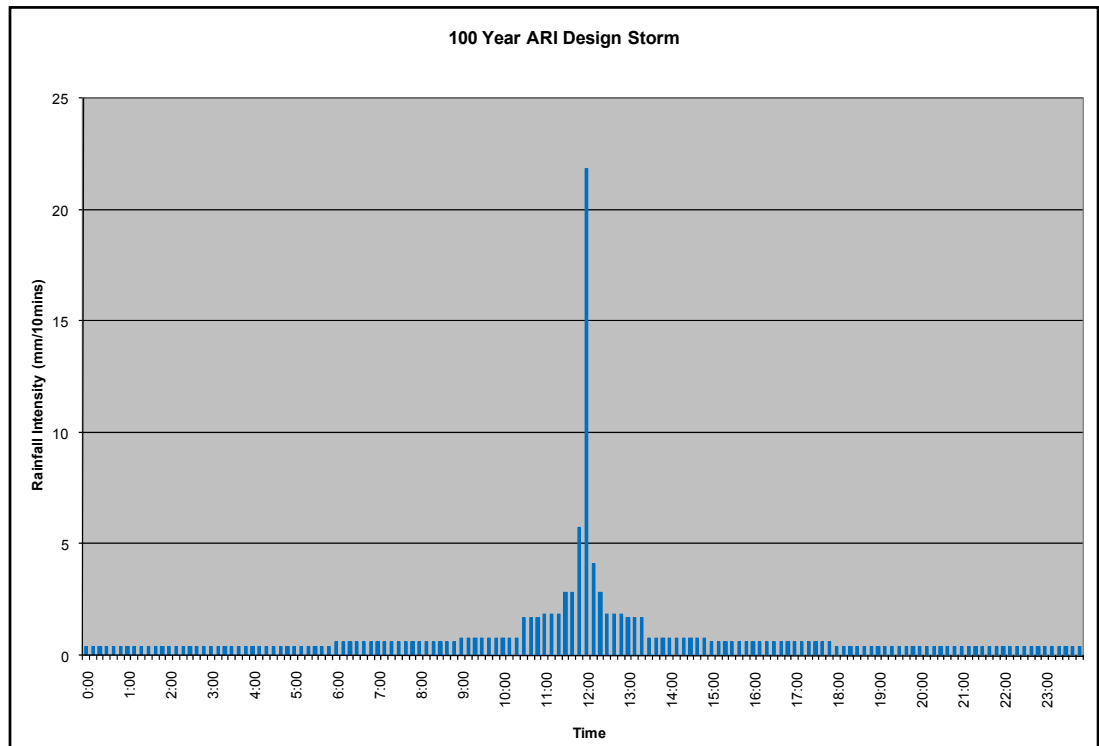


Figure 2-6 100 year ARI design storm

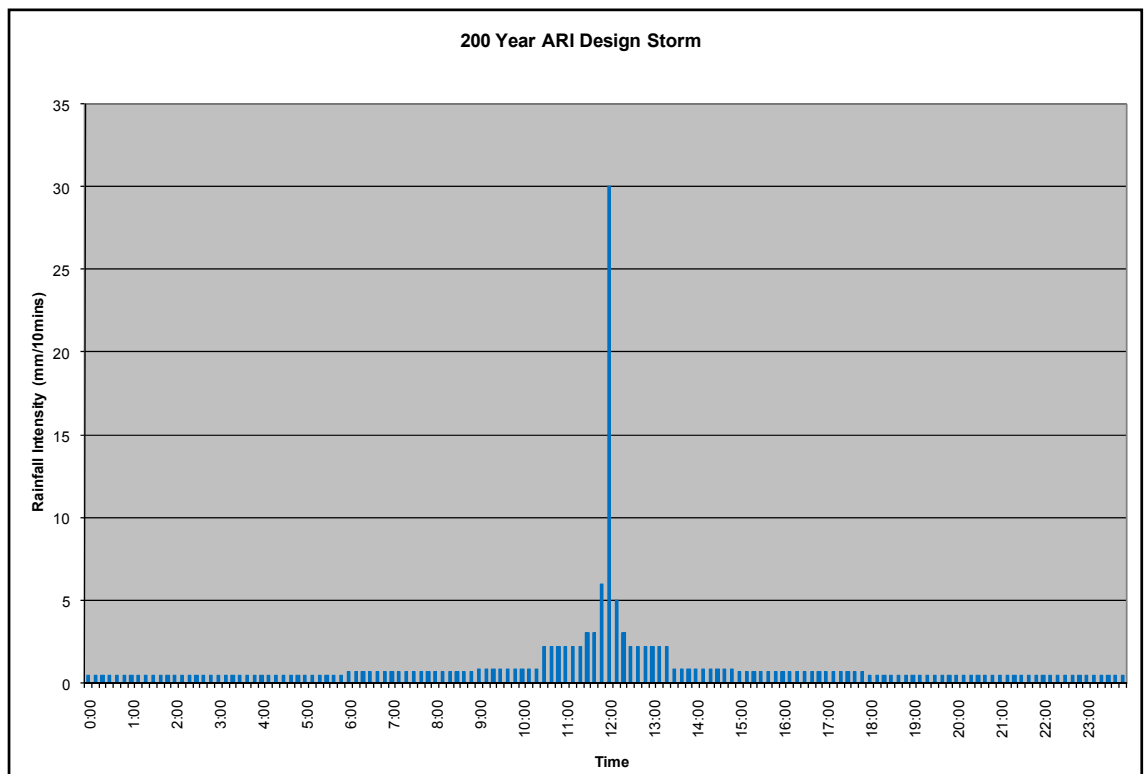


Figure 2-7 200 year ARI design storm



3 HYDRAULIC MODEL DEVELOPMENT AND VALIDATION

3.1 Model Description

The hydraulic model comprises separate 1D and 2D models, dynamically linked to enable full exchange of flows between the two model domains. The modelling software used was MIKE 11 for the 1D component and MIKE 21 for the 2D component. The coupling between the two models is provided via MIKE FLOOD (MF), (DHI, 2008). The model extents are shown in Drawing 3.

3.2 Data availability

3.2.1 Land Level Data

Land level information was provided by HRC consisting of LiDAR data which was flown in 2006. The extent of the LiDAR can be seen in Drawings 2 and 3. HRC provided DHI with a “bare earth” version of the data which has had buildings and trees removed. HRC also supplied 20m LINZ contour data to be used for the area north of the LiDAR extent to the top of the catchment.

3.2.2 GIS Data

Road, railway and stream data was supplied by HRC, along with land use mapping and flood detention dam locations. Colour aerial photography of the catchment area was also supplied.

3.2.3 Cross Sections and Topography

MIKE 11 model cross sections have been extracted from the LiDAR 1m grid at various intervals with an average spacing of 130 metres. A total of 242 cross sections have been extracted using MIKE 11 GIS. A typical cross section is shown in Figure 3-1. The resolution of the LiDAR data is sufficient to describe the main properties of the cross section. The cross sections were processed to delineate the extent used in the MIKE 11 calculations to avoid duplication of conveyance and storage within the MIKE 21 extent. This is shown in the figure by the vertical red lines, which demarcate the extents of the MIKE 11 cross section used in the hydraulic calculations.

HRC have provided river cross sections of the upper catchment in electronic format from a survey carried out in 2007. These 27 cross sections were surveyed in the Tutae-nui Stream between the upper extent of the LiDAR data and the Marton Water Supply Dam C. See Drawing 5 & 6 for the cross section locations. Further cross sections have been interpolated in MIKE11 where needed for modelling purposes.

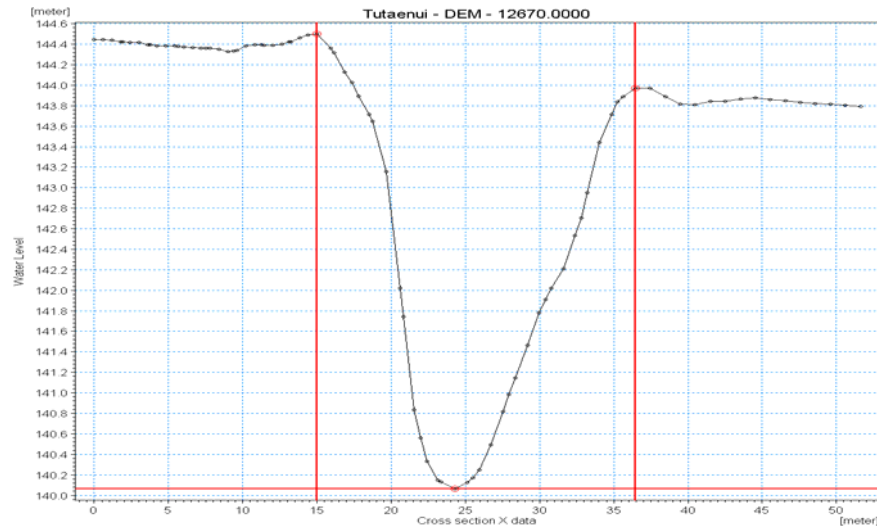


Figure 3-1 Cross section Tutaenui 12670 extracted from LiDAR

3.2.4 Structures

A number of key bridges were surveyed by HRC as listed in Table 3-1.

Table 3-1 HRC Surveyed Structures

Structure Name	Structure Type	Location	
Arahina (Pvte)	Bridge	2712981	6122346
Beaven (Pvte)	Bridge	2713002	6122982
Calico Line	Bridge	2713163	6124190
Hammond Foot	Bridge	2713166	6123686
Hawkestone Road	Bridge	2713315	6120931
Hereford Road	Bridge	2713129	6123384
Kensington Road	Bridge	2712998	6121963
Lower High (Pvte)	Bridge	2713086	6123535
Makirikiri Road	Bridge	2713386	6120039
Railway Bridge	Bridge	2712997	6122396
SH3 Main Culvert	Culvert	2712820	6113233
SH3 Overflow	Culvert	2712843	6113152
Station Road	Bridge	2712932	6122602
Supertex Pvte	Bridge	2712924	6122853

The survey data included cross sections, deck and soffit levels, pier locations and levels and abutment locations and levels. Other less critical structures were measured approximately by inspection as listed in Table 3-2. See Drawings 5 & 6 for structure locations.



Table 3-2 DHI/HRC Surveyed Structures

Structure Name	Structure Type	No.	Height (m)	Width (m)	Diameter (m)	Estimated by DHI, *	Surveyed by
Tutaenui Road/Galpins Rad	Culvert	1	3.4	3.2	-	-	DHI
Jeffersons Line	Culvert	1	2.2	2.2	-	-	DHI
Somersal Lane	Bridge	1	3.26	12.5	-	-	DHI
Curls Bridge	Bridge	1	4.1	15	-	-	DHI
Hanratty at Trickers Rd	Culvert	1	-	-	1	-	DHI
Hanratty Bypass	Culvert	1	-	-	0.6	-	DHI
Trickers Rd	Bridge	1	3.5	21.6	-	-	DHI
Brandon Hall Rd	Bridge	1	4.4	37.6	-	-	DHI
Folly Stream at Marumaru St	Culvert	1	1.7	4.1	-	-	HRC
Folly Stream at Station Rd	Culvert	1	1.7	3.12	-	-	HRC
Folly Stream at Kensington Rd	Culvert	1	1.8	1.15	-	*	DHI
Folly Stream at Canteen St	Culvert	1	2	3.2	-	-	DHI
Painui Stream at Purakau St	Culvert	1	1	1.5	-	-	HRC
Painui Stream at French St	Culvert	1	1	1.5	-	*	DHI
Painui Stream at Matai Street	Culvert	1	0.9	1.65	-	-	HRC
Painui Stream under access Rd	Culvert	2	-	-	0.75	-	HRC
Painui Stream at Railway Line (East)	Culvert	1	-	-	1.55	-	HRC
Painui Stream at Railway Land (a)	Culvert	2	-	-	0.65	-	HRC
		1	-	-	1.2	-	
Painui Stream at Railway Land (b)	Culvert	2	-	-	0.8	-	HRC
Painui Stream at Railway Land (c)	Culvert	2	-	-	0.8	-	HRC
Painui Stream at King St	Culvert	1	1.2	1.96	-	-	HRC
Painui Stream at Railway Line (West)	Culvert	1	0.96	2.72	-	-	HRC
Painui Stream at Kensington Rd	Culvert	1	1.25	1.95	-	-	HRC
Painui Stream at Alexandra St	Culvert	1	1.25	2.4	-	*	DHI
Marton West Stream at Hendersons Line	Culvert	1	-	-	1	-	DHI
Marton West Stream at Mill Stream	Culvert	1	1	2	-	-	DHI
Unnamed Channel near Painui Stream at French St	Culvert	1	1	1	-	*	DHI
Unnamed Channel near Painui Stream at Railway East	Culvert	1	-	-	1.24	-	HRC
Unnamed Channel near Painui Stream at Railway West	Culvert	1	0.96	2.72	-	*	DHI

The DHI survey obtained the widths and depths/diameters for culverts and bridge openings and deck thicknesses. Some structures that were not surveyed have been estimated based on the size of the structures upstream and downstream. Using LiDAR data the soffit and invert levels of each structure have been estimated. Where LiDAR was not available cross sections have been interpolated in MIKE 11 at the structures and relative levels calculated with respect to channel inverts. All of the structures listed in Table 3-1 and Table 3-2 have been included in the MIKE 11 model.

A photographic record of each structure was also taken by DHI, and these have been archived for future use by HRC if required. Some examples are shown in Figure 3-2 below.



Figure 3-2 From Top Left clockwise: Tutaenui at Somersal Lane; Tutaenui at Curls Bridge; Tutaenui at Trickers Road; Tutaenui at Brandon Hall Road.

3.2.5 Detention Dams

There are a total of 18 detention dams in the catchment. Three dams were constructed in 1962-1965 and the remaining fifteen over the period from 1976-1985. Hard copy construction plans were provided by HRC, along with stage/storage curves of all detention dams in electronic form.

3.2.6 Water Supply Dams

Design drawings for the Marton Water Supply Dams were supplied from the District Council via HRC. Two dams, known as Dam B and Dam C are connected via a spillway (an earlier culvert connection has been decommissioned). HRC provided stage-area data for the lower and larger Dam C, along with dam spillway details. The stage-area data for the upper Dam B has been estimated by DHI, based on measured dam surface area and assuming vertical reservoir walls.

3.2.7 Flood Levels and Extents

HRC has supplied a hard copy flood map of the February 2004 event, which was recorded on the ground by a staff member. DHI have also been provided with a number of photographs of the 2004 event. Figure 3-3 shows a sample of these photographs.

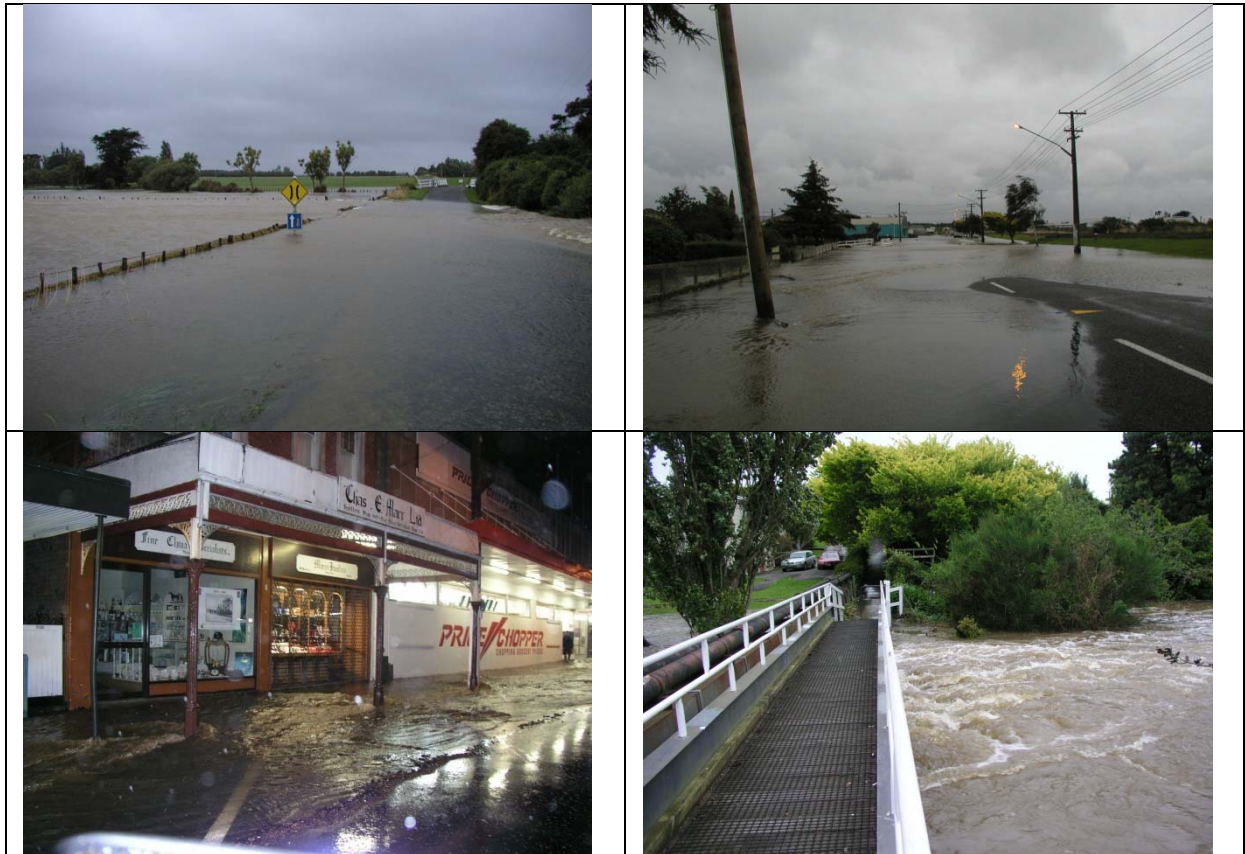


Figure 3-3 February 2004 Flood Event (Source: HRC)

3.3 Model Extent and Development

3.3.1 Model Extent

The MIKE FLOOD hydraulic model developed for the Tutaenui catchment comprises a 1D MIKE 11 model of the Tutaenui Stream extending from the water supply dams to the confluence with the Rangitikei River, coupled to a 2D MIKE 21 model of the floodplain where LiDAR data exists. A number of other tributaries and important channels have been included in the MIKE 11 model where these have been identified as key flood channels or are known to have a history of flooding. These include Folly Stream, Painui Stream, Marton West Stream, Marton West Diversion, Lower Tutaenui overflow channel and Hanratty Drain.

All channels downstream of the flood detention dams have been included in the combined MIKE FLOOD model. Where LiDAR was available actual cross section have been generated and a generic section has been used in other areas. Detention dams have been included in the MIKE 11 model as short branches incorporating a weir structure and small diameter culvert outfall, and connecting to either a MIKE 11 branch of the downstream channel or to the 2D model of the floodplain. The dam storages have been incorporated in the MIKE 11 branch (link channel) representing the dam structure.

The MIKE 21 model makes use of both a 10m and 5m grid using the new MIKE 21 Multi-cell Overland Solver feature. This feature solves the modified shallow water equations on the coarse grid taking the variation of bathymetry within each fine grid cell into account. Results are presented on the fine scale grid. The benefit of using the



multi-cell solver is that it can present results on a 5m grid while retaining the stability of the 10m grid model, allowing for faster run times. The MIKE 21 domain is 16,260 x 6,210m in size making a total of 1 million grid points in the 10m grid and 4 million points in the 5m grid. Approximately 60% of the grid is represented by land points.

3.3.2 1D MIKE 11 Model

Inflows to the MIKE 11 model are derived from the calibrated rainfall-runoff model. Inflow points are located from topographical considerations and taking into account the locations of the detention dams and water supply dams. Where the location of the catchment inflow is clearly defined (eg via a small stream or drain), these are applied at the identified point. Where the inflows are more diffuse, catchment inflows are linearly distributed along the appropriate MIKE 11 branch. Two catchment inflows are defined outside the MIKE 11 model area and these are applied as source points in the MIKE 21 model.

A constant Manning's "n" of 0.033 has been applied throughout the MIKE 11 model for the in-channel areas. Floodplain areas that are upstream of the LiDAR extent have been assigned a roughness value of 1.5 times the in-channel value.

It has been assumed that all detention dams are empty at the beginning of all events simulated. The water supply dam has been modelled for two scenarios, full and 2 metres below full.

The downstream boundary of the MIKE 11 model is the Rangitikei River water level. A water level boundary of 30.7m has been applied for all model runs.

3.3.3 2D MIKE 21 Model

Topography and Features

LiDAR data was provided by HRC in digital point *.las* format. The bare earth data in this dataset was used to create a 1m resolution grid using ArcGIS. This 1m grid was converted to 10 and 5m grids for input to the MIKE 21 model. Important features such as road and stopbank levels were taken from the 1m grid and burned into these coarser model grids.

Boundaries

The downstream water level boundary is situated where the Tutaenui Stream joins the Rangitikei River. This boundary was set to a constant water level of 30.7m. This level is 1 metre above the water surface level recorded at the time of the LiDAR being flown. All inflows to the MIKE 21 model originate from the MIKE 11 model via the MIKE Flood lateral and standard links.

Hydraulic Resistance

A 2D hydraulic resistance map has been derived from the land use GIS layer supplied by HRC. Land use types were mapped to various hydraulic resistances (Manning numbers) based on experience and accepted use in the industry. The adopted mapping is shown in Table 3-3. The mid to lower portion of the floodplain is covered in grassland and therefore is assigned a Manning's n value of 0.05. The upper reaches of the MIKE 21 model includes the Marton Township; this is classed as "Built-up Area" and is assigned a value of 0.1. A map of the resistance used is shown in Figure 3-4.



Table 3-3 Adopted hydraulic resistance based on land use types

Description (LCDB2)	code	n	M
High_Producing_Exotic_Grassland	40	0.05	20
Pine_Forest-Closed_Canopy	66	0.125	8
Manuka_and_or_Kanuka	52	0.125	8
Pine_Forest-Open_Canopy	65	0.125	8
Indigenous_Forest	69	0.125	8
Orchard_and_Other_Perennial_Crops	32	0.125	8
Built-up_Area	1	0.1	10
Short-rotation_Cropland	30	0.05	20
Vineyard	31	0.125	8
Broadleaved_Indigenous_Hardwoods	54	0.125	8
Other_Exotic_Forest	67	0.125	8
Urban_Parkland/Open_Space	2	0.033	30
River	21	0.02	50
River_and_Lakeshore_Gravel_and_Rock	11	0.02	50
Gorse_and_or_Broom	51	0.125	8
Afforestation_(imaged_post_LCDB_1)	63	0.125	8
Deciduous_Hardwoods	68	0.125	8
Lake_and_Pond	20	0.02	50
Major_Shelterbelts	61	0.125	8
Surface_Mine	3	0.05	20
Transport_Infrastructure	5	0.1	10
Afforestation_(not_imaged)	62	0.125	8
Low_Producing_Grassland	41	0.05	20
Mixed_Exotic_Shrubland	56	0.05	20
Forest_Harvested	64	0.125	8
Flaxland	47	0.05	20
Fresh_water_Vegetation	41	0.1	10
Saline_Vegetation	45	0.1	10
Mangroves	70	0.1	10

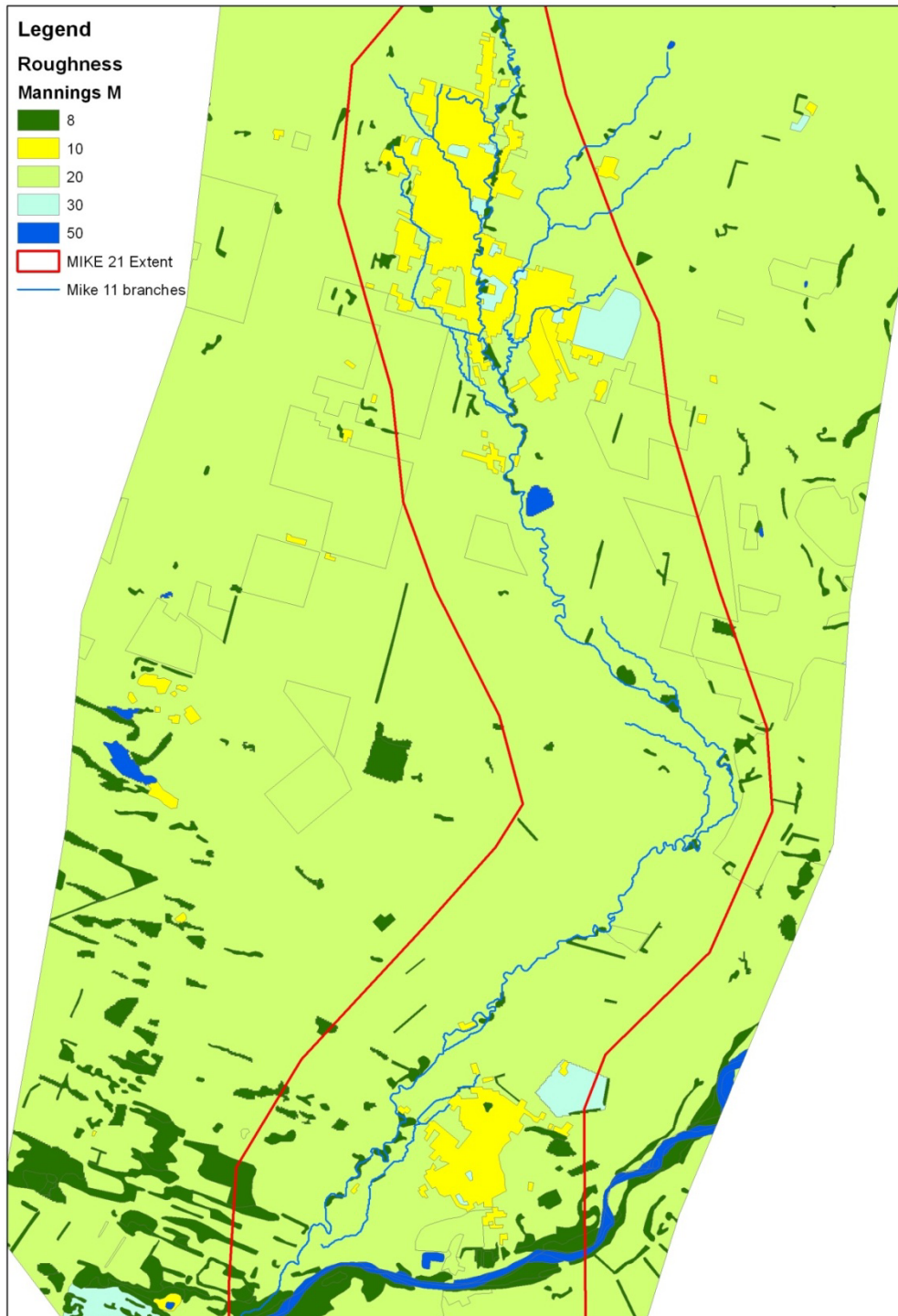


Figure 3-4 Hydraulic roughness map ($M = 1/n$)

3.4 MIKE Flood Model Build

3.4.1 Linkages

There are 87 Lateral links in the MIKE FLOOD model joining the MIKE 11 branches to the MIKE 21 domain. Centreline links were applied to all of the MIKE 11 branches,



where the bank spill level is taken from the ground level interpolated between the two bank levels. The exception is where stop banks are present where the Tutaenui Stream crosses State Highway 3. In this area separate links were applied at either side of the stopbanks.

In order to avoid duplication of the stream conveyance it is necessary to fill in the area of the river between the two levee banks in the 2D model. This has been done along the entire MIKE 11 channel reach. When the water in the MIKE 11 cross section reaches the level of the MIKE 21 linked cell, the water will start to spill onto the flood plain, see Figure 3-5.

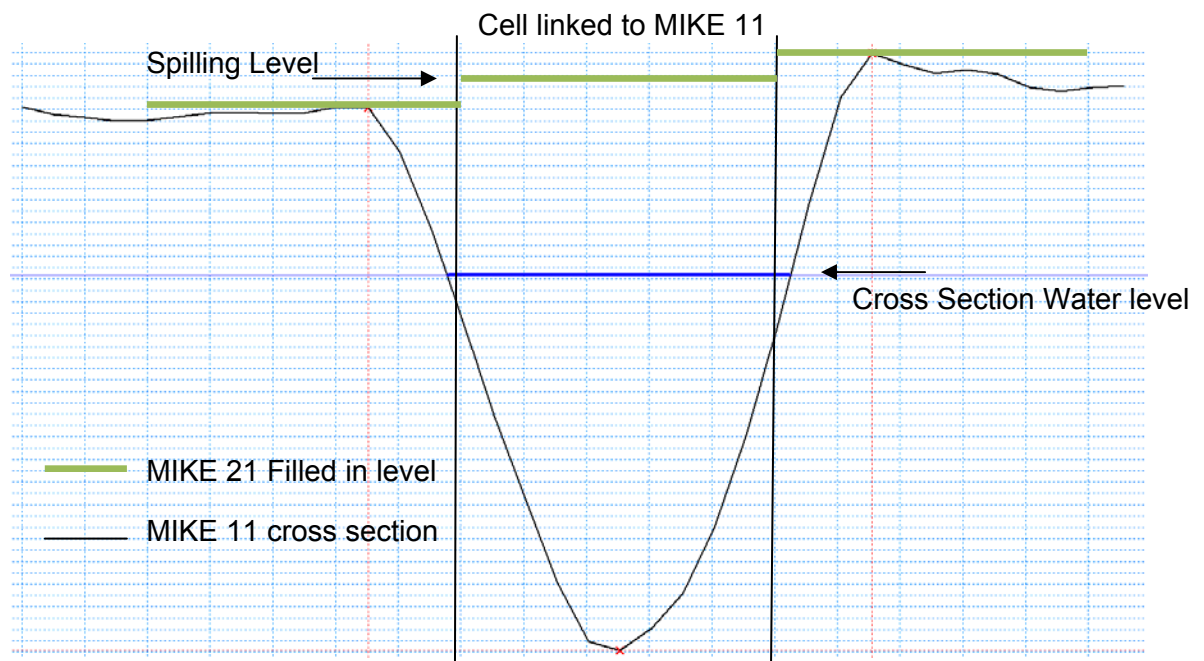


Figure 3-5 Coupling Schematic

Standard links were used to link two of the dams to the MIKE 21 model; these were the W2 and W4 dams, see Drawing 5. As there was no significant channel leading from either of these dams it was decided to route the outflow from these dams via the MIKE 21 model.

3.4.2 Model simulations

The coupled models run with a 1 second time-step. The MIKE 21 results are saved every 20 minutes and the MIKE 11 results are saved every 5 minutes. The model simulations take approximately 48 hours to run on an HPxw4400 workstation, with Dual Core 2.4GHz processor and 2GB ram.

3.5 MIKE Flood Model Validation

3.5.1 Validation

The MIKE FLOOD model was validated against the February 2004 event which was mapped by HRC staff around Marton and Bulls. This event is the largest on record and is the largest to have occurred during the last 40 years.



As previously mentioned there are no recording rainfall gauge sites located within the Tutaenui catchment that can be used to generate the necessary data for a hydrological model. It was anticipated that the nearest available gauge at Ohakea could be used as a representation of the Tutaenui catchment rainfall, but this site appears to have not been active in February 2004.

As an alternative approach, two sites that captured the 2004 event at a suitable temporal resolution have been used to synthesise an hourly record for Tutaenui Mill Street. The two sites are Valley Road and Makino at Cheltenham. The 2004 hourly rainfall depth profiles at both sites were used as a basis for a synthesised profile at Tutaenui Mill Street using the daily rainfall total recorded at this site. Because the profiles are different it was decided to run both through the hydraulic model and use the one that provides the closest match to the actual flood extent. Figure 3-6 and Figure 3-7 show the rainfall profiles used for Valley Road and Makino at Cheltenham respectively.

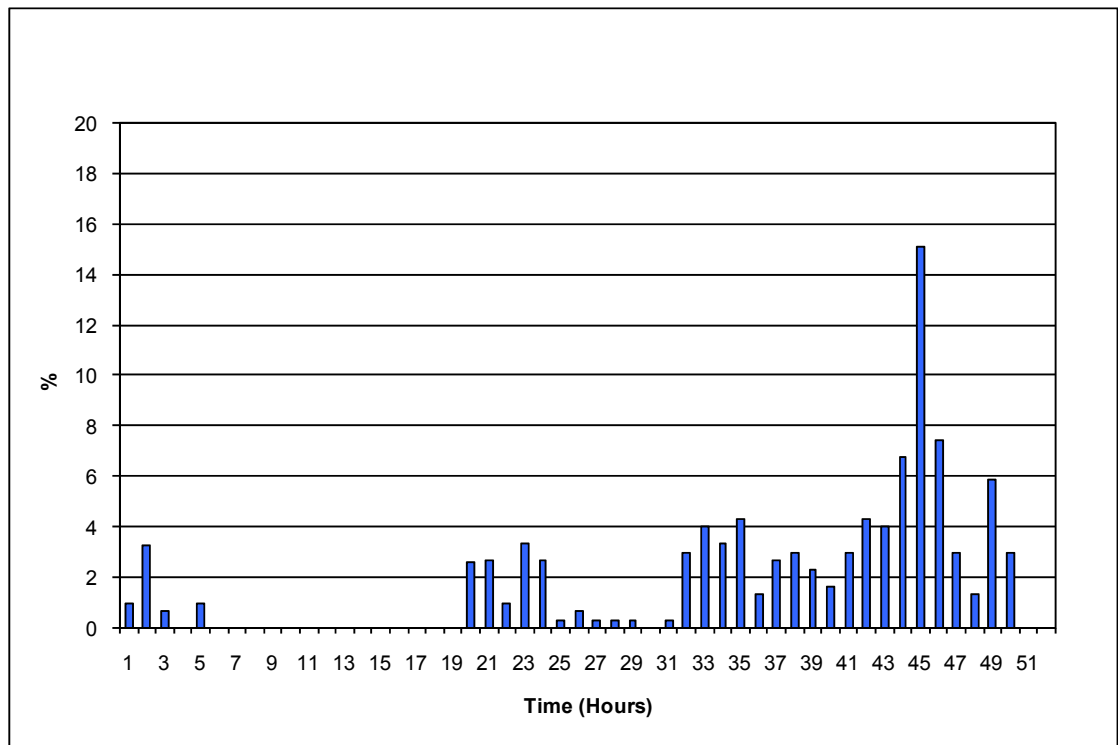


Figure 3-6 Valley Road Rainfall Profile for Feb 2004 event

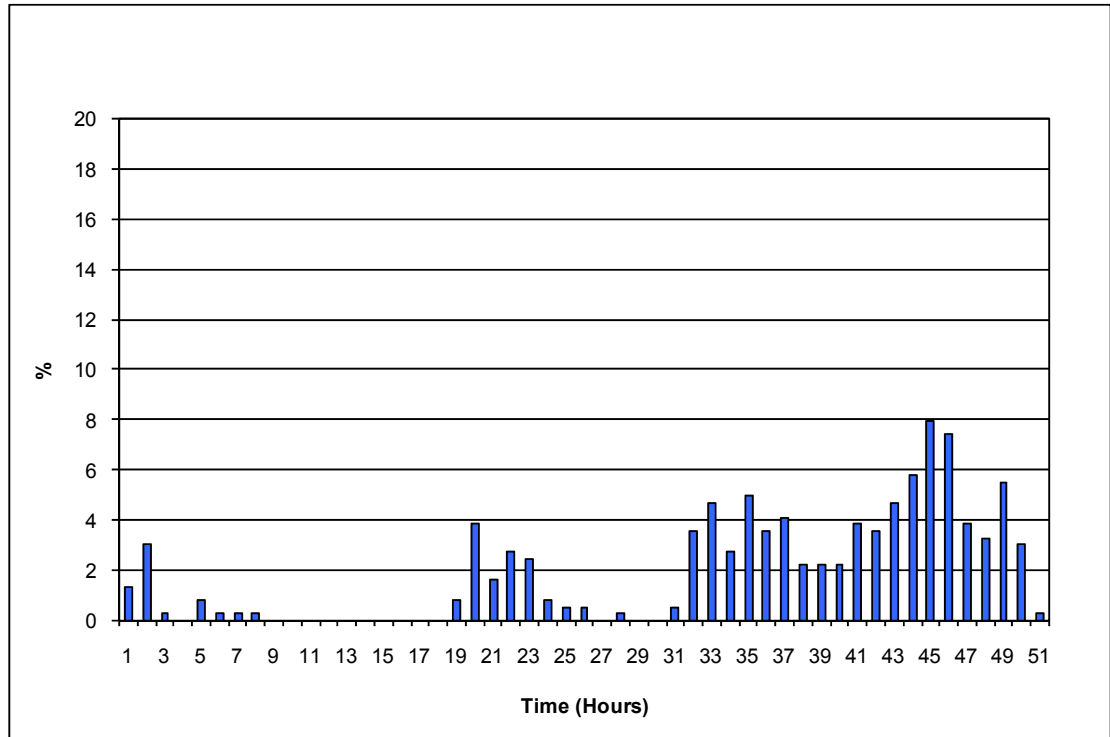


Figure 3-7 Makino at Cheltenham Rainfall Profile for Feb 2004 event

The daily rainfall at Tutaenui Mill Street was distributed according to each of the profiles at Valley Road and Makino at Cheltenham. A third profile was also generated consisting of the Valley Road profile being shortened to 18 hours, which from anecdotal evidence is probably a more realistic storm duration. The latter profile provided the best fit to the mapped extents. The simulated flood extents are shown in Drawings 7, 8 and 9. Drawing 30 shows the flood depth and extent for the 2004 event upstream of Marton in the area not covered by the LiDAR. This has been mapped from the MIKE 11 results based on surveyed cross section extents.

The simulation indicates breakouts occur from the Tutaenui, Folly Stream, Painui Stream and Marton West Stream through Marton Township. The flood extent compares reasonably well for Marton. The Bulls flood extent compares reasonably well on the west side of the town but on the east side closest to Bulls the model is not able to reproduce the observed flood extent. There may have been blockages in one of the SH3 culverts that forced the flood water east during this event, however this has not been confirmed.

Generally the model provides a satisfactory match to the observed flood extents for the February 2004 event.



4 FLOOD RISK ASSESSMENT

The MIKE FLOOD models have been used to simulate the 100 and 200 year ARI flood events. Catchment inflows have been generated from the calibrated hydrological model as described in Section 2. The models have been used to determine flood extent, depth, level, flow speed and flood hazard.

The results are shown on Drawings 10 – 29. Flood hazard has been classified according to the NSW Floodplain Development Manual (NSW DIPNR, 2005)) as shown in Figure 4-1. The MIKE 21 model results have been post-processed to compute the velocity-depth product at each grid cell and each timestep, and a maximum taken of the final result.

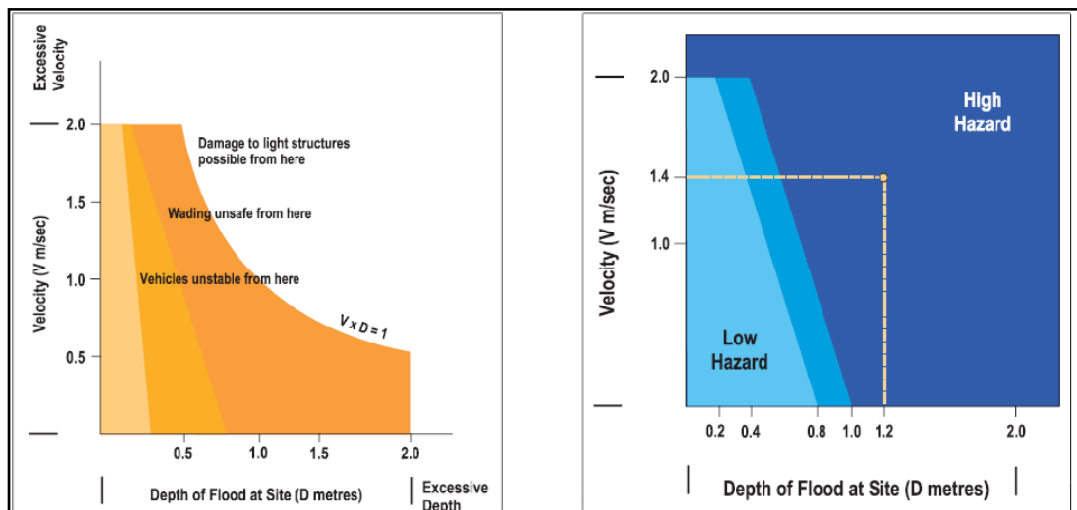


Figure 4-1 Floodplain Hazard Categories (Source: NSW Floodplain Development Manual, App. L)

The flood extents for Marton township show that there is considerable flooding for both the 100 year and 200 year ARI events. This includes some of the major tributaries that have been included in the model, namely Folly Stream, Painui Stream and Marton West Stream. The middle reaches of the Tutaenui between Marton and Bulls show considerable flooding downstream of Curles bridge. Between Marton and Curles Bridge flooding is generally confined to between the river banks. SH1 may be inundated by these events downstream of Curles Bridge. The lower section of the Tutaenui, near Bulls, shows minor flooding in the urbanised areas with extensive rural floodplain inundation.

Generally for the upper Tutaenui, around Marton, the flood hazard is low with small isolated pockets of medium to high hazard. The middle reaches between Marton and Bulls have a mostly low flood hazard with, once again, pockets of areas displaying medium or high flood hazard. The lower reach, near Bulls, has a low hazard in residential Bulls with areas of medium to high hazard in the primary floodplain areas. The medium or high hazard areas for this study occur mainly due to deep floodwater.



Drawings 28-29 show the flood depth and extent for the 100 year ARI and 200 year ARI flood events respectively upstream of Marton in the area where no LiDAR information currently exists. These extents have been generated directly from the MIKE 11 results based on the surveyed cross sections. It is evident at some of the cross section locations that the surveyed extent needs to be extended to cater for the 200 year ARI floodplain width. The reliability of the flood extents in this area is less certain compared to the areas with LiDAR coverage.

4.1 Water Supply and Detention Dam Performance

Because of the large number of detention dams in the catchment their operation is key to accessing the level of flood protection in Marton. It is interesting therefore to see how these dams, along with the Marton water supply dams (see Figure 4-4), perform during a 100 year flood event. Additional results have been extracted from the 100 year ARI flood event as detailed in Table 4-1 as well as at the water supply Dam C to analyse the scheme performance.

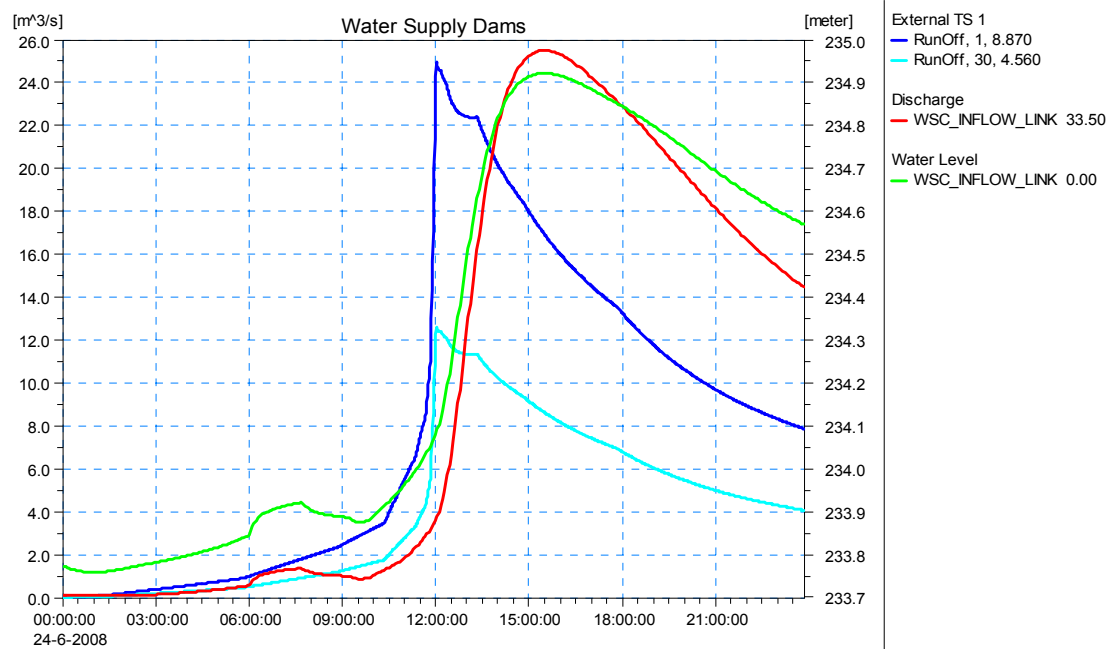


Figure 4-2 Dam C Inflows, Outflow and Water Level

The water supply dam response is seen in Figure 4-2. The dark and light blue lines represent the catchment inflows to Dams B and C respectively. The red line is the outflow from the dam C spillway, while the green line is the water level in the dam. The attenuation provided by the dam is clear, with the peak total inflow of around $36\text{m}^3/\text{s}$ reduced to about $25\text{m}^3/\text{s}$ on the outflow.

The above assumed a full dam (water level at spillway level) at the start of the simulation. The sensitivity of the simulated downstream flood levels to the assumption of full or less than full water supply dams was investigated. Two scenarios were simulated; one with the initial water level 2 metres below the spillway crest levels and a second with the water level at spillway level. It was found that while the shape of the hydrograph for the two scenarios at Hammond Street was quite different but the peak discharge remained unchanged and the flood extents of the MIKE FLOOD model were not noticeably different.



Figure 4-3 shows the inflow and outflow discharges of Dam C for the two scenarios consisting of the dam being full (at spillway crest level) and the initial water level 2 metres below the spillway crest. The red line is the direct runoff from sub catchment 30 to Dam C, with the dark green line the outflow for the dam full scenario and the dark blue line the outflow for the 2 metres below crest level scenario. When comparing the dark green line and the dark blue line the peak discharge reduces from 25.5m³/s to 20.5m³/s with an associated time delay to peak of approximately 2 hours. There is approximately 0.5m³/s reduction in peak flow for the Dam B spillway for the 2 metres below crest level scenario with no noticeable difference of the timing of the peak discharge between the two scenarios.

The total runoff inflow into Dam C is 1,042,200m³ for the 100 year ARI event which is a combination of direct runoff from sub catchment 30 and spillway discharge from Dam B. The reduction in spillway discharge volume afforded by allowing the initial water level to be 2 metres below the crest level is 257,250m³ which equates to 25% of the entire inflow for a 100 year ARI event. The model predicts an increase in water level in Marton (at Hammond Street) for the case of the lower reservoir start level. This is caused by the delay in the outflow peak which then becomes synchronous with flood peaks from the contributing catchments between the dams and Marton. This is probably an unrealistic result considering that it has been assumed that a homogenous rainfall distribution has been applied across the catchment and the all detention dams are empty at the beginning of the storm.

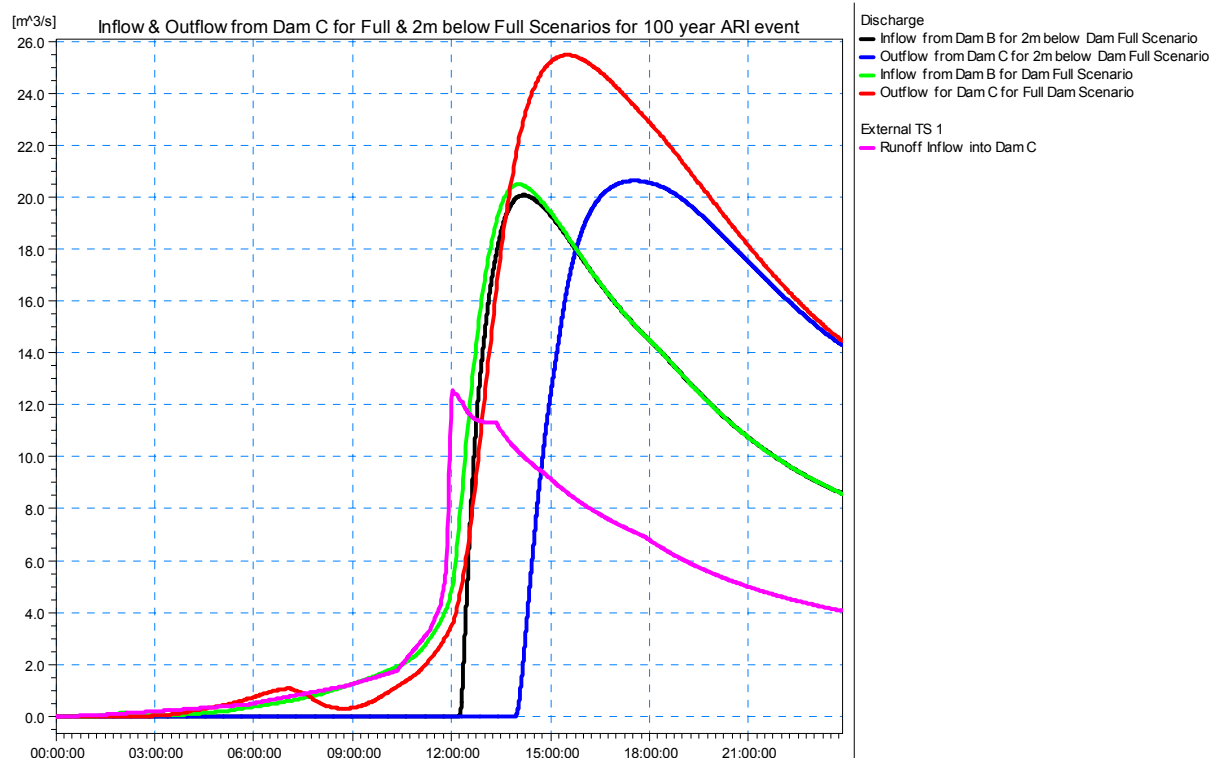


Figure 4-3 100 year ARI event scenarios- Dam Full & 2 metres below Dam Full



Figure 4-4 Water supply dam wall (left) and dam W8 outlet (right)

Figure 4-5 shows the operating regime of Dam E4 for the 100 year ARI flood event. As indicated by Table 4-1 this is the largest dam in terms of catchment area (8.27 km²), and it also provides the second largest storage volume per unit peak inflow. The dam inflow, represented by the blue line, peaks at 15.0m³/s. The outflow (red line) initially passes through the 1m diameter culvert outlet, increasing to 5.0m³/s at which time the water level inside the dam (green line) reaches the spillway crest level of 180.42m, after which the total outflow rapidly peaks at 12.0m³/s. The water level at this point gradually falls as outflows continue over the spillway and through the culvert.

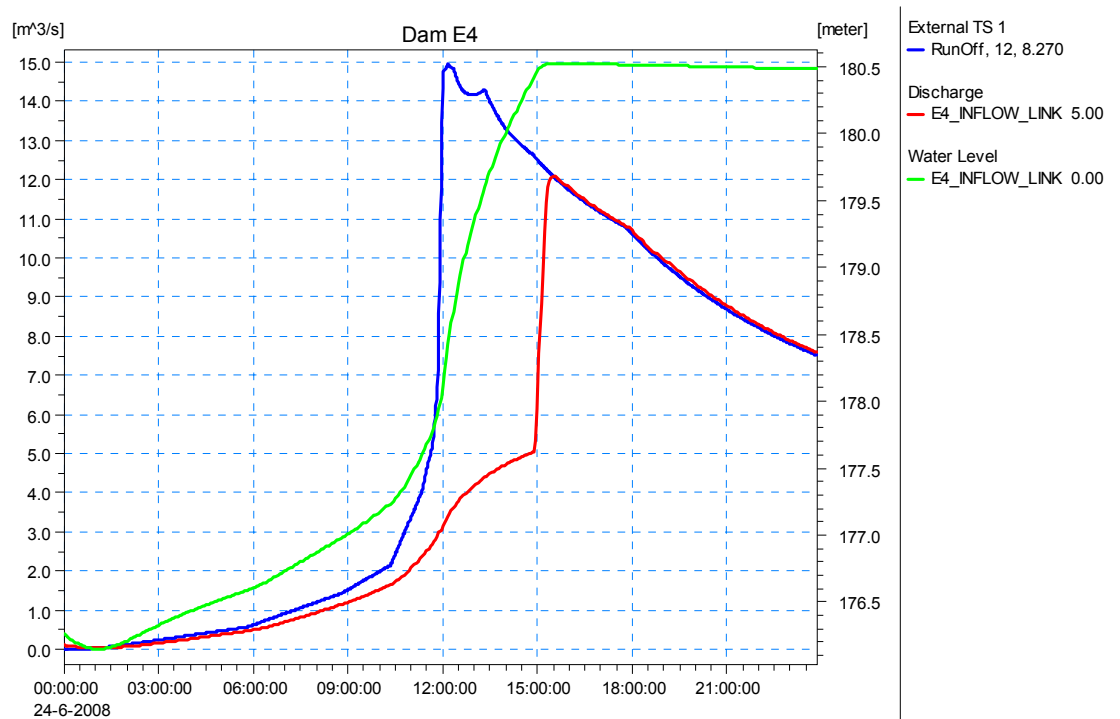


Figure 4-5 Dam E4 Inflows, Outflow and Water Level

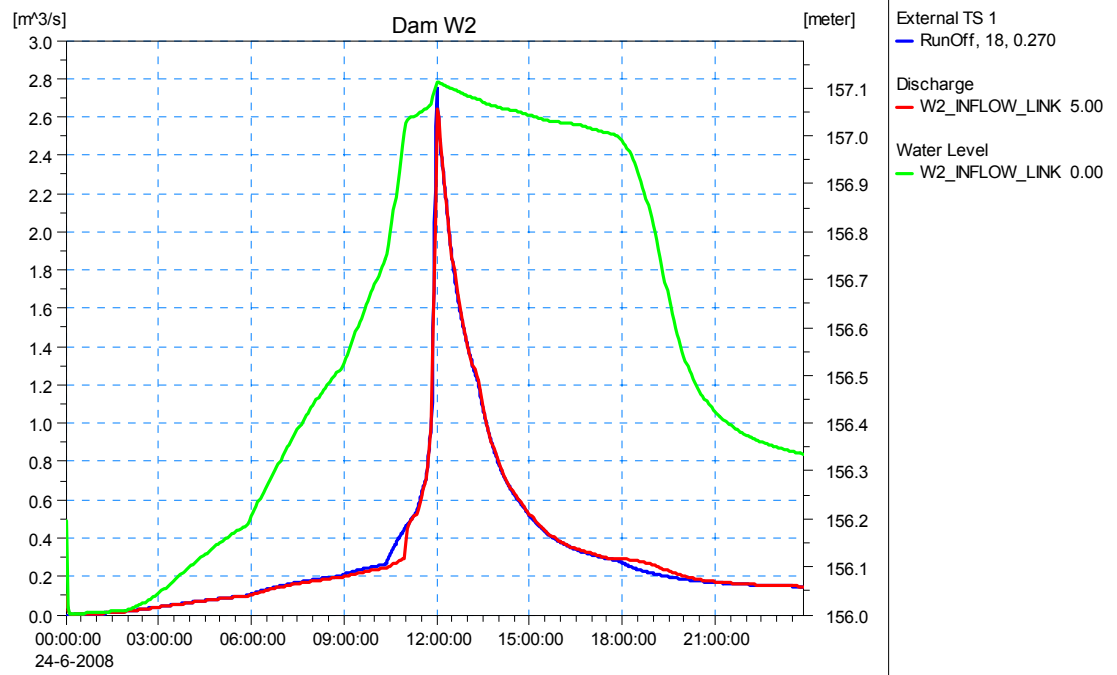


Figure 4-6 Dam W3 Inflows, Outflow and Water Level

Figure 4-6 show the operation of Dam W2 during a 100 year ARI flood event. This is the smallest dam in terms of catchment area (0.27 km^2) and the storage volume is also very small at just under 2500 m^3 . In the 100 year flood event the dam is mostly ineffectual, as the inflow (blue line) and outflow (red line) are almost identical.

Table 4-1 summarises the performance of all dams. Interesting ratios are the dam storage volume/catchment area, and storage volume/peak discharge. The former shows the volume of water (in mm depth over the catchment) that can be stored in the dam and the latter is the number of hours the dam would take to fill at the peak 100 year storm discharge. All dams, apart from W3, overflow during the 100 year event, and the reduction in peak flow varies from 0.1 to $5.4 \text{ m}^3/\text{s}$.

Using the model it would be possible to test the performance of the dams for other ARI flood events as well as assess how flooding would occur if TCCS dams did not exist.

In addition the water supply dams could be investigated further for their flood mitigation potential.



Table 4-1 Detention dam details and performance during the 100 year flood event

Name	Cat Area	Cat No.	Stor. Volume	Stor Vol/Cat Area	Crest Level	Culvert Invert			100 yr ARI						
						US	DS	Dia	Qpeak inflow	Specific Q	Stor Vol/ Qpeak	Q out-flow	Reduction	Peak WL	Above Crest
						m	m	m	m3/s	m3/s/km2	hr	m3/s	m3/s	m	m
	km2		m3	mm	m	m	m	m	m3/s	m3/s/km2	hr	m3/s	m3/s	m	m
E1_inflow_link	6.03	15	60000	10.0	110.33	104.23	104.23	0.675	12.7	2.1	1.31	11.7	1.0	110.46	0.13
E10_inflow_link	1.64	4	52000	31.7	231.03	228.00	228.00	0.85	8.6	5.3	1.67	3.2	5.4	231.06	0.03
E11_inflow_link	0.89	5	20000	22.5	234.60	232.00	232.00	0.45	6.6	7.4	0.85	4.6	2.0	234.73	0.13
E2_inflow_link	1.63	14	40000	24.5	154.30	152.00	152.00	0.45	6.0	3.7	1.85	4.6	1.4	154.41	0.11
E3_inflow_link	2.40	13	70000	29.2	173.50	171.00	171.00	0.625	7.4	3.1	2.62	4.6	2.8	173.60	0.10
E4_inflow_link	8.27	12	140000	16.9	180.42	176.00	175.50	1.04	15.0	1.8	2.60	12.1	2.9	180.52	0.10
E6_inflow_link	4.62	8	60000	13.0	198.55	196.00	196.00	0.7	11.7	2.5	1.42	10.6	1.2	198.68	0.13
E7_inflow_link	1.75	9	30000	17.1	184.99	182.00	182.00	0.525	8.0	4.5	1.05	6.5	1.5	185.11	0.12
E8_inflow_link	1.17	7	36000	30.8	198.20	194.00	194.00	0.525	5.3	4.5	1.90	2.7	2.5	198.28	0.08
E9_inflow_link	1.56	3	40000	25.6	214.95	211.00	211.00	0.4	8.9	5.7	1.25	6.6	2.3	215.09	0.14
W1_inflow_link	2.01	16	40000	19.9	96.65	94.13	94.13	0.525	7.6	3.8	1.46	6.2	1.4	96.78	0.13
W2_inflow_link	0.27	18	2467	9.1	157.00	155.80	155.80	0.375	2.7	10.2	0.25	2.6	0.1	157.11	0.11
W3_inflow_link	0.96	17	56740	59.1	165.40	160.80	160.80	0.450	4.7	4.9	3.38	1.0	3.7	165.24	-0.16
W4_inflow_link	0.31	19	12335	39.8	163.48	159.90	159.90	0.300	2.4	7.7	1.44	0.7	1.7	163.55	0.07
W5_inflow_link	1.20	11	35000	29.2	180.00	176.00	176.00	0.400	5.9	4.9	1.64	3.8	2.1	180.14	0.14
W6_inflow_link	0.93	10	25000	26.9	180.80	178.00	178.00	0.375	5.7	6.1	1.23	3.9	1.8	180.96	0.16
W7_inflow_link	1.46	6	25000	17.1	201.39	198.00	198.00	0.450	7.7	5.3	0.90	6.1	1.6	201.55	0.16
W8_inflow_link	1.10	2	28000	25.5	201.50	198.00	198.00	0.450	6.8	6.2	1.14	4.7	2.2	201.62	0.12
WSB_inflow_link	8.87	1			243.70				25.0						
WSC_inflow_link	4.56	30			233.70				12.6						



5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

A hydrological and hydraulic flood risk assessment has been conducted for the Tutaenui Stream which runs through Marton and Bulls.

The aim of the assessment was to quantify the magnitude of the 100 and 200 year ARI events based on the analysis of gauged flows, analysis of rainfall records and hydrological model predictions, and to map the resulting flood extents, depths and hazard.

The hydrological model calibration was complicated by the presence of 18 flood detention and two water supply dams, as well as a paucity of suitable rainfall data in the catchment. HRC have recently installed two new rainfall gauges in the catchment, one located at Ribby Farm and the other at Green Haven Farm, in order to address this latter issue.

A hydrological model comprising 30 sub-catchments was developed and calibrated against the only flow gauge in the catchment, at Hammond Street in Marton. The calibration was acceptable in terms of flood peaks and flow volumes but included a significant phase error. The hydrological model was used to generate 100 year and 200 year ARI design storms developed from HIRDS rainfall data, and the peak flows were verified against a flood frequency analysis at the gauge site.

The hydraulic floodplain model developed for the study area comprises a coupled 1D-2D description using MIKE FLOOD. The 1D MIKE 11 model extends from the water supply dams upstream of Marton to the Rangitikei confluence. It includes the 18 flood detention dams and two water supply dams. The 2D model domain covers the entire LiDAR data extent, which extends from just upstream of Marton to the Rangitikei confluence. The two models are fully coupled allowing flow exchanges between the 1D channel and 2D floodplain components. Rainfall-runoff inflow hydrographs are introduced into MIKE 11 model, and routed where required through the flood detention dams before entering the 1D-2D MIKE FLOOD model domain.

The MIKE FLOOD model has been successfully verified against the February 2004 flood extent. The validated model has been used to simulate the 100 and 200 year flood events and generate flood extents, depths and flood hazard.

Potentially the water supply dams can provide significant flood storage benefits. The effect of the dams on flood levels first needs to be verified for an actual future event. The verification could be undertaken using observed data from the new HRC rain gauges in the catchment, provided water level measurements are available from the dam. Once the model is verified it can be used to investigate a suitable operational policy for the dam, maximising security of the water supply at the same time as providing potential flood benefits to Marton.



5.2 Recommendations

- 1) A freeboard allowance should be applied to the results of the floodplain mapping to allow for uncertainties. The results produced are hydraulic levels obtained directly from the model where no freeboard allowance has been made. From the mapped flood extent comparisons it is recommended to apply 0.5 metre freeboard to the hydraulic levels.
- 2) The model should be recalibrated when a suitable rainfall event is captured on both the Hammond St flow gauge and either the Ribby Farm or Green Haven Farm hourly SCADA rainfall gauges.
- 3) A water level recorder should be installed in Water Supply Dam C so as to provide data for future historical storm events and their subsequent modelling and to also provide data for possible future optimisation of flood storage during a large flood event.
- 4) Additional land level survey is required upstream of Marton outside of the LiDAR extent where some cross sections do not extend across the full floodplain width for the 200 year ARI event.



6 REFERENCES

DHI Water & Environment (2008); *MIKE FLOOD Reference Manual*.

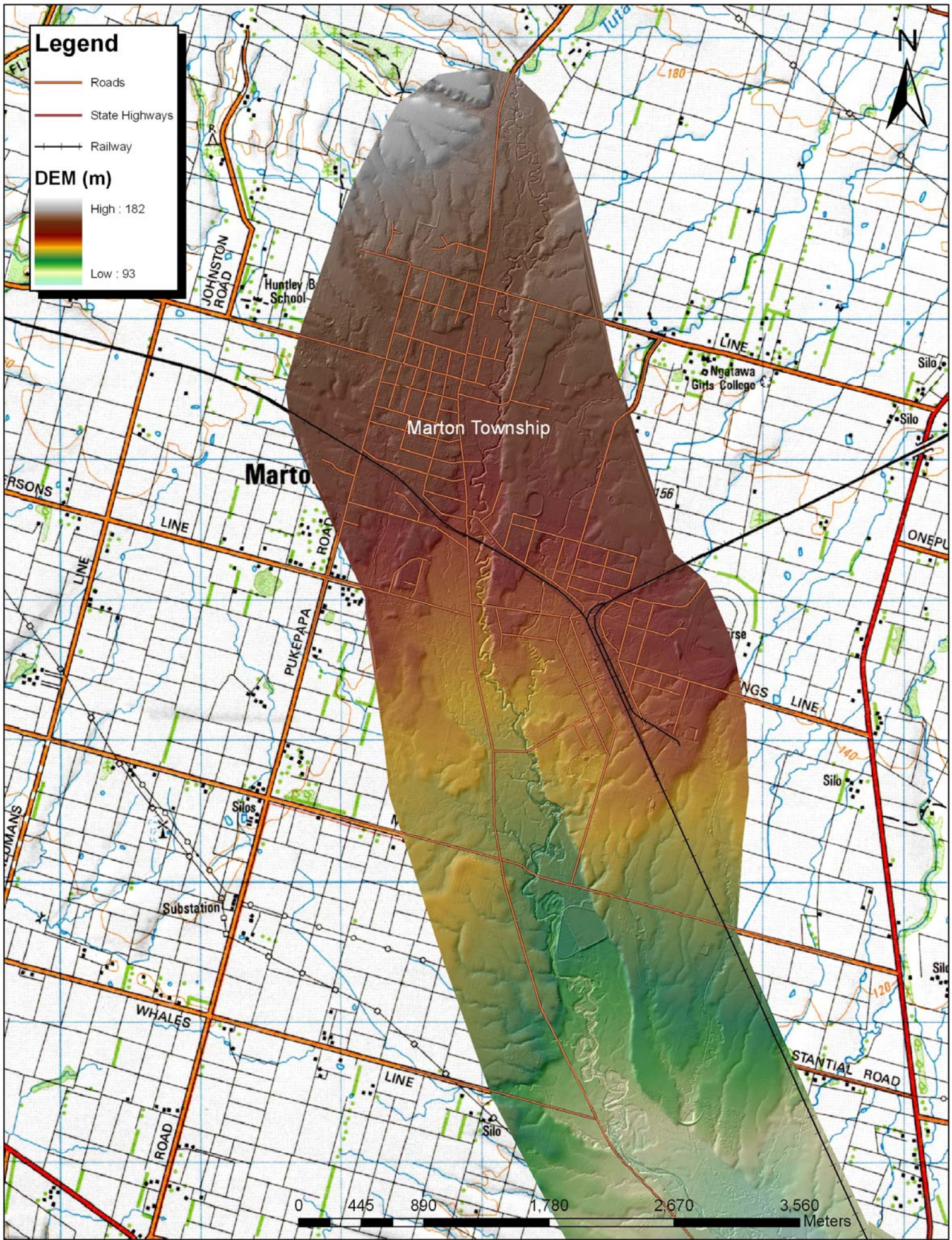
John Philpott & Associates, (2006); *The Tutaenui Scheme Review*, Report prepared for Horizons Regional Council, April 2006

Kuczera, G. (1999); *Comprehensive at-site flood frequency analysis using Monte Carlo Bayesian inference*, Water Resources Research, 35(5), 1551-1558, 1999

McKerchar, A.I. and Pearson, C.P.(1989); *Flood Frequency in New Zealand. Publ. No. 20*, Hydrology Centre, Christchurch, 1989.



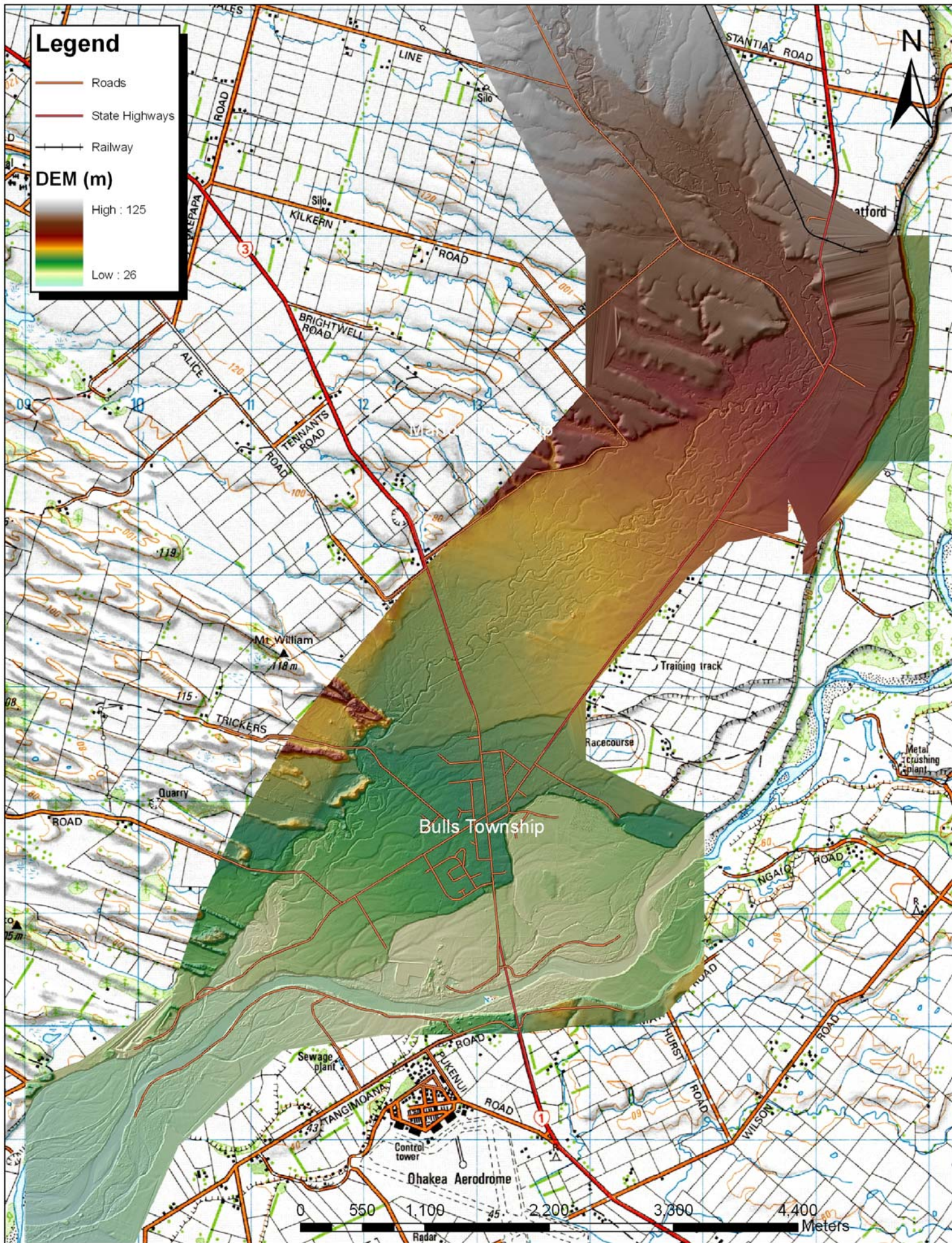
D R A W I N G S



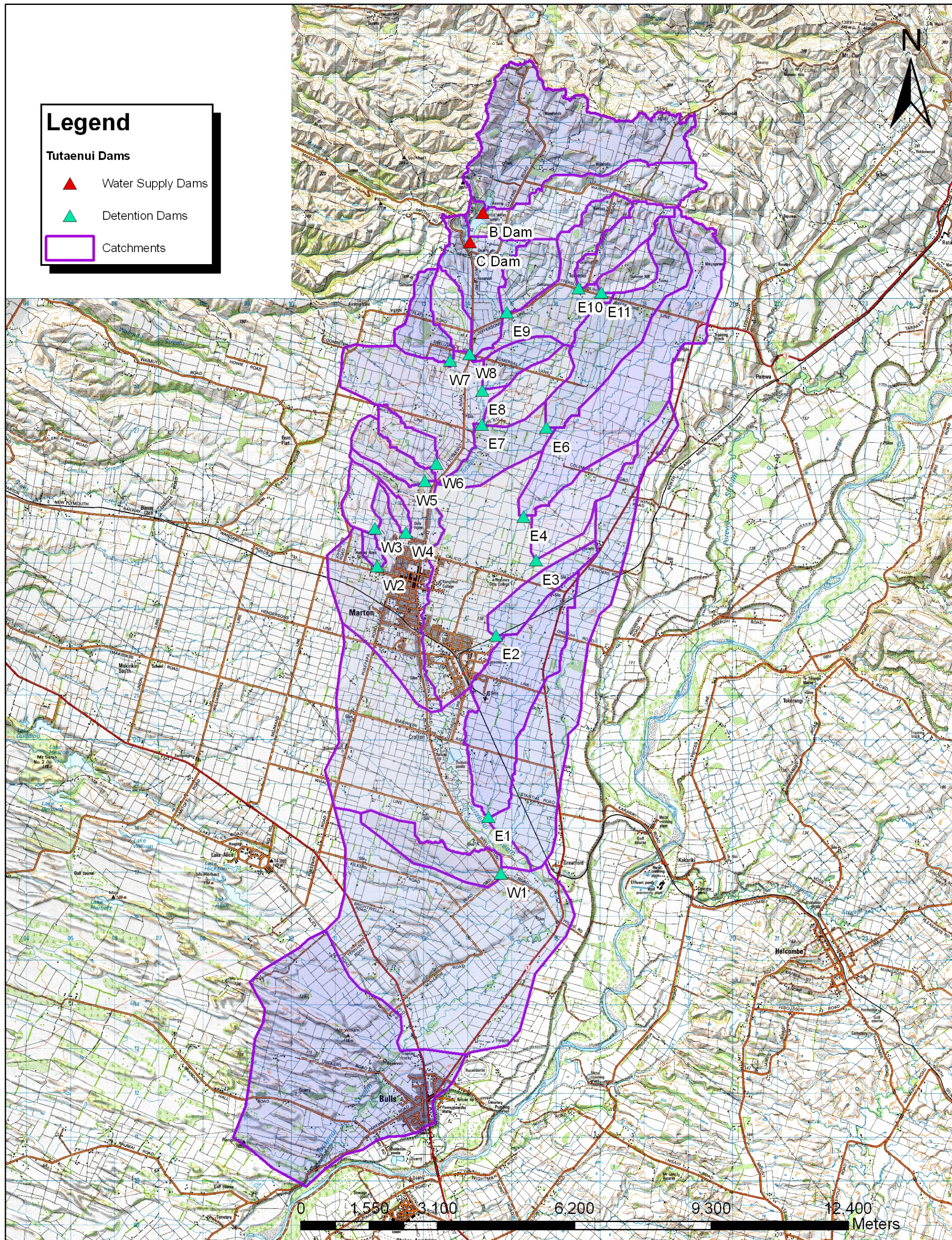
Tutaenui Flood Hazard Assessment

Study Area - Marton

Location	Marton Area
Drawing No.	1
Creation Date	02/07/2008
Prepared By	DHI Water and Environment Ltd.
Approved By	TvK



Location	Bulls Area
Drawing No.	2
Creation Date	02/07/2008
Prepared By	DHI Water and Environment Ltd.
Approved By	TvK



Legend

Tutaenu Dams

- ▲ Water Supply Dams
- ▲ Detention Dams
- Catchments



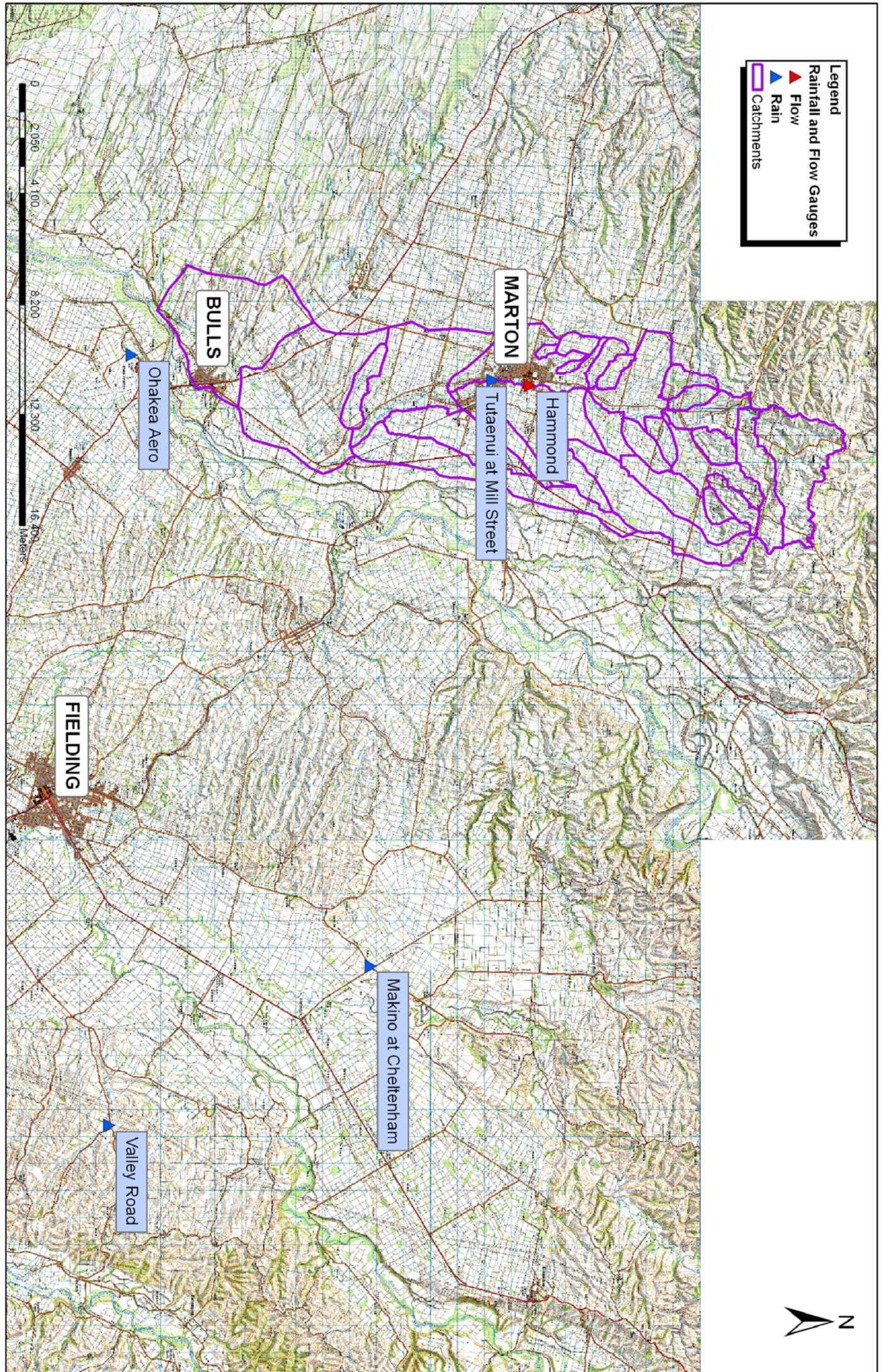
Tutaenu Flood Hazard Assessment

Hydrology - Dams and Catchments

Location	Marton/Bulls
Drawing No.	3
Creation Date	02/07/2008
Prepared By	DHI Water and Environment Ltd.
Approved By	TvK

Legend

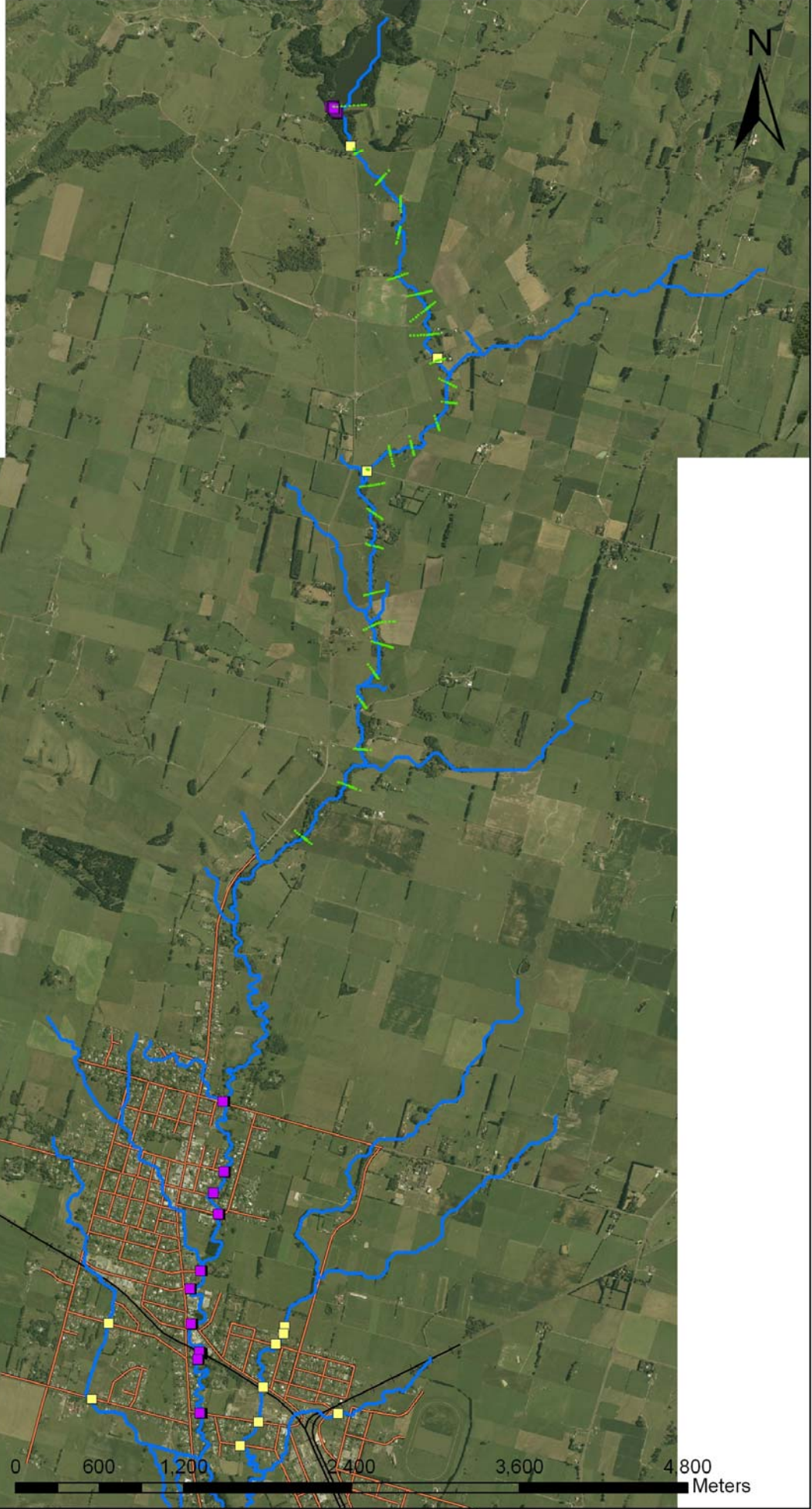
- ▲ Rainfall and Flow Gauges
- ▲ Rain
- Catchments



Location	Marton/Bulls/Fielding
Drawing No.	4
Creation Date	02/07/2008
Prepared By	DHI Water and Environment Ltd
Approved By	TK

Legend

- HRC Bridge Survey
- DHI Structure Survey
- HRC Cross Sections
- MIKE 11 Branches
- Railway
- Roads
- State Highways

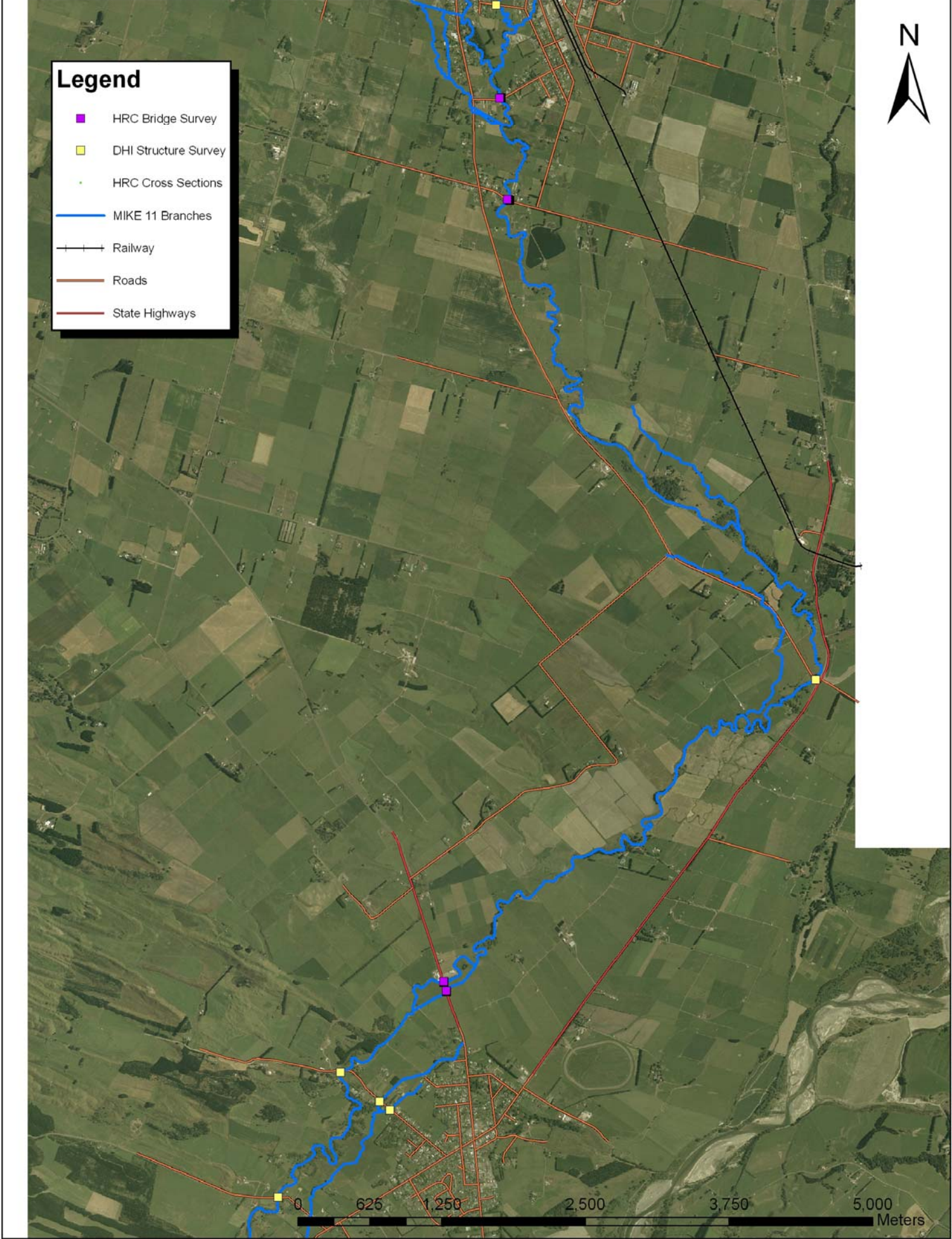


Tutaenui Flood Hazard Assessment
Structures and Cross Section Surveys
Marton Area

Location	Marton Area
Drawing No.	5
Creation Date	02/07/2008
Prepared By	DHI Water and Environment Ltd.
Approved By	TvK

Legend

- HRC Bridge Survey
- DHI Structure Survey
- HRC Cross Sections
- MIKE 11 Branches
- Railway
- Roads
- State Highways



Tutaenui Flood Hazard Assessment
Structures and Cross Section Surveys
Bulls Area

Location	Bulls Area
Drawing No.	6
Creation Date	02/07/2008
Prepared By	DHI Water and Environment Ltd.
Approved By	TvK



A P P E N D I C E S



A P P E N D I X A

Depth Duration Frequency Rainfall Tables

Mangaone at Valley Road
3-Mar-1987 16:15:00 to 6-Jun-2007 14:00:00
Rainfall total (mm)

	Interval								
ARI	30min	60min	2 hours	3 Hours	6 Hours	12 hours	24 Hours	48 Hours	72 Hours
Mean annual(2.33) or 1 year	12.7	16.8	23.2	28.1	35.6	41.9	52.7	62.9	69.5
5	18.9	24.4	30.8	37	44.2	53.9	71.7	83.6	92.5
10	25	31.4	37.3	43.2	50.9	64.3	88	109	111.7
20	31.2	38.6	43.7	47.9	57.1	74.4	104	117.4	129.9
50	39.7	48.3	51.9	52.5	64.8	87.4	124.8	138.5	153.2
100	46.2	55.6	58	55	70.4	97.2	140.3	154.2	170.4
200	52.7	63	64	57	75.9	106.8	155.7	169.6	187.4

Tutaenui at Mill St Marton (Daily Gauge)
1-Jan-1962 00:00:00 to 30-Mar-2007 07:00:00

	Interval								
ARI	30min	60min	2 hours	3 Hours	6 Hours	12 hours	24 Hours	48 Hours	72 Hours
Mean annual(2.33) or 1 year							49	63.7	70.7
5							63.7	81.3	88.6
10							76.2	95.9	102.9
20							88.4	109.9	116.3
50							104.1	127.7	133.1
100							115.8	140.9	145.4
200							127.4	153.8	157.4

Mangaone at Valley Road
3-Mar-1987 16:15:00 to 6-Jun-2007 14:00:00
Depth Duration-Frequency (mm/h)

ARI	Interval								
	30min	60min	2 hours	3 Hours	6 Hours	12 hours	24 Hours	48 Hours	72 Hours
Mean annual(2.33) or 1 year	25.4	16.8	11.6	9.4	5.9	3.5	2.2	1.3	1.0
5.0	37.8	24.4	15.4	12.3	7.4	4.5	3.0	1.7	1.3
10.0	50.0	31.4	18.7	14.4	8.5	5.4	3.7	0.2	1.6
20.0	62.4	38.6	21.9	16.0	9.5	6.2	4.3	2.4	1.8
50.0	79.4	48.3	26.0	17.5	10.8	7.3	5.2	2.9	2.1
100.0	92.4	55.6	29.0	18.3	11.7	8.1	5.8	3.2	2.4
200.0	105.4	63.0	32.0	19.0	12.7	8.9	6.5	3.5	2.6

Tutaenui at Mill St Marton (Daily Gauge)
1-Jan-1962 00:00:00 to 30-Mar-2007 07:00:00
Depth Duration-Frequency (mm/h)

ARI	Interval								
	30min	60min	2 hours	3 Hours	6 Hours	12 hours	24 Hours	48 Hours	72 Hours
Mean annual(2.33) or 1 year							2.0	1.3	1.0
5.0							2.7	1.7	1.2
10.0							3.2	2.0	1.4
20.0							3.7	2.3	1.6
50.0							4.3	2.7	1.8
100.0							4.8	2.9	2.0
200.0							5.3	3.2	2.2

Mangaone at Valley Road (mm) High Intensity Rainfall Design System (HIRDS)										
ARI	10m	20m	30m	60m	2h	6h	12h	24h	48h	72h
2	6.9	9.5	11.6	16	21.3	33.5	44.5	59.2	69.9	77
10	10.6	14.3	17.1	23	30.3	46.6	61.1	80.3	93.3	101.9
20	12.8	17.1	20.3	27.1	35.4	54	70.4	91.9	106.1	115.4
30	14.4	19.1	22.6	30	39	59.1	76.9	99.9	114.8	124.6
40	15.7	20.8	24.4	32.3	41.8	63.2	81.9	106.3	121.7	131.8
50	16.9	22.1	26	34.2	44.3	66.6	86.2	111.6	127.5	137.9
60	17.9	23.4	27.4	35.9	46.4	69.7	90	116.3	132.6	143.1
70	18.8	24.5	28.7	37.5	48.3	72.4	93.4	120.4	137.1	147.8
80	19.6	25.5	29.8	38.9	50.1	74.9	96.4	124.2	141.2	152.1
100	21.1	27.4	31.9	41.4	53.3	79.3	101.9	131	148.4	159.7
125	22.8	29.4	34.2	44.2	56.7	84.1	107.8	138.3	156.3	167.9
150	24.3	31.3	36.3	46.7	59.8	88.4	113.1	144.7	163.1	175

Mangaone at Valley Road Standard Errors										
ARI	10m	20m	30m	60m	2h	6h	12h	24h	48h	72h
2	0.6	0.8	1	1.3	1.7	2.8	3.3	4.2	5	5.3
10	1	1.4	1.7	2.1	2.6	4.2	4.9	6.5	7.7	8
20	1.3	1.7	2	2.5	3	4.8	5.5	7.5	8.8	9.1
30	1.5	1.9	2.3	2.7	3.2	5.2	5.9	8.2	9.6	9.8
40	1.6	2.1	2.5	3	3.5	5.4	6.2	8.6	10.1	10.3
50	1.7	2.2	2.7	3.1	3.6	5.7	6.4	9	10.5	10.7
60	1.8	2.3	2.8	3.3	3.8	5.9	6.6	9.3	10.8	11
70	1.9	2.5	2.9	3.4	3.9	6	6.8	9.6	11.1	11.3
80	2	2.6	3.1	3.5	4	6.2	6.9	9.8	11.4	11.6
100	2.1	2.8	3.3	3.8	4.2	6.4	7.1	10.3	11.9	12
125	2.3	3	3.5	4	4.5	6.7	7.4	10.7	12.4	12.5
150	2.5	3.2	3.8	4.2	4.7	6.9	7.6	11.1	12.8	12.9

Tutaenui at Mill St Marton (Daily Gauge) (mm) High Intensity Rainfall Design System (HIRDS)										
ARI	10m	20m	30m	60m	2h	6h	12h	24h	48h	72h
2	7.3	9.8	11.7	15.8	20.7	32	42	55.1	65.2	71.9
10	11.1	14.6	17.1	22.5	29.3	44.3	57.5	74.6	86.9	94.9
20	13.4	17.4	20.3	26.4	34.1	51.2	66.1	85.4	98.7	107.4
30	15	19.4	22.5	29.1	37.5	56	72.1	92.9	106.8	115.9
40	16.3	21	24.3	31.3	40.2	59.8	76.8	98.7	113.2	122.6
50	17.5	22.4	25.9	33.1	42.5	63	80.8	103.7	118.5	128.2
60	18.5	23.6	27.2	34.8	44.5	65.9	84.3	108	123.2	133.1
70	19.4	24.7	28.4	36.2	46.3	68.4	87.5	111.8	127.4	137.4
80	20.3	25.7	29.6	37.6	48	70.7	90.3	115.3	131.1	141.4
100	21.8	27.5	31.6	40	50.9	74.8	95.4	121.6	137.9	148.4
125	23.5	29.5	33.8	42.6	54.2	79.3	100.9	128.4	145.1	155.9
150	25	31.3	35.8	44.9	57	83.3	105.8	134.3	151.5	162.5

Tutaenui at Mill St Marton (Daily Gauge) Standard Errors										
ARI	10m	20m	30m	60m	2h	6h	12h	24h	48h	72h
2	0.6	0.9	1	1.3	1.6	2.6	3.1	3.9	4.6	4.9
10	1	1.5	1.7	2.1	2.4	3.9	4.5	6	7	7.3
20	1.3	1.8	2	2.4	2.8	4.4	5.1	7	8.1	8.4
30	1.4	2.1	2.3	2.7	3	4.8	5.4	7.5	8.7	9
40	1.5	2.2	2.4	2.9	3.2	5	5.7	8	9.2	9.4
50	1.7	2.4	2.6	3.1	3.4	5.2	5.9	8.3	9.6	9.8
60	1.8	2.5	2.7	3.2	3.5	5.4	6	8.6	9.9	10.1
70	1.8	2.6	2.9	3.3	3.6	5.5	6.2	8.9	10.2	10.4
80	1.9	2.7	3	3.4	3.7	5.7	6.3	9.1	10.4	10.6
100	2.1	2.9	3.2	3.6	3.9	5.9	6.5	9.5	10.9	11
125	2.3	3.1	3.4	3.9	4.1	6.1	6.7	9.9	11.3	11.5
150	2.4	3.4	3.6	4.1	4.3	6.3	6.9	10.3	11.7	11.8