Utuhina Stream Flood Modelling and Mapping

Report prepared for
Bay of Plenty Regional Council
by

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1 Introduction

The Utuhina Stream drains a catchment of around 60 km^2, rising to the west of Rotorua before flowing through residential and industrial areas within Rotorua City and discharging into Lake Rotorua. Several tributaries join the main stream within the urban limits, including the Mangakakahi Stream and the Otamatea Stream. Figures 1 and 2 show the extent of the catchment and the main branches of the Utuhina Stream.

According to the BOP Rivers and Drainage AMP, Utuhina Stream flood defences downstream of State Highway 5 (Old Taupo Road) are required to provide a 1% AEP level of protection to the floodplain. Existing defences are limited to stopbanking along the western (left bank) side and sections of floodwall along the right bank, downstream of Lake Road.

Modelling work carried out over the last decade however has highlighted deficiencies in the protection. While some improvements to the left bank stopbank have been carried out in recent years, practical difficulties in providing the design level of protection in other areas (particularly upstream of Lake Road) have meant that no other improvements have occurred (see Everitt, 2009).

In order to progress design options, BOPRC commissioned an update of the modelling, with required outputs being flood maps of the existing flood hazard and indicative design heights for flood defences.

This report documents the latest investigations and presents the model findings.

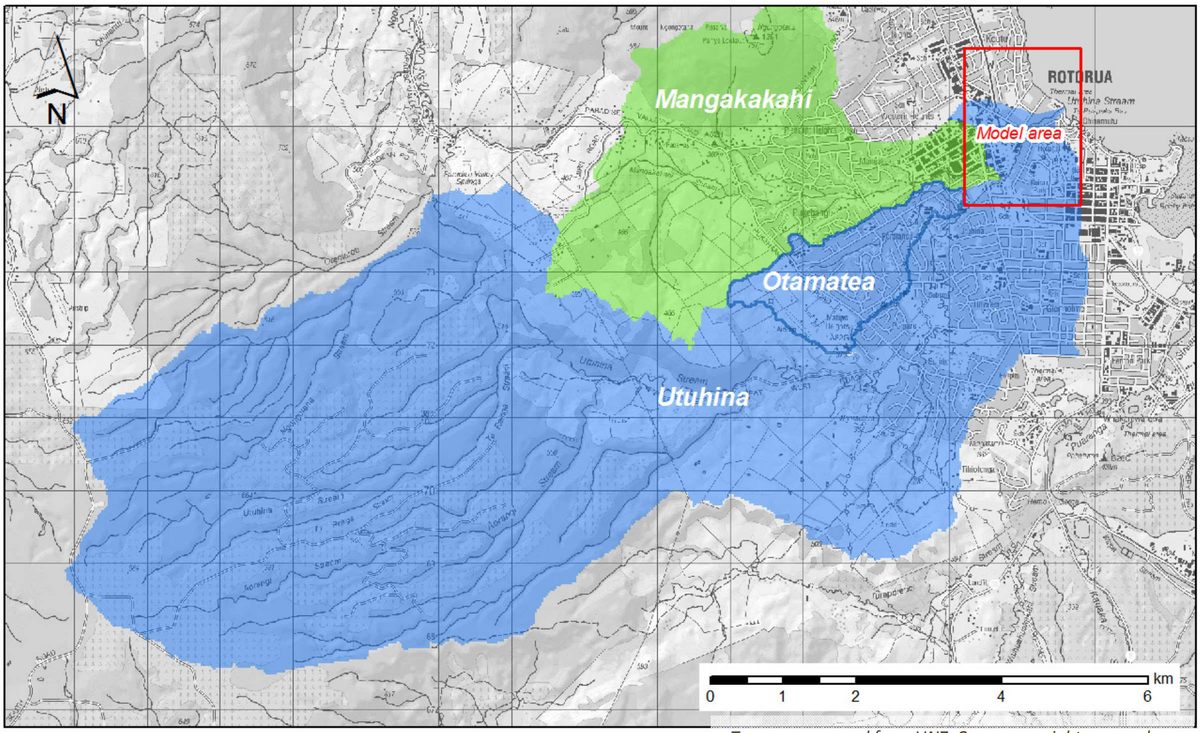

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Figure 1 Utuhina Stream catchment

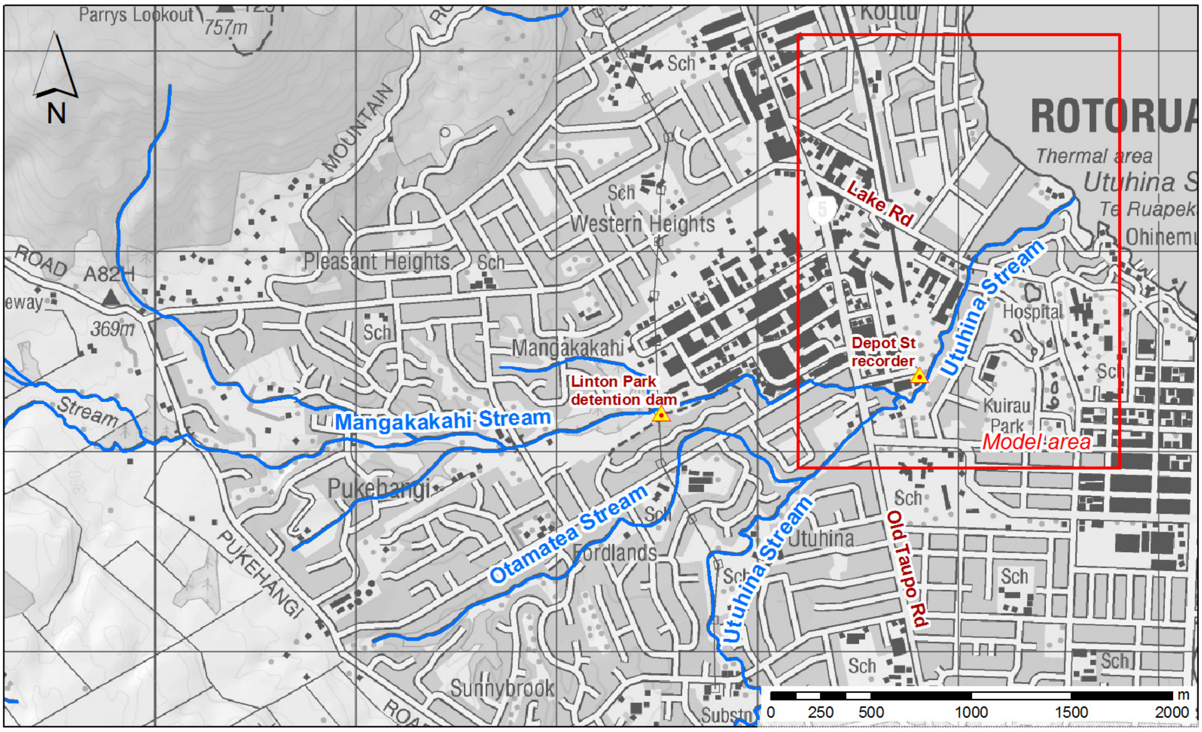

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Figure 2 Location map, Utuhina Stream

2 Previous modelling

2.1 Hydraulic models of Utuhina and Mangakakahi Streams

The Utuhina Stream has been modelled with MIKE 11 (simulating one-dimensional unsteady flow) since 2002. Riley Consultants first developed a model of the stream with MIKE 11 (Riley, 2003), with the aid of calibration information obtained from a flood in May 1999.

The model was subsequently refined over the following few years, making use of additional cross-section data and software refinements. (Wallace, 2006)

The model was recalibrated in 2011, following two flood events in January of that year. The modelling at that time also assessed the impact of a planned bridge replacement at Lake Road. (The replacement was carried out in 2012.) The recalibration led to an increase in design flood levels.

Barnett and MacMurray developed an Aulos model (again, simulating one-dimensional unsteady flow) of the Mangakakahi Stream in 2009, for Rotorua District Council (RDC). As with MIKE 11, the Aulos software simulates one-dimensional unsteady flow. The model extended as far upstream as the urban boundary at Pukehangi Road, with its downstream boundary being the Utuhina Stream. The model was subsequently used in-house by RDC for investigations into upgrading the flood detention dam in Linton Park.

2.2 Hydrologic models of Utuhina and Mangakakahi Catchments

The hydrology for the Mangakakahi Stream has previously been modelled with the aid of HEC-HMS software, initially by RDC and then revised by Barnett & MacMurray. The catchment was broken up into 65 subcatchments as illustrated in the Barnett & MacMurray report.

RDC subsequently used HEC-HMS to produce inflow hydrographs for a MIKE 11 model as part of design investigations for the Lake Road bridge upgrade (Dine, 2011). (That MIKE 11 model was based on the 2006 model referred to above, and superseded by the 2011 modelling.) The HEC-HMS model was presumably based on the Barnett & MacMurray HEC-HMS model, although it covers the entire Utuhina and Mangakakahi catchments as well as using a different loss method. The resulting hydrographs shapes (Figure 3) have been used in the 2011 and current modelling, although they have been scaled so that the resulting Utuhina flow downstream of the Mangakakahi confluences matches the design flows described below. Of note is that the inflows of the Mangakakahi and the lower stormwater catchments peak well before that of the Utuhina.

An RDC report on the detention dam on the Mangakakahi Stream (RDC, 2010) indicated that further urban development in the catchment would take the design flow for that stream to 40m^3/s, the flow adopted in the design hydrographs provided by RDC (Figure 3). However other correspondence from RDC (Dine, 2010) makes it clear that no allowance need be made for further growth in the Utuhina Stream. The urban catchment was almost fully developed by the 1970s, RDC does not support growth beyond the existing urban limits and in any case future development will be required to be hydrological neutral.

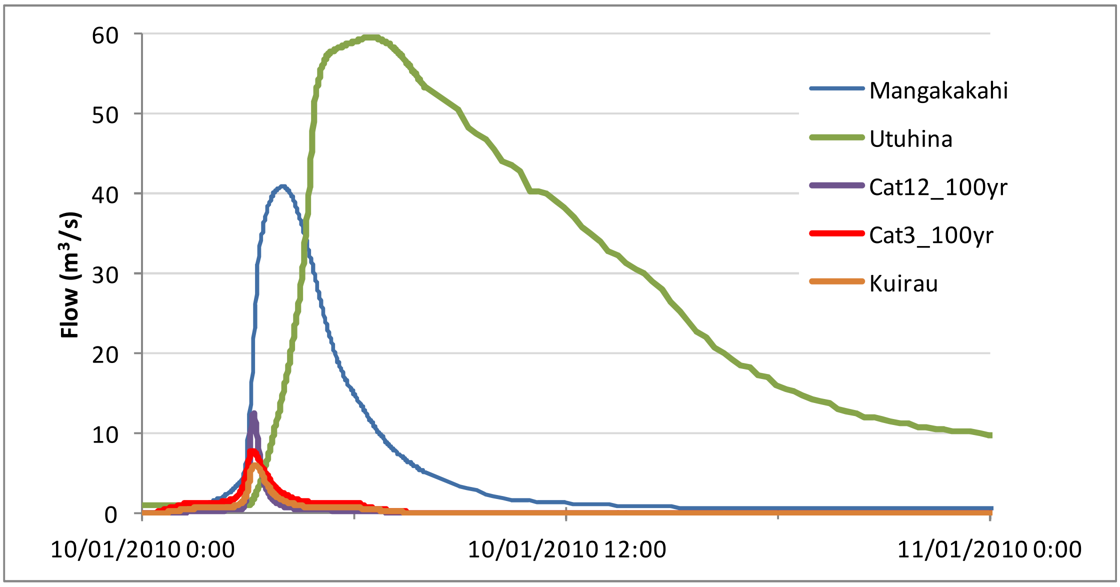

Figure 3 MIKE FLOOD model inflow hydrograph shapes, from RDC HEC-HMS model

3 Mike Flood Model

The current modelling has been undertaken with MIKE FLOOD software. This incorporates MIKE 21 (i.e. 2-D flow equations) and MIKE 11 (1-D flow equations), allowing them to be dynamically linked during a simulation. This program is better suited to floodplain modelling than MIKE 11 alone. It still however allows the use of MIKE 11 in well-defined flow channels such as rivers and canals.

The model area covers the Utuhina and Mangakakahi Streams from around 300m upstream of Old Taupo Road to the lake (Figures 1 and 2). The floodplain area covered by the model is shown in more detail in Figure 4. The model also allows inundation from high lake levels to be simulated.

Figure 4 MIKE FLOOD model: MIKE 11 channel network and MIKE 21 topography

4 Hydrology

This current modelling exercise has incorporated some revisions to the hydrology used in the 2011 modelling, as described below.

4.1 January 2011 Floods

New data have been supplied by BOPRC for the January 2011 flood events. These indicate slightly lower flows to the data that were supplied by BOPRC in 2011 (Figure 5). For example, the peak flow on 23 January 2011 is now given as 25.0 m^3/s, compared to 26.2 m^3/s adopted in the 2011 modelling. The peak flow for 29 January 2011 has dropped from 34.8 m^3/s to 31.1 m^3/s.

Flow data for the Kuirau Stream, entering the Utuhina Stream at Tarewa Street, have now been made available. The existence of that data set was not known at the time of the 2011 modelling. Peak flows from that catchment were 1.4 m^3/s and 2.7 m^3/s for the 23rd and 29th January 2011 events respectively. The hydrographs peaked at similar times to the peak flows recorded in the Utuhina Stream at Depot Street (the location of which is shown in Figure 2).

No changes to the Lake Rotorua levels and the stage hydrograph at the Depot Street recorder have been made.

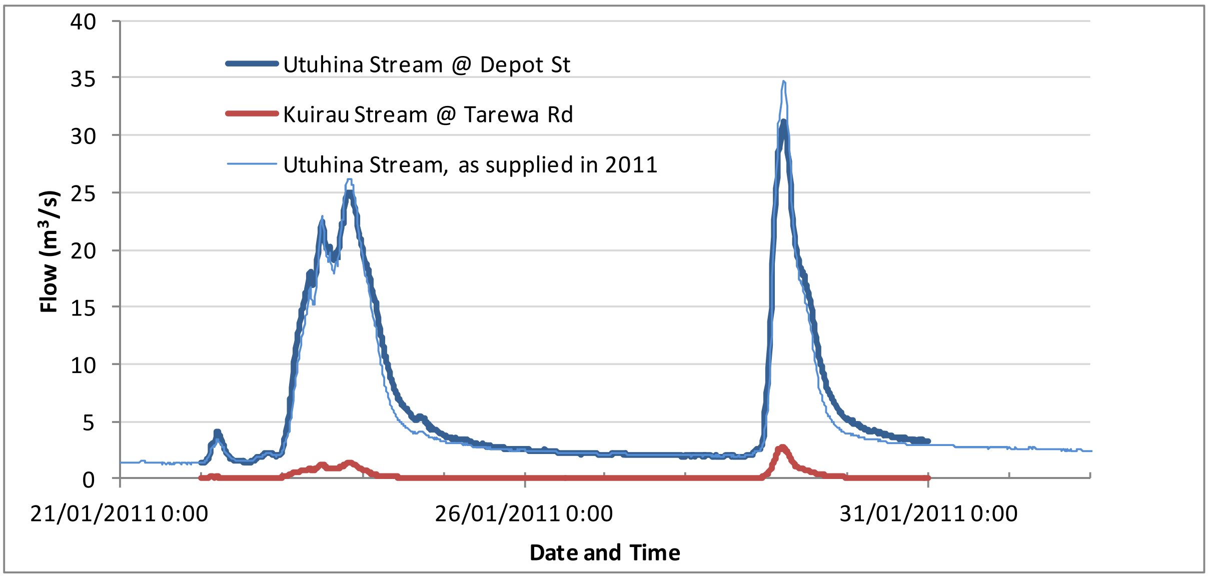

Figure 5 Recorded flows, Utuhina and Kuirau Streams, January 2011 events

4.2 Design Flows

In 2011, the design flows for the Utuhina Stream were based on an earlier analysis of data from the Lake Road recorder site. The analysis incorporated data from start of the record in 1968 until the site closed in 1996, as well as the estimated peak flow of a flood in February 1967. With a Log Pearson III distribution, the 2% AEP and 1% AEP flow estimates were 55 m^3/s and 67.9 m^3/s respectively (Blackwood, 2001).

A new recorder site (Depot Street) opened in 2005, approximately 700 m upstream. Analysis of the period 2005-2012 carried out by BOPRC gives a 2% AEP flow of 34 m^3/s (Appendix A).

The difference in the flood estimates between the two recorder data sets is too large to attribute to the additional inflow (stormwater catchments and the Kuirau Stream) between the Depot Street and Lake Road sites. Peter Blackwood's memo 2001 on Utuhina flows notes that the Lake Road recorder site flow record straddled a cycle of the Interdecadal Pacific Oscillation (IPO) and so wouldn't be expected to show any bias to flood-rich or benign periods. Recent IPO values (e.g. http://www.jisao.washington.edu/pdo/) suggest that if anything, the period since 2005 might be expected to be a flood-rich period (following Blackwood's logic), and the lower design flow cannot therefore be attributed to a benign IPO phase.

For this current modelling, the two data sets have been combined and reanalysed to provide new design flood estimates. Depot Street annual maxima flows have been increased by 10%, to allow for the additional catchment inflow downstream to Lake Road. For the 29 January 2011 event, the Kuirau peak coincided with the Depot St peak, and was about 8% of the Depot St peak. Other events don't seem to coincide as well, so a 10% allowance for the Kuirau and the other two main subcatchments would be conservative.

Annual maxima have been provided by BOPRC for the Lake Road site (the data and related correspondence are given in Appendix B). These values differ slightly from those listed in Blackwood's analysis, and for this current analysis the more recent values are adopted.

With the combined and revised data set, including the 1967 peak flow used in the earlier analysis, the 2% AEP and 1% AEP flow estimates are 47 m^3/s and 55 m^3/s respectively. (Appendix C).

As noted above, the hydrograph shapes produced by the RDC HEC-HMS modelling have been used in this current modelling. The RDC modelling used rainfall totals derived from HIRDS v1.5, which has now been superseded by HIRDS v3. While HIRDS v3 gives slightly lower rainfall totals values for the area, this is not a concern as the design flood hydrographs are scaled to the flood frequency values above.

Robert Monk of Sigma Consultants Limited carried out an analysis of the January 2011 hydrology for RDC. Although his analysis of data from the Lake Road recorder gives 2% AEP and 1% AEP flows of 52 m^3/s and 62 m^3/s respectively, he proposed a longer term relationship using data from the long Whakarewarewa rain gauge records. That would give 2% AEP and 1% AEP flows of 41 m^3/s and 46 m^3/s respectively (exclusive of climate change). His analysis is summarised in Appendix D. No assessment of his analysis is offered here but further consideration would be warranted.

4.3 Lake Levels

The 2011 modelling assumed design Lake Rotorua levels of 280.544 m (5% AEP lake level) and 280.787 m (1% AEP lake level), as given in Environment Bay of Plenty (2007). More recent analysis provided by BOPRC gives a 5% AEP lake level of 280.283 m (Appendix E). Although results were supplied as "draft", these lower levels seem reasonable given that control over lake levels has been possible since 1989 by means of stoplogs at the lake outlet to the Ohau Channel. The lower levels have accordingly been adopted in the current modelling.

4.4 Climate change

The 1% AEP inflow hydrographs provided by RDC incorporated climate change to 2090, with resulting flows increased by approximately 17% from current day values. Thus the previous 1% AEP flow of 67.9 m^3/s flow was increased to 80 m^3/s. The revised 1% AEP and 2% AEP flows have similarly been scaled up to account for climate change.

Using similar assumptions, the design flows for Utuhina Stream (Lake Road site) considered in this current modelling are as given in Table 1. While the design flows recommended here are lower than those used previously, simulations have also been made using the previous values as sensitivity tests.

Note that the 1% AEP revised flow (no climate change) is equal to the previous 2% AEP flow estimate (no climate change) and the 2% AEP revised flow (with climate change). Hence only a single simulation was needed to provide results for all three scenarios.

Table 1 Design Flows, Utuhina Stream at Lake Road (m^3/s)

	Current climate	Climate change to 2090
2% AEP flow (previous)	55.0	64.2
2% AEP flow (revised)	47.0	55.0
1% AEP flow (previous)	67.9	80.0
1% AEP flow (revised)	55.0	64.8

No changes to the lake level design values in the climate change scenario have been made, on the assumption that lake level control measures will not lead to a change in the level frequency distribution.

5 Additional data

Since 2011, a significant amount of additional data has been collected and made available. The additional hydrology data are as discussed above. Limited use of LiDAR flown in 2006 was made in some of the previous modelling to extend cross-sections but new and more detailed aerial LiDAR data were collected in 2011 and these have been used to build the model floodplain topography for the MIKE 21 2-d component. A 2 m cell size has been used. LiDAR data (non-ground returns) have also been used to help build a resistance map of the floodplain.

The LiDAR data predate the Lake Road upgrade works, and design drawings and as-built drawings have been used to define the model topography of the new road layout.

Aerial photographs collected in the LiDAR survey assisted in the model development.

Several of the Utuhina Stream cross-sections were resurveyed in 2013, where it was unclear precisely where previous cross-sections were surveyed. Additional sections were also surveyed in the Mangakakahi Stream downstream of Old Taupo Road. Cross-section locations are shown in Appendix F.

Bank levels, particularly where the top of bank was obscured by vegetation in the aerial LiDAR survey, and profiles along the top of the concrete flood wall downstream of Lake Road were also surveyed in 2013.

6 Calibration Checks

The model has been rerun with the two flood events of January 2011 (23rd and 29th). As outlined in the 2011 modelling report, the calibration used 2007-2010 cross-sections. The assumption made was that the 2011 cross-section survey (carried out two months after the flood event) represents bed changes that occurred after the flood peak, on the recession. Mannings n values, already high, would also need to be raised further if the calibration was to be based on the 2011 cross-sections.

The calibration reported in 2011 has been improved slightly by increasing effect of the rail bridge structure and by increasing Mannings n over a short reach upstream of that bridge. Final results are presented in Figures 6 – 9.

Figures 6 and 7 show that the model underpredicts the flood levels at the recorder site around the peak of the flood. Peak flood levels in the vicinity also appear to be underpredicted (Figures 8 and 9). Further calibration refinements could possibly be made to improve the predictions. However calibration is good in the reach of immediate interest to BOPRC (downstream of the rail bridge).

Flood levels upstream of the Mangakakahi Stream confluence also appear to be underpredicted. The assumption regarding the split between the Utuhina and Mangakakahi contributions to the flow at the recorder site (80% and 20% of the recorder flow respectively) may be the cause of this underprediction.

(Note that Robert Monk suggested that the hydrograph of the 23rd January event could be broken down into components from the Otamatea, Mangakakahi and Utuhina catchments, and with the peak of each occurring in sequence and showing in the three peaks of the hydrograph for that event (Appendix D). No such pattern is apparent in the event of the 29th.)

A record of water levels in the Mangakakahi Stream (NIWA site 1114681), about 15 m downstream of Old Taupo Road is also available that could be used as another calibration check. As yet the datum has not been levelled in terms of Moturiki Datum and so no firm conclusions can be made about the calibration in that vicinity. However, the shape of the modelled and recorded hydrographs are at least similar, as shown in Figures 10 and 11. (For the purposes of comparing the shapes, a recorder datum of 280.25 m is assumed.)

No flow data are available for the two urban subcatchments that enter the Utuhina Stream at the old railway crossing. The size of each of these two catchments is of the same order of magnitude as that of the Kuirau Stream. For the calibration, however, the flow in each of these two is assumed to be 50% of the recorded Kuirau Stream. If the contributions were actually greater, then lower stream resistance values would be needed to calibrate the model, so this assumption is likely to be conservative for design purposes.

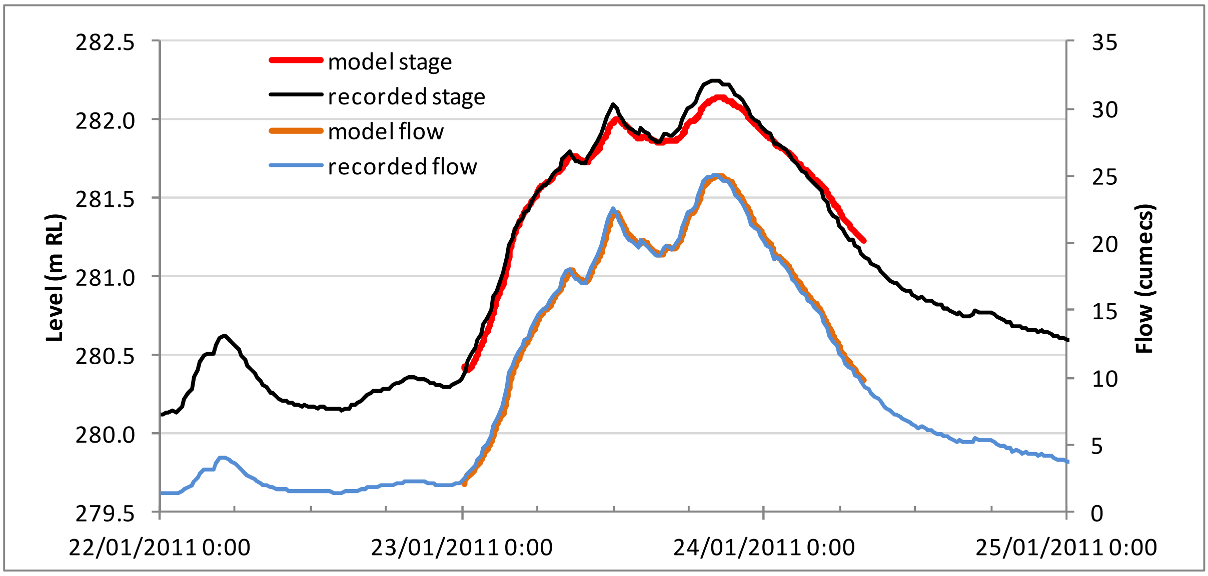

Figure 6 Observed and modelled water levels and flows at Depot St recorder site, 23 January 2011 flood event

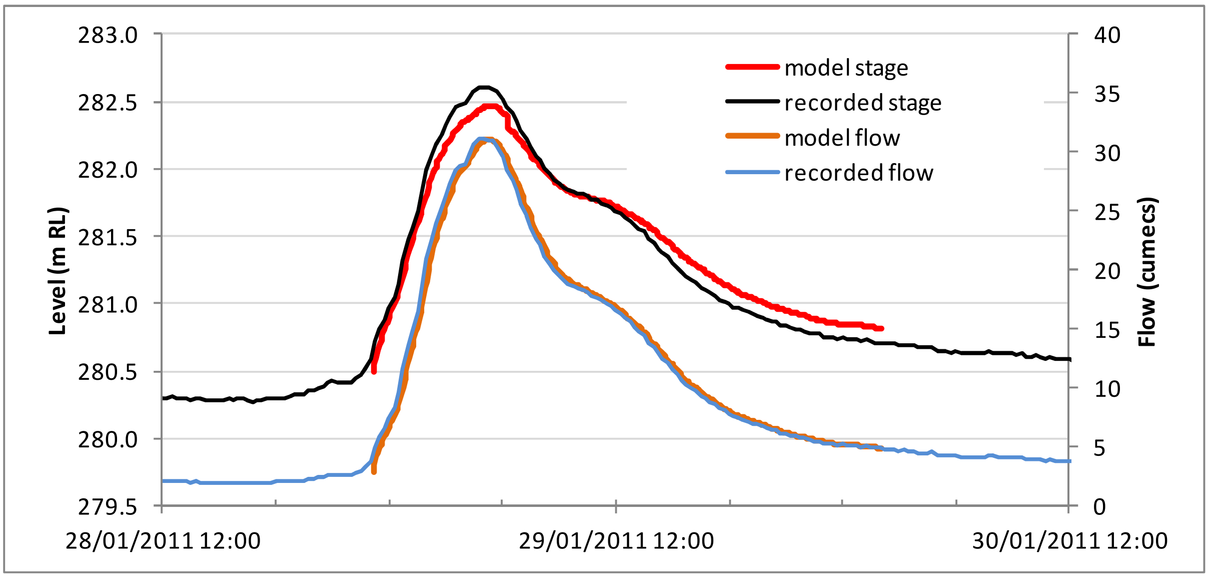

Figure 7 Observed and modelled water levels and flows at Depot St recorder site, 29 January 2011 flood event

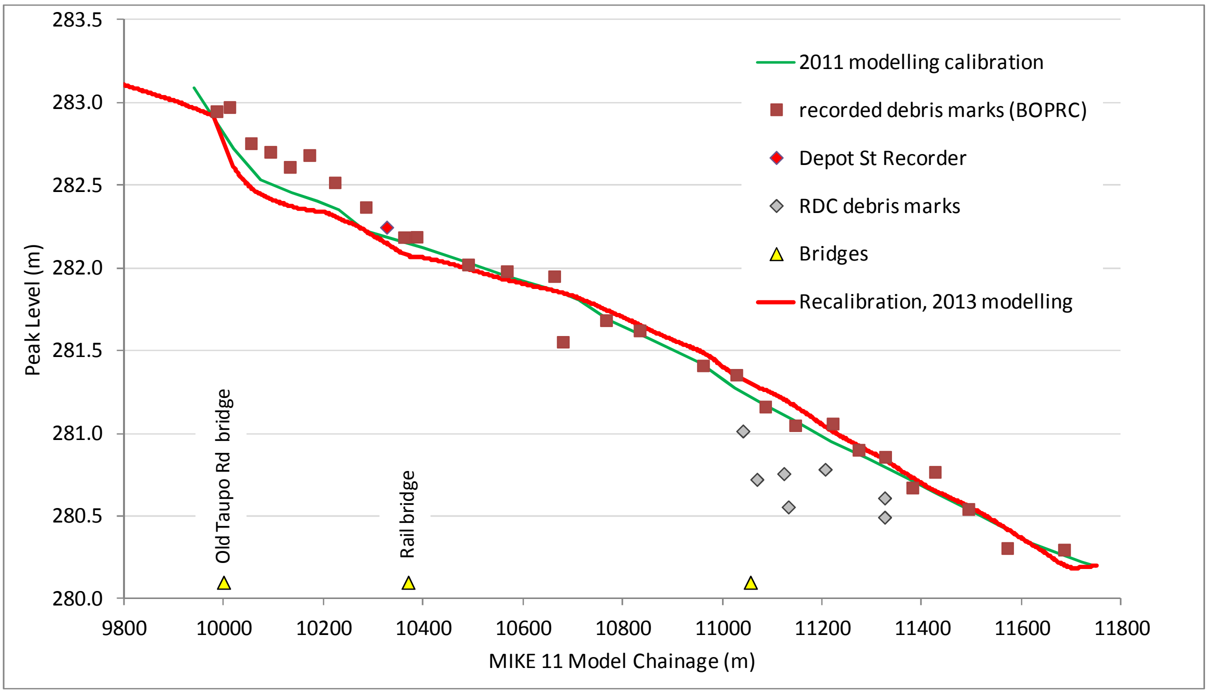

Figure 8 Model calibration, peak Utuhina Stream levels, 23 January event

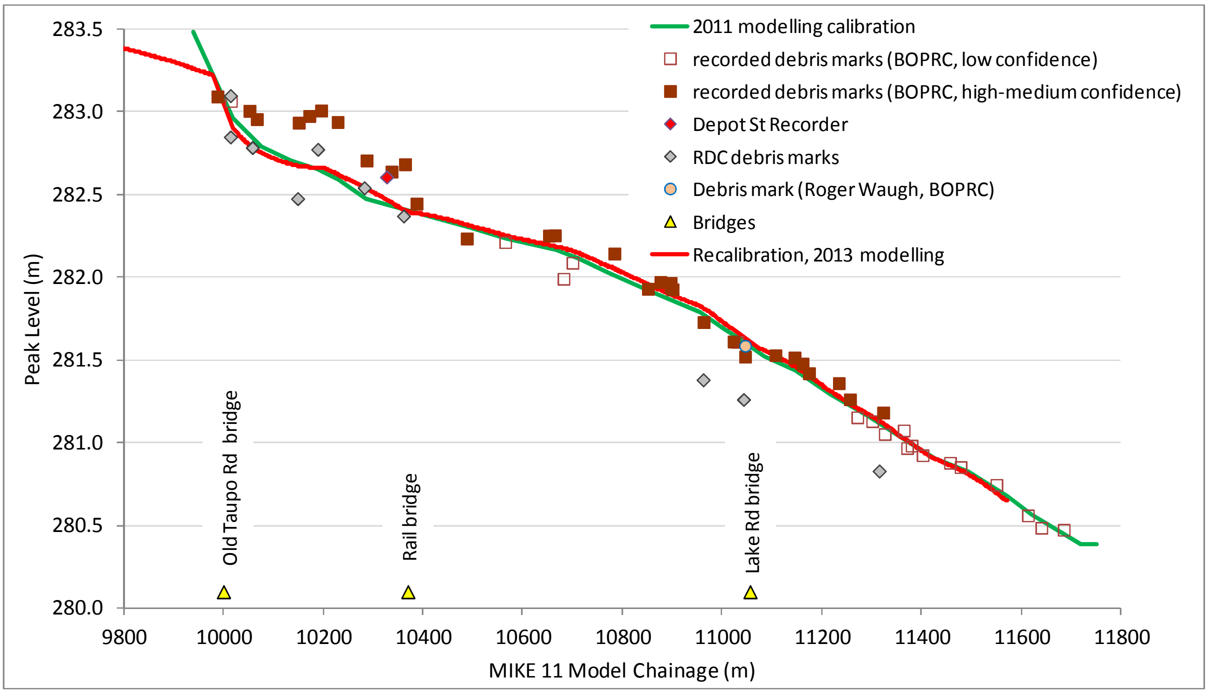

Figure 9 Model calibration, peak Utuhina Stream levels, 29 January event

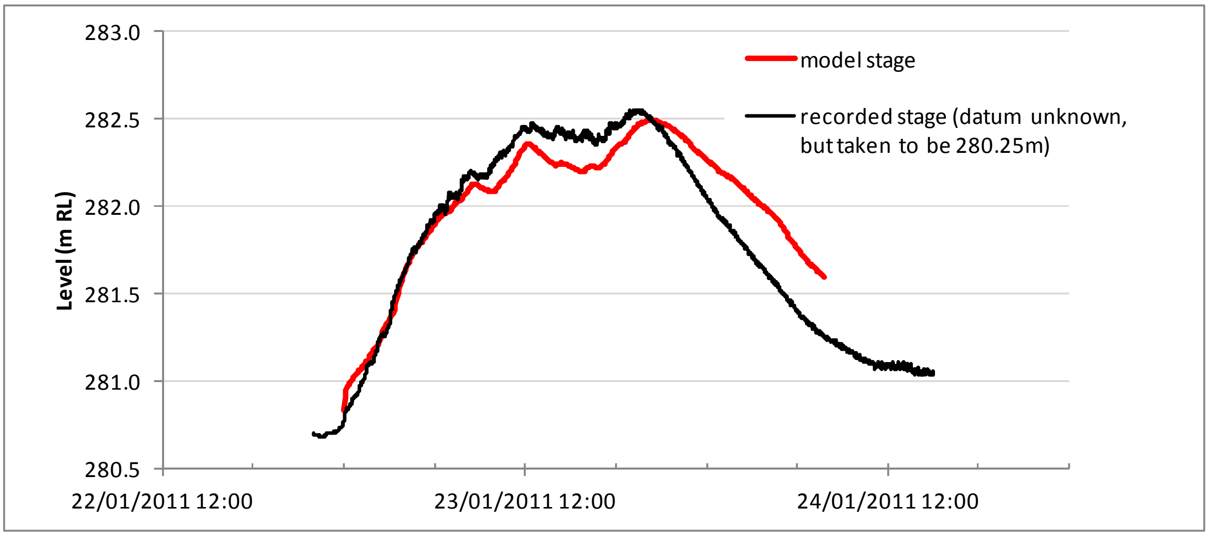

Figure 10 Comparison of modelled and predicted water level hydrograph shapes, Mangakakahi at Depot St recorder, 23 January event

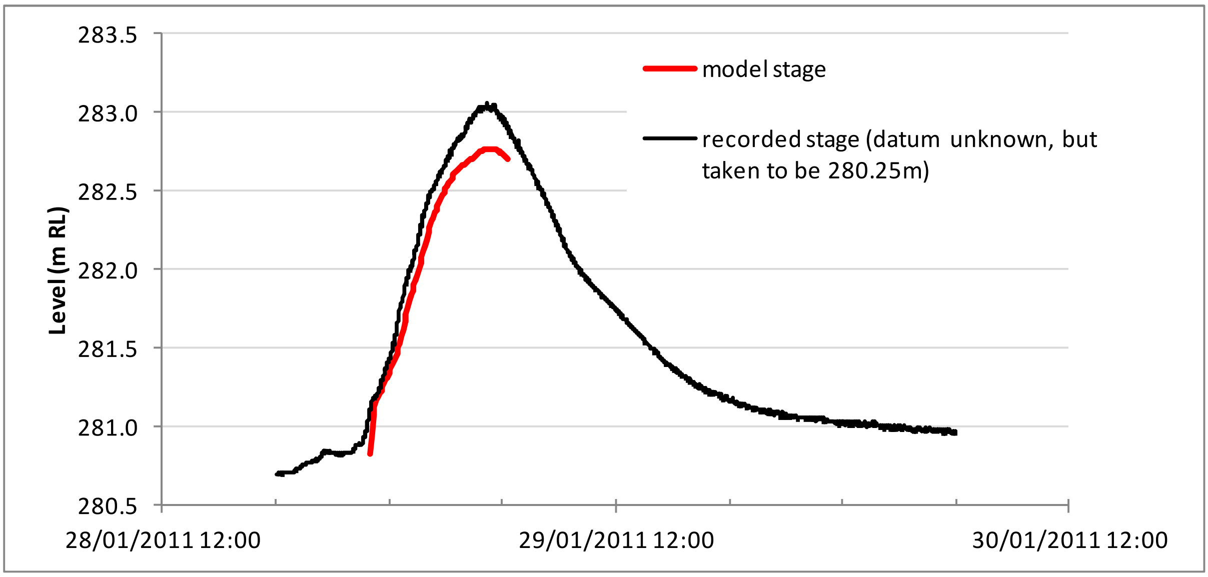

Figure 11 Comparison of modelled and predicted water level hydrograph shapes, Mangakakahi at Depot St recorder, 29 January event

7 Model of Existing Situation

The MIKE FLOOD model has been run for the existing situation for design flood events. Here the model uses the most recent cross-section data available:

- 2011 and 2013 cross-sections of the Utuhina Stream (downstream of Old Taupo Rd)
- A single surveyed cross-section (c2006) plus sections extracted from Lidar (with an assumed invert level) upstream of Old Taupo Rd
- 2006 and 2013 cross-sections of the Mangakakahi Stream, downstream of Old Taupo Road

- A single surveyed cross-section (c2006) and 2003 cross-sections of the Mangakakahi Stream, upstream of Old Taupo Road.

Cross-section 1 immediately upstream of the mouth has been assumed to scour out, similar to the assumption made in the 2006 and 2011 modelling (Figure 12). The scour assumption and its impact are discussed in more detail in Appendix G, but in summary it lowers the 1% AEP peak flood levels by up to 300 mm in the lower reaches of the stream (and even so, the results are expected to be conservative).

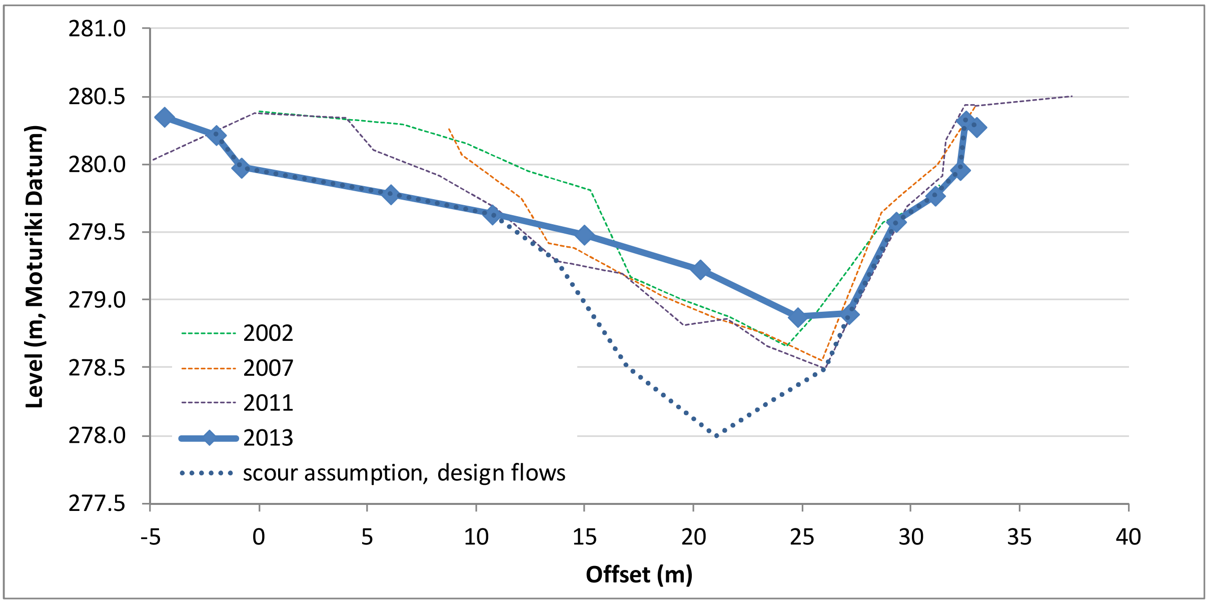

Figure 12 Surveyed mouth cross-section and assumed cross-section for design flood simulations

The model has been run for the 1% AEP flood scenario, this being the level of protection specified in the Asset Management Plan. As in the 2011 modelling, a climate change allowance has been included. (Due to the difficulties of providing a 1% AEP level of protection in this urban environment, it would be preferable to only go through a construction process once rather than repeating it.) However, a scenario without climate change has also been modelled for comparison.

Peak flood extent and depth maps are shown in Figures 13 and 14 while peak stream levels are shown in Figure 15. No freeboard has been applied to the results. Model results indicate that flow would overtop both Old Taupo Road and Lake Road.

The model has also been run with the previous design flow estimates. Results indicate more extensive inundation downstream of Lake Road, as shown in the flood map presented in Appendix H.

The model was also run with a potential upgrade to the Mangakakahi Stream detention dam. Model hydrograph outputs from the RDC modelling mentioned in Section 2.1 above, for the case of a higher dam crest level (288 m RL), were applied to the Mangakakahi Stream in this current modelling. Results indicated that the delayed peak outflow from the dam would coincide more closely with Utuhina flows, and hence result in greater flooding downstream of the confluence. (Appendix I).

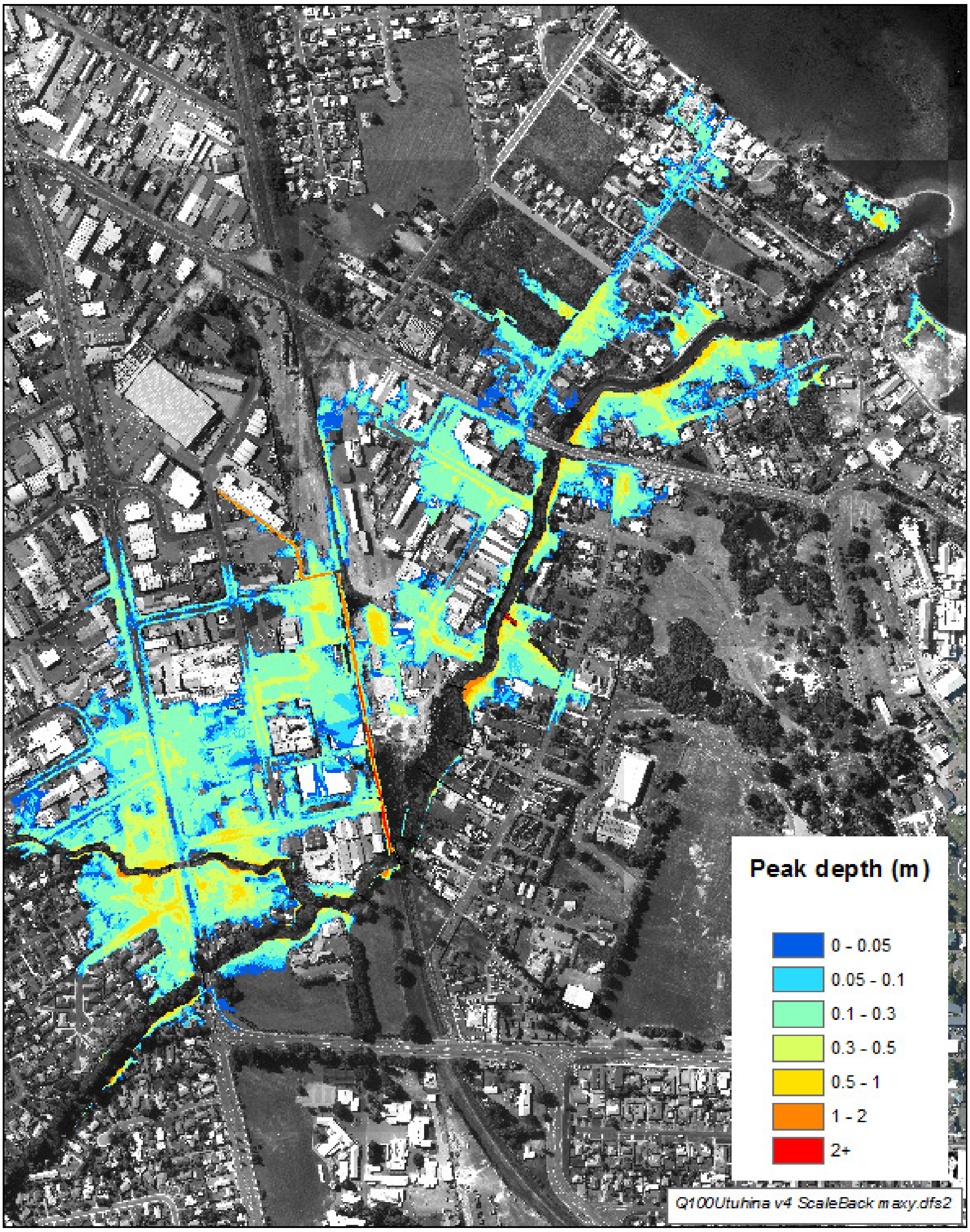

Figure 13 Peak flood extent and depths, 1% AEP flood event with climate change, revised flows, existing situation

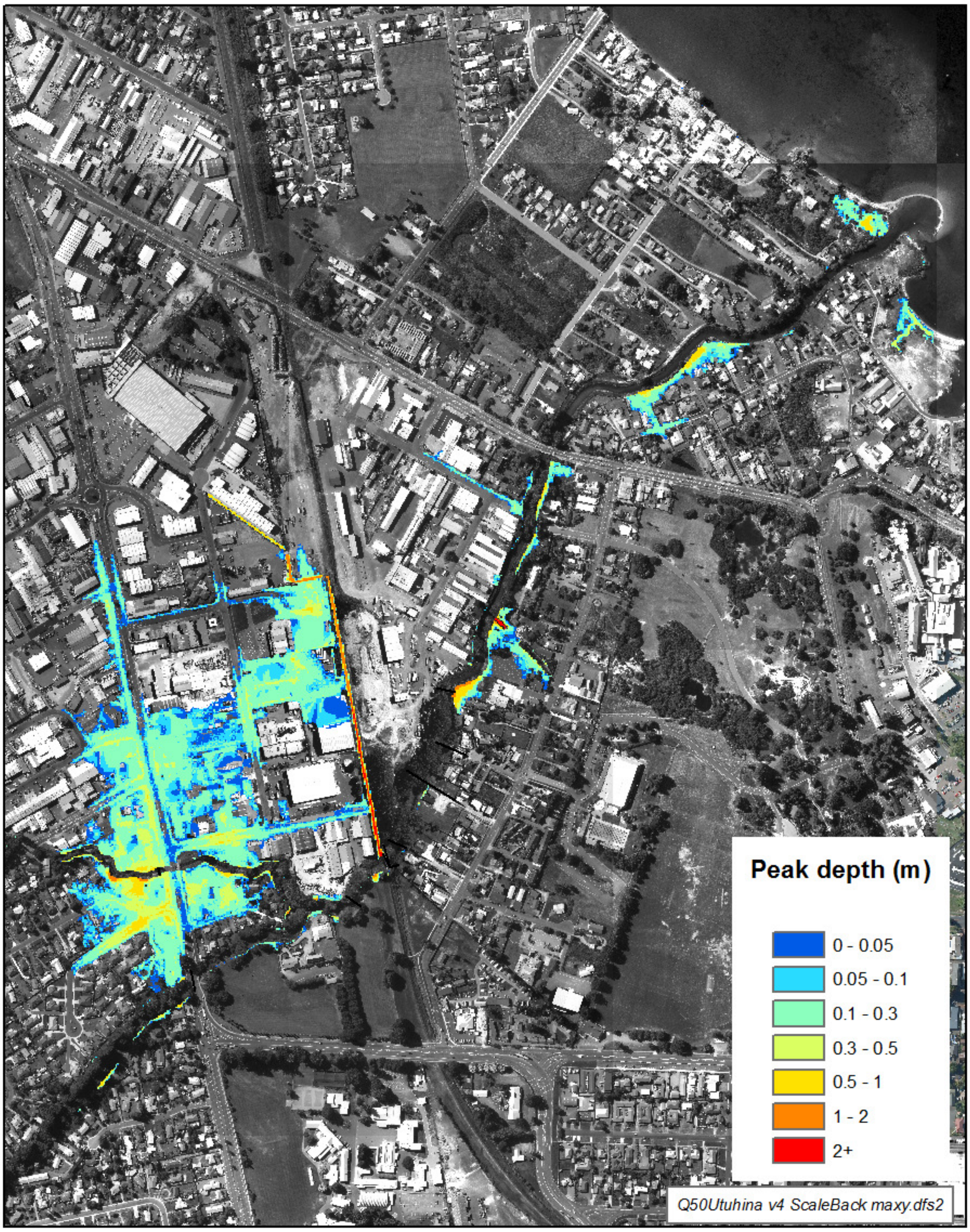

Figure 14 Peak flood extent and depths, 1% AEP flood event, current climate, revised flows, existing situation (also 2% AEP climate change, revised flows and 2% AEP current climate, previous flows)

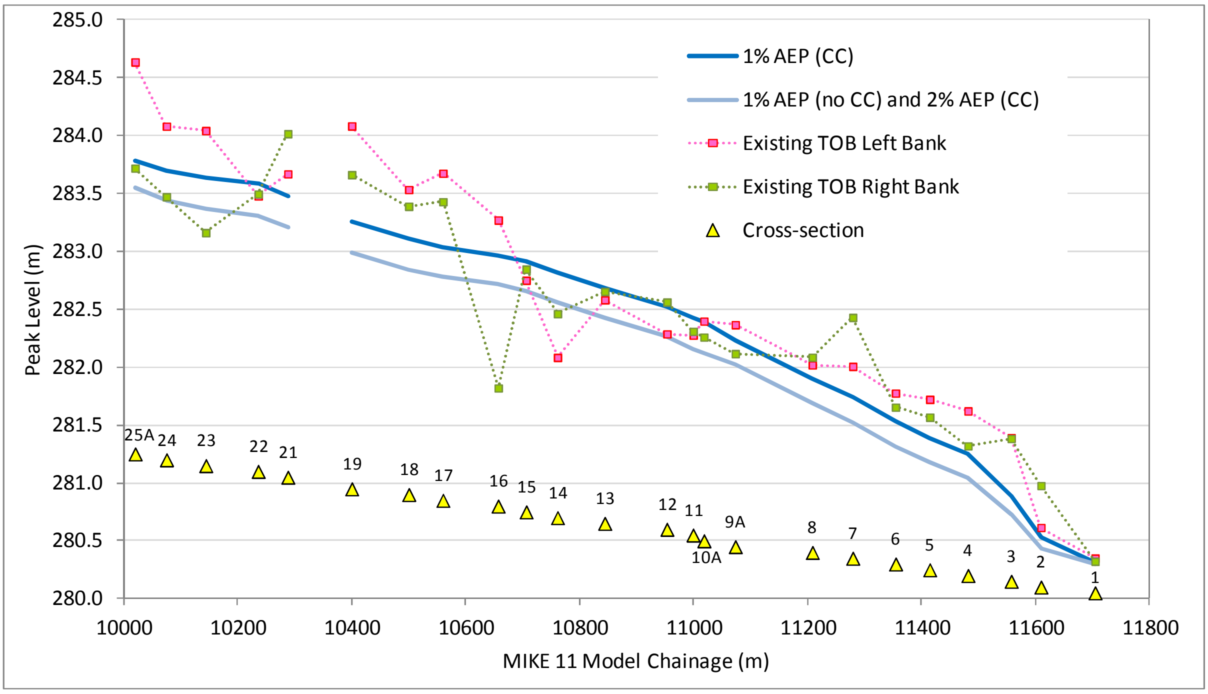

Figure 15 Peak flood levels, Utuhina Stream, existing situation

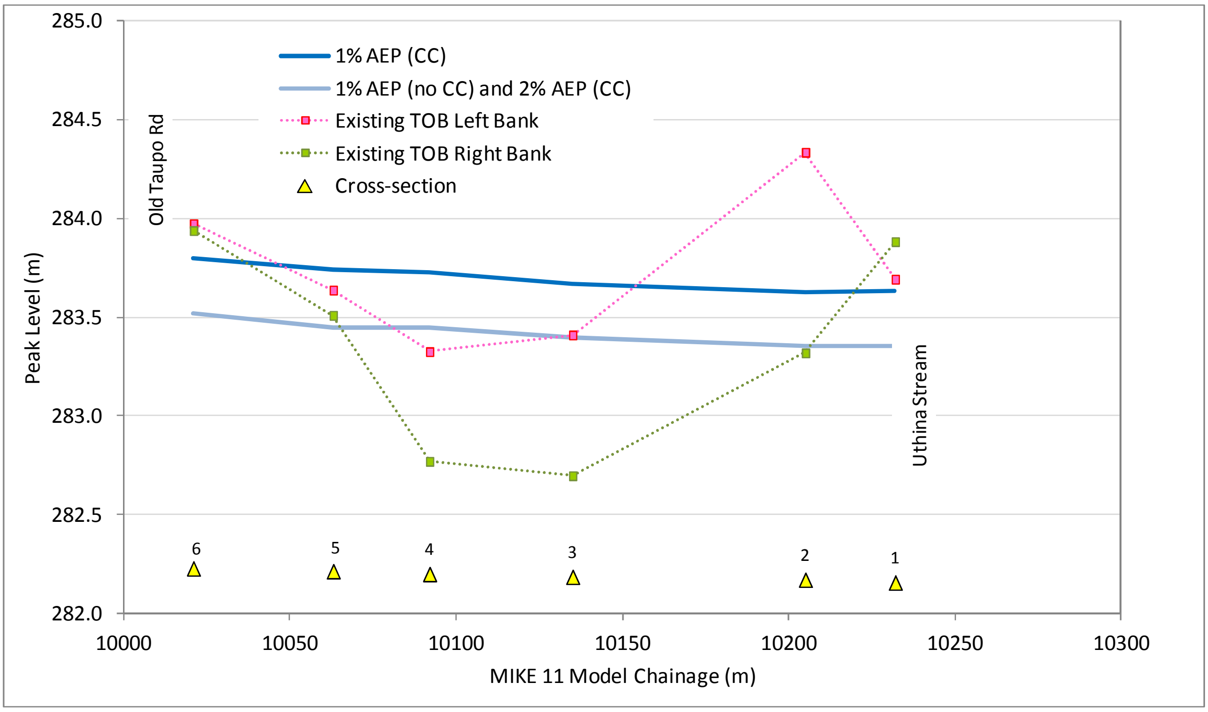

Figure 16 Peak flood levels, Mangakakahi Stream, existing situation

8 Design Stopbank and Floodwall Requirements

The model has been run with raised stopbanks or floodwalls along the entire modelled reaches of the Utuhina Stream and Mangakakahi Streams, including upstream of Old Taupo Road. Results are indicative as levels would depend on the exact location and batter slopes of the flood defences and the width of the flood channel.

Design levels are as indicated in Figures 17 and 18 and Appendix J. A freeboard of 500 mm is assumed, as specified in the Rivers and Drainage Asset Management Plan.

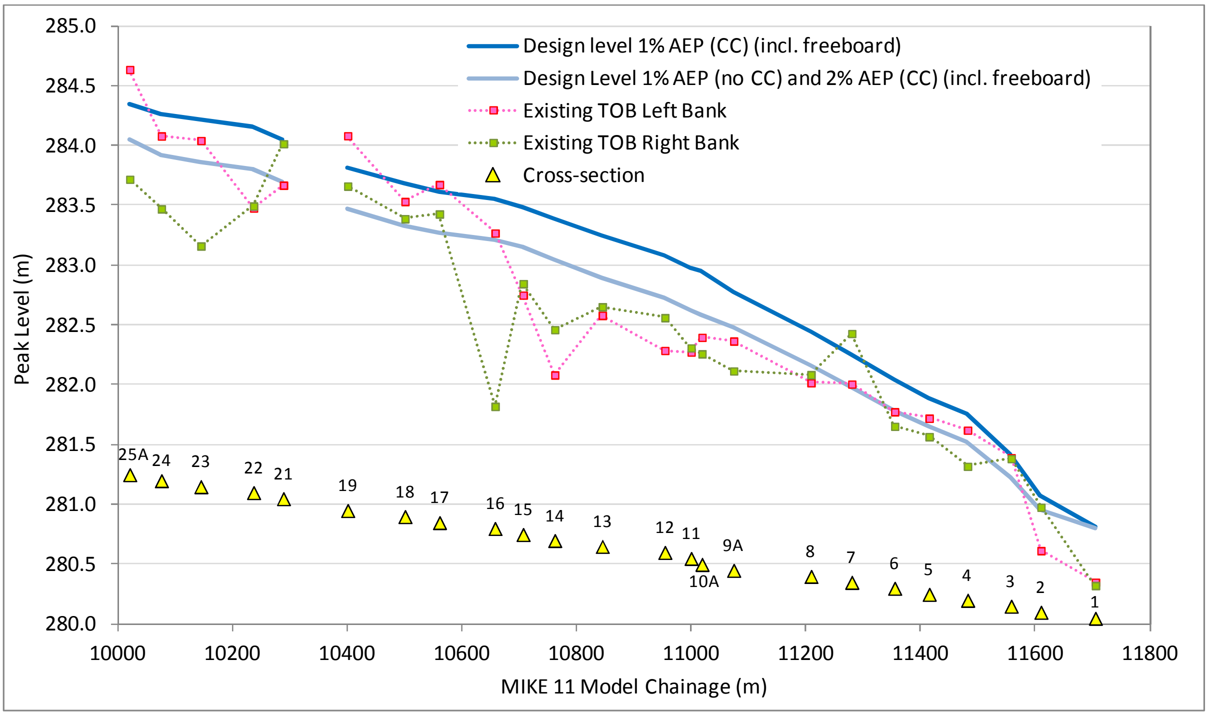

Figure 17 Design levels (including freeboard) for indicative flood defence option, Utuhina Stream

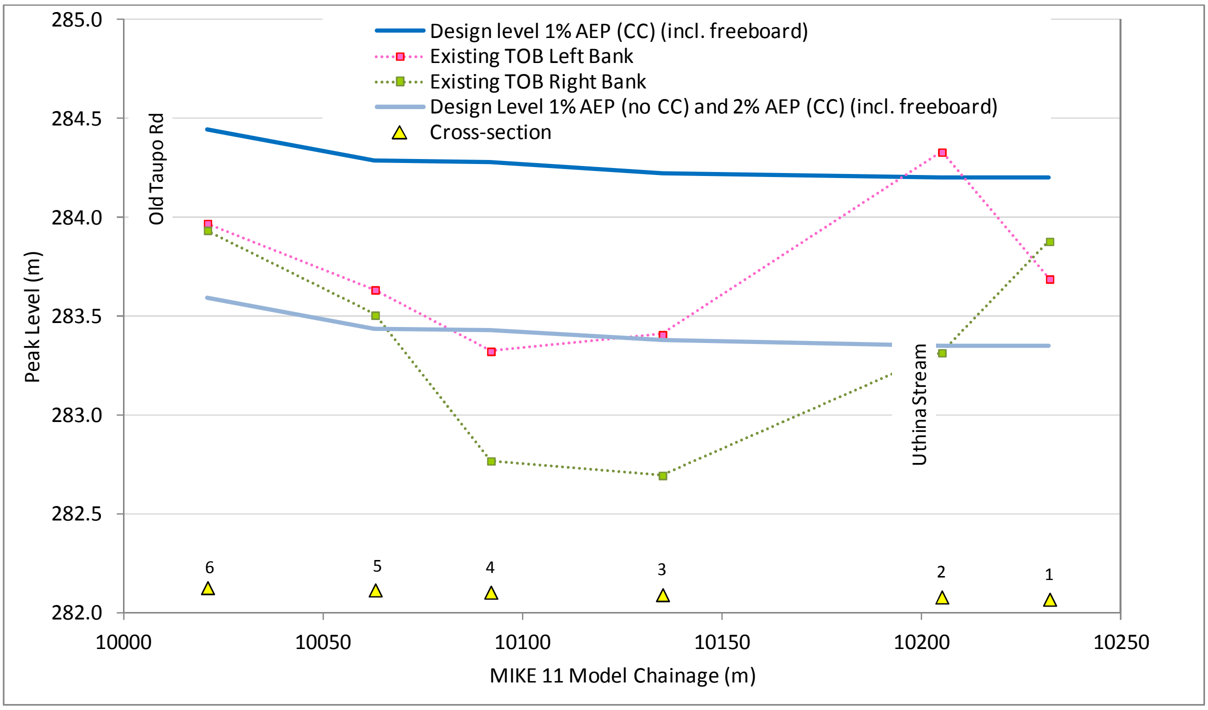

Figure 18 Design levels (including freeboard) for indicative flood defence option, Mangakakahi Stream

9 Discussion and Recommendations

Extending the Utuhina model to the floodplain, utilising the latest LiDAR data, has enabled the flood hazard to be more accurately mapped. It is clear that the industrial and residential properties in the vicinity, as well as the road network, are at risk of significant flooding, more so under climate change scenarios.

A reduction in estimated design flows has however significantly reduced the predicted flood extent downstream of the abandoned railway line. The flood hydrology of the stream nonetheless remains an area for further monitoring and analysis. The HEC-HMS hydrologic model used by RDC could be reviewed, and at the least updated for HIRDS v3. The sensitivity of downstream flows to temporal and spatial patterns of storm rainfall in the Utuhina and Mangakakahi catchments could be tested. The work of Robert Monk in using the long record of Whakarewarewa rainfall data to refine the stream flood frequency estimates could also be reviewed.

Further design work on the effect of changes to the Mangakakahi detention dam should be carried out, again in conjunction with tests on sensitivity to temporal and spatial patterns of storm rainfall.

Continued monitoring of flood events, including high flow gauging and collecting flood level data, is strongly encouraged.

To better understand the effect of bank overflows upstream of Old Taupo Road on downstream flows, as well as assessing any flood risk to those upstream areas, it is recommended that the hydraulic model be extended upstream at least as far as the Otamatea confluence. Survey cross-sections in the Utuhina Stream between the Otamatea Stream and Old Taupo Road will be required for that.

Similarly the model should be extended up the Mangakakahi Stream, at least as far as the detention dam. The model could be combined with the RDC model for this, but in the first instance the raw Mangakakahi Stream survey data used in the RDC model should be obtained and reviewed. After such review, it may be that a new survey is deemed necessary. At the same time, the datum of the Mangakakahi at Depot St recorder should be levelled in terms of Moturiki Datum.

The likelihood and effect of additional scour of the main channel bed, over and above that assumed in the current modelling, is another issue that could be investigated further. As the model stands now the predictions are likely to be conservative, although this is entirely appropriate for design purposes at this stage.

Finally, it is worth noting that it is now possible within MIKE FLOOD to combine stormwater and surface water models and run them as a single dynamically linked model (i.e. a 3-way coupled model: pipes-open channel –floodplain). The ability of the stormwater network to cope with runoff and deliver it to the stream is of relevance to the flood hazard, especially in the lower catchment in flood events. At some point in the future, it will be worthwhile to at least consider developing such a 3-way coupled model to provide a more complete understanding of the flood hazard.

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Appendix A Flow Summary, Utuhina Stream at Depot Street, 2005-2012

Environment Bay of Plenty
Hydrological Flow Summary

Date Complied	November 2013	**Site Number**	14637
Compiled by	C G Putt	**River**	Utuhina
		Station	S.H.5 Bridge.
Metric Map Reference	U16:939 358		
Catchment Area (km²)	55	**Period of Summary**	2005 to 2010

Statistical Summary

Flow (ℓ/s)			
Minimum Flow	613	Maximum Flow	31146
Mean Annual Minimum Flow	963	Mean Annual Maximum Flow	18111
Mean Flow	1852	Mean Summer Flow	1684
Median Flow	1666	Mean Autumn Flow	1754
Mean Specific Flow (/km²)	34	Mean Winter Flow	2180
		Mean Spring Flow	1854
Low Flow Distribution Fit	GEV	Peak Flow Distribution Fit	GEV
7 day Low Flow (Minimum)	877	Peak Flow (5 yr Return)	25250
7 Day Low Flow (Mean Annual)	1283	Peak Flow (10 yr Return)	28800
7 day Low Flow (5 yr Return)	1055	Peak Flow (20 yr Return)	31400
7 Day Low Flow (10 yr Return)	918	Peak Flow (50 yr Return)	34000
		Peak Flow (100 yr Return)	

Annual Summaries

Year	Flow (ℓ/s)				Year	Flow (ℓ/s)		
	Minimum	Mean	Maximum			Minimum	Mean	Maximum
2006	1273	1850	21688					
2007	825	1638	15071					
2008	711	1791	22012					
2009	969	1739	15982					
2010	613	1723	11667					
2011	1245	2117	31146					
2012	1386	2122	22244					

Flow Distribution

Flow (ℓ/s)

Percentiles	0	1	2	3	4	5	6	7	8	9
0	31146	5689	4019	3416	3099	2888	2730	2621	2537	2468
10	2408	2354	2312	2274	2236	2203	2172	2140	2112	2086
20	2061	2038	2018	1999	1981	1965	1949	1935	1922	1909
30	1896	1885	1873	1860	1848	1836	1825	1813	1801	1790
40	1777	1766	1753	1741	1728	1717	1706	1695	1685	1675
50	1666	1656	1645	1636	1626	1617	1608	1599	1590	1581
60	1572	1564	1556	1547	1539	1531	1522	1515	1508	1500
70	1492	1484	1476	1468	1461	1452	1443	1436	1428	1421
80	1413	1404	1394	1385	1373	1361	1349	1337	1326	1311
90	1298	1283	1262	1234	1193	1151	1115	1080	1020	923
100	613									

Appendix B Utuhina Stream Flow Recorder Data

Email correspondence between Craig Putt (BOPRC) and Philip Wallace (River Edge Consulting).

From: Craig Putt [Craig.Putt@envbop.govt.nz]
Sent: Tuesday, 12 November 2013 4:37 p.m.
To: Philip Wallace
Subject: RE: Utuhina stream hydrology
Attachments: Mangakakahi at Depot St 1114681.csv

Hi Phil,

See attachment and notes below.

Regards,

Craig Putt | Environmental Data Officer | Rotorua | Extn: 7579

From: Philip Wallace [mailto:philip.wallace@riveredge.co.nz]
Sent: Tuesday, 12 November 2013 11:19 a.m.
To: Craig Putt; Debbie Fransen
Cc: Mark James; 'Peter Blackwood'
Subject: RE: Utuhina stream hydrology

Hi Craig,
Some more thoughts:

1. Rating curves for Lake Rd – Bit hard to see from the graph you sent, but it does not look like the rating curves show a simple before and after situation (e.g, upper curve has 1972, 1974 and April79 gaugings, while Feb79, 1980 and 1982 gaugings fit on lower curve. 1965 gauging in between). So does that mean that it would be uncertain what rating to apply to any given annual peak?

Yes.

2. The following comment in the cmm file for Depot St that you sent me has caught my eye: *Site was previously known as Utuhina at Old Taupo Road, when it was approximately 400m upstream from Depot Street location. Mangakakahi Stream inflow between two sites. High flow gaugings were still performed from the Old Taupo Road bridge until July 2010.*

Site No. '14637' was originally assigned to Utuhina at Old Taupo Rd Bridge, but there was never any data collected there prior to the Depot St site being installed. The only high stage gauging performed off Old Taupō Rd (before we got the ADCP), was on 21/10/2005 (0.841m stage , 3329L/s flow).

The previous site was at Lake Rd, not Old Taupo Rd (or was there another site there as well?). What were the high flow gaugings at OTR until 2010? Or is this an error? (Possible that the confusion arises because the Lake Rd site was also referred to as Utuhina@SH5. SH5 used to go along Lake Rd, now SH5 is Old Taupo Rd). Is it possible that the 2 rating curves you sent for "Lake Rd" are in fact two different sites (Lake Rd and OTR)?

The 2 rating curves for "Lake Rd" are for the Lake Rd site (14610).

3. 2011 flood gauging: A comment you made to me shortly afterwards was along the lines of "Results also suggested that the newer ADP flow meter technology used gives higher flow estimates than conventional meters." So, previous (Lake Rd) data set could be underestimating the flows, and flood freq analysis therefore underestimates design flows for that period (1968-1997)?

I don't have enough evidence to get into that discussion. We have not deliberately attempted to compare mechanical meter gaugings with concurrent ADCP gaugings at a range of flows, at this site.

4. *Mangakakahi Stream flow data has been examined in relation to this event* [Aug2010], *but it does not show any unusual trends.* What flow data are these? Is there a Mangakakahi flow recorder? (RDC?) If there is, then the data from that could be very helpful.

I'll send it to you. The file is large and it only covers the peaks, as the resolution is quite high.

5. You also mention that your Depot St data will be audited – is this by NIWA? When do you think that will be completed? In the interim, I'm going to assume that your data are all fine.

Audit is by Doug McMillan (Environmental Quality Systems, Christchurch). I'll let you know when it's done.

Notwithstanding all these uncertainties etc, for our immediate design purposes, what I suggest is:
The Depot St annual peaks be added to the Lake Rd record, and the flood frequency be recalculated for this combined data set. To be conservative, maybe you could increase the Depot St peaks by 10% to allow for inflows further downstream? (For the 29Jan2011 event, the Kuirau peak coincided with the Depot St peak, and was about 8% of the Depot St peak. Other events don't seem to coincide as well, so a 10% allowance for the Kuirau and the other 2 main subcatchments would be conservative). Allowing for climate change introduces more uncertainty, so I am not too concerned about any minor effects like such lower stormwater inflows assumptions.

Would you be able to reprocess the flood frequency accordingly please Craig? (Or at least send me the annual peaks 1968-1996 for Lake Rd, so that I can do it). As this is for our design purposes, the results don't have to go in your data summaries if you'd rather they didn't.
Annual peaks from 1968-1996:

```
~~~ NIWA Tideda ~~~ Environment Bay of Plenty            12-NOV-2013 16:35
~~~ PEXTREME ~~~
Source is Utuhina at SH 5 Bridge 14610.m* Site 14610 Utuhina at SH 5 Bridge
From 19680101 000000 to 19961231 240000
Interval =          0
Rating applied
Flow m3/s
```

Year	Mean	Coeff. of Var.	Minimum	Date	Maximum	Date
1968	2.2230	0.33	1.1450	19680303 240000	11.615	19680410 055000
1969	2.1925	0.44	1.3210	19690102 120000	13.982	19690925 224000
1970	2.2115	0.58	0.89600	19700303 240000	21.243	19700814 050500
1971	2.9414	0.44	1.3210	19710411 240000	25.418	19710513 064500
1972	2.4782	0.44	1.1870	19720222 240000	18.241	19720309 210300
1973	1.8690	0.33	1.1040	19730224 240000	13.881	19730421 033000
1974	2.1687	0.75	1.1970	19740303 240000	35.509	19741203 150200
1975	2.1652	0.34	1.4150	19751224 013000	17.017	19750615 002000
1976	2.0147	0.50	1.3740	19761123 194500	27.383	19760708 050000
1977	1.9071	0.43	1.2180	19770209 194500	15.600	19770628 200000
1978	1.6275	0.37	1.0630	19780210 211500	13.251	19780418 050000
1979	2.1475	0.50	1.1550	19790203 020000	13.733	19790802 034500
*1980	1.8546	0.25	1.3260	19800821 130301	10.196	19801220 140546
*1981	1.9883	0.37	1.3570	19810107 171634	15.569	19811116 013234
*1982	1.5865	0.29	1.0720	19821103 182410	11.498	19820622 190751
*1983	1.7697	0.62	1.0670	19830322 220657	17.493	19831025 084500
*1984	1.7613	0.32	1.0990	19840628 222908	17.149	19840401 050000
*1985	1.6860	0.42	1.0870	19850512 122220	12.993	19850904 020000
*1986	1.7389	0.72	0.98000	19860516 060353	28.403	19860104 170000
*1987	1.4054	0.28	1.0030	19870221 225312	11.100	19871217 154500
*1988	1.6173	0.58	1.0510	19880202 144500	22.488	19880808 200000
*1989	2.1019	0.43	1.4110	19890430 143931	18.408	19890926 120000
*1990	2.0332	0.52	1.4450	19900406 172908	22.759	19900805 190028
*1991	1.6713	0.37	1.2650	19910301 174500	15.874	19910928 164500
*1992	1.8584	0.51	1.4230	19920111 224627	18.702	19921203 133000
*1993	1.5834	0.45	1.2630	19930326 181500	22.790	19930516 184308
*1994	1.9606	0.56	1.1810	19940410 173000	20.454	19940412 103000
1995	2.1898	0.67	1.2270	19950327 081422	24.785	19950528 231500
*1996	2.1366	0.69	1.3460	19960202 232800	47.746	19960522 050000

```
Average Annual Minimum    1.2018          Maximum    19.358     (complete yrs)

'*' denotes years with gaps in the data or incomplete years
Coeff. of Var. = sd/mean

Minimum is          0.896000     at 19700303 240000
Maximum is           47.7460     at 19960522 050000
Mean is              1.96538
Std. Dev. is         1.02749
Coeff. of Var. is      0.523

End of process
```

Am happy to give you a call if you want to discuss.

Regards
Phil

PHILIP WALLACE
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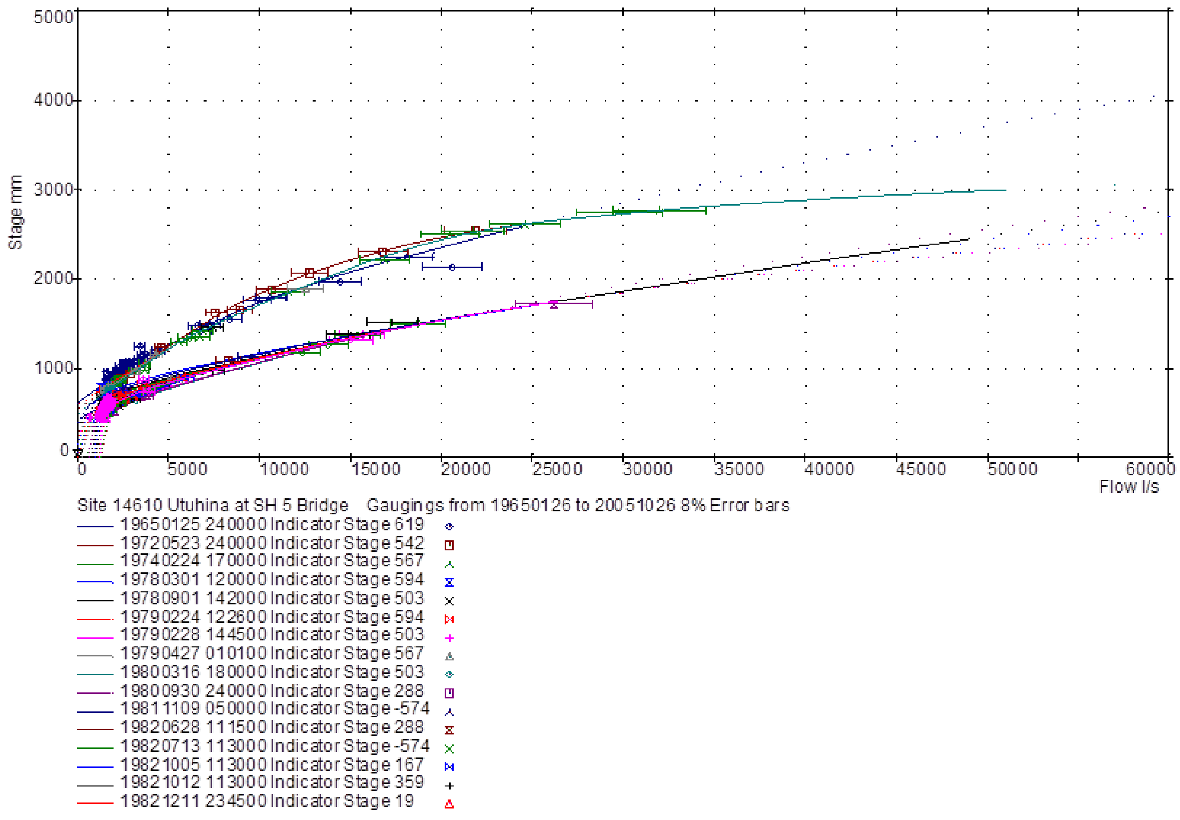
Wellington 6141
Tel 021 238 7515
Fax 04 802 5424
www.riveredge.co.nz

From: Craig Putt [mailto:Craig.Putt@envbop.govt.nz]
Sent: Friday, 8 November 2013 4:26 p.m.
To: Philip Wallace
Subject: RE: Utuhina stream hydrology

Phil,

Here is what the Utuhina at Lake Rd Bridge discharge ratings look like:



As you can see, there are two rating profiles, which could be projected in various directions. There aren't any gaugings above the 30-32m3/s flow range and so a Q50 of 55m3/s is essentially an 'educated guess', based on the available data. A Q50 of 34m3/s is not out of the question, bearing in mind that we only have 7 years of data at Depot St.

Regards,

Craig Putt | Environmental Data Officer | Rotorua | Extn: 7579

From: Philip Wallace [mailto:philip.wallace@riveredge.co.nz]
Sent: Friday, 8 November 2013 1:22 p.m.
To: Craig Putt
Cc: Debbie Fransen; Mark James; 'Peter Blackwood'
Subject: RE: Utuhina stream hydrology

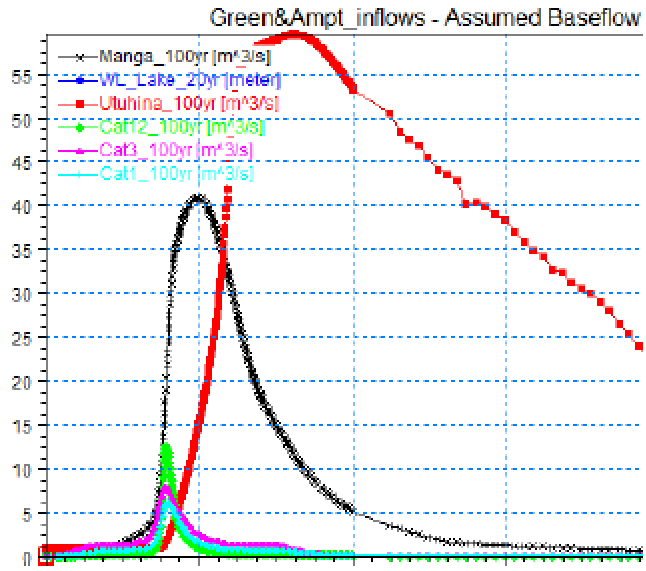
Great, thanks. I see that the Depot St flows have changed (slightly lower peaks) than what I was given in 2011 and had used for calibration – presumably because you've updated the rating curve.

For the 29th event at least, the Kuirau peaks at about the same time as the Utuhina and is about 10% of the Depot St flows – that would be significant for that event at least.
Below is a plot of the RDC hydrology model results, for a 100yr+ClimateChange scenario, FYI. The Kuirau catchment is "Cat1_". I note that these results give larger flows for "Cat3_" and "Cat_12", which are the catchments for the drains along the old railway. The Utuhina plot refers to the stream upstream of the Mangakakahi confluence.

Anyway, this still leaves us to decide what to do about the design flows. – ie has the Q50 etc decreased? The difference between the Depot St results post-2005 (Q50= 34 m3/s) and the Lake Rd site pre1996 (Q50 = 55m3/s (although older rating?)) seems too large to attribute to the stormwater/Kuirau etc inflows. Peter Blackwood's memo 2001 on Utuhina flows notes that the Lake Rd recorder site flow record straddled a cycle of the Interdecadal Pacific Oscillation and so wouldn't be expected to show any bias to flood-rich or benign periods. Recent IPO values suggest that if anything, the period since 2005 might be expected to be a flood-rich period. So we can't attribute the lower design flow to a benign IPO phase.

We could just assume that the Utuhina design flows should stay the same, seeing as we only have ~7 years of additional data. However, that might be overly conservative and there could be significant cost savings (to provide the 1% standard of protection) if we could be confident that design flows have dropped.

Lots of factors to consider here. I'd be interested in any thoughts anybody might have.
Regards
Phil



From: Philip Wallace [mailto:philip.wallace@riveredge.co.nz]
Sent: Friday, 8 November 2013 11:22 a.m.
To: Craig Putt
Cc: Debbie Fransen
Subject: RE: Utuhina stream hydrology

Thanks,
FYI, I've done a bit more analysis on the data you just sent. If we compare the same (more or less) flood events for the 2 sites, then the Depot St peaks (max moving average you supplied) are typically 20-30x the peaks in the Kuirau, and typically occur after the Kuirau peak. See columns M,N in the attached. Might get a better idea comparing actual hydrographs for the largest events. Anyway, I'll send the hydrological model results later.

Could you send me the Kuirau flow hydrographs for the 2 flood events in Jan 2011 please? (ie 23rd, 29th Jan 2011). – I've used those events to calibrate the Utuhina model so would be good to at least check that my assumptions for that subcatchment are reasonable.

Cheers
Phil

From: Craig Putt [mailto:Craig.Putt@envbop.govt.nz]
Sent: Friday, 8 November 2013 10:58 a.m.
To: Philip Wallace
Cc: Debbie Fransen
Subject: RE: Utuhina stream hydrology

Phil,

The Kuirau Stream at Tarewa Road record started 25/09/2008 and is still in operation.

See attachment for the 50 largest flows for each site, based on maximum moving averages over 6hr interval (non-overlapping). Most of the peaks correlate well, in terms of timing, but there is not a consistent relationship in terms of flow volume.

Regards,

Craig Putt | Environmental Data Officer | Rotorua | Extn: 7579

From: Philip Wallace [mailto:philip.wallace@riveredge.co.nz]
Sent: Friday, 8 November 2013 8:18 a.m.
To: Craig Putt
Cc: Debbie Fransen
Subject: RE: Utuhina stream hydrology

Thanks Craig,

Results from some hydrological modelling that RDC carried out indicate that in flood flows, the stormwater peak flows occur well before the main Utuhina and are substantially smaller anyway. The implication of that is that peak flows at Lake Rd would be very similar to those of Depot St. I'll send you some more info on that later today. However, you might be able to confirm that by comparing the Kuirau Stream recorder and Depot St recorder for specific flood events?

Useful for me to know that there is a recorder at Tarewa Rd – could be useful for future calibration. How long is the record?

Regards
Phil

From: Craig Putt [mailto:Craig.Putt@envbop.govt.nz]
Sent: Friday, 8 November 2013 8:08 a.m.
To: Philip Wallace
Subject: RE: Utuhina stream hydrology

Hi Phil,

Normally we would do a 5 year period, but since it's such a short data set and the ratings have had a complete overhaul, I included 2011-2012 – my typo.

I don't recall any obvious debris causing a backwater at the time of the August 2010 gaugings. A debris blockage at the old rail bridge would make sense, as from time to time willow branches have been seen to be trapped on the abutments.

I was reluctant to combine the Lake Rd and Depot St data sets, without quantifying the storm water inflows first. However, a 21m3/s increase is highly unlikely. We have a recorder on the Kuirau Stream at Tarewa Rd which collects most of the runoff from Kuirau Park (except for the sports fields). When the storm water pipe is nearly full, it has been gauged at 400L/s. From my personal observations, I would say that this is the largest formed inflow, between the two sites.

The .cmm file contains comments relevant to the Utuhina at Depot St site. It is a text file which can be opened with WordPad or Notepad.

Regards,

Craig Putt | Environmental Data Officer | Rotorua | Extn: 7579

From: Philip Wallace [mailto:philip.wallace@riveredge.co.nz]
Sent: Thursday, 7 November 2013 5:52 p.m.
To: Craig Putt; Debbie Fransen
Subject: RE: Utuhina stream hydrology

Hi Craig,
Thanks for this.
I'm a bit confused though – the summary talks about the period of data 2005 to 2010, but you've got 2011 and 2012 in the annual summaries. I assume that your summary is actually for 2005 to 2012.
Re the Aug 2010 event - do you think there could have been some backwater from debris blockage at the old rail bridge? I guess we'll never know.

Interesting that the Q50 figure you've given (34m3/s) is substantially less than the prev data summary (1966-96) for the Lake Rd site (55m3/s). There are only a few stormwater subcatchment inflows between the two sites. Would it be reasonable to combine the two data sets (1966-96 plus 2005-2012)?

Not sure what the cmm file is, or if any use to me.

Regards
Phil

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Fax +64 7 871 9178
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From: Craig Putt [mailto:Craig.Putt@envbop.govt.nz]
Sent: Thursday, 7 November 2013 4:45 p.m.
To: Debbie Fransen; philip.wallace@riveredge.co.nz
Cc: Craig Putt
Subject: RE: Utuhina stream hydrology

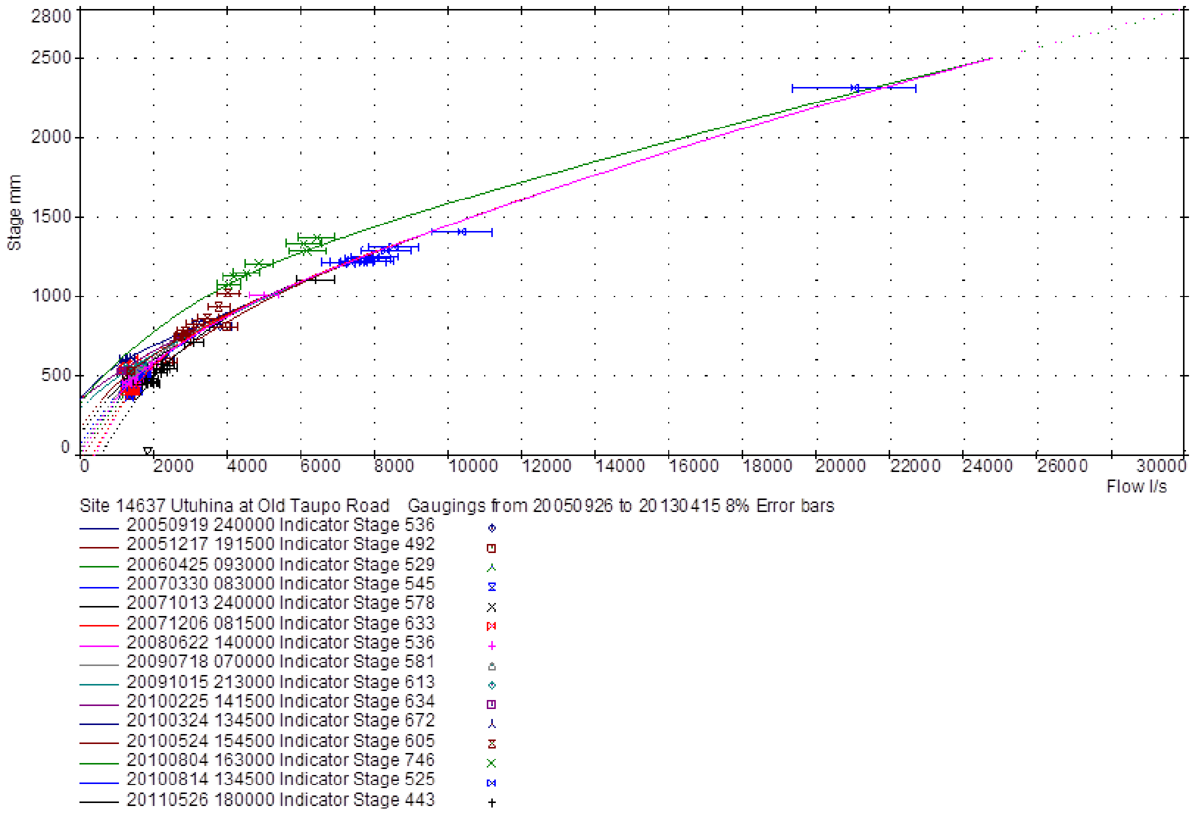
Debbie & Phil,

Utuhina at Depot Street (#14637) flow data summary attached, as requested.

Note that this data has been audited, but is yet to be independently reviewed. I am sending it away for a review, this week.

Phil – we were unable to resolve the unusual results for flood gaugings during 04 August 2010 storm event. We have settled on a standard rating curve for the site, but this event does not fit. Subsequent high stage gaugings fit the standard shape very well. See comment and green rating in the chart below:

@@ 14637 20100804 153000
Rating 20100804 153000 differs from the usual rating shape. ADCP gaugings #415246 to #415259 indicate a substantial and unusual backwater effect. These gaugings were collected over a single event, during the period on 20100804 153400 to 20100804 180700. On-site staff gauge observations were recorded throughout the gaugings. Mangakakahi Stream flow data has been examined in relation to this event, but it does not show any unusual trends.



Regards,

Craig Putt | Environmental Data Officer | Bay of Plenty Regional Council | Rotorua, New Zealand | Ph: 0800 884 881 x7579 | Web: www.boprc.govt.nz
Please consider the environment before printing this email

Appendix C Utuhina Stream Flood Frequency Analysis

Table C.1 Stream Flow Annual Maxima (m^3/s)

Flows, Utuhina @ Lake Rd				
Year	Annual maximum flow	Comment		
1967	48.5			from PLB memo 25May2001: 48.5
1968	11.615	19680410	55000	
1969	13.982	19690925	224000	
1970	21.243	19700814	50500	
1971	25.418	19710513	64500	
1972	18.241	19720309	210300	
1973	13.881	19730421	33000	
1974	35.509	19741203	150200	PLB memo 25May2001: 35.5
1975	17.017	19750615	2000	
1976	27.383	19760708	50000	
1977	15.6	19770628	200000	
1978	13.251	19780418	50000	
1979	13.733	19790802	34500	
1980	10.196	19801220	140546	
1981	15.569	19811116	13234	
1982	11.498	19820622	190751	
1983	17.493	19831025	84500	
1984	17.149	19840401	50000	
1985	12.993	19850904	20000	
1986	28.403	19860104	170000	
1987	11.1	19871217	154500	
1988	22.488	19880808	200000	
1989	18.408	19890926	120000	
1990	22.759	19900805	190028	
1991	15.874	19910928	164500	
1992	18.702	19921203	133000	
1993	22.79	19930516	184308	
1994	20.454	19940412	103000	
1995	24.785	19950528	231500	
1996	47.746	19960522	50000	PLB memo 25May2001: 54
2006	23.8568	Assumed = Depot St flow + 10%		
2007	16.5781	Assumed = Depot St flow + 10%		
2008	24.2132	Assumed = Depot St flow + 10%		
2009	17.5802	Assumed = Depot St flow + 10%		
2010	12.8337	Assumed = Depot St flow + 10%		
2011	34.2606	Assumed = Depot St flow + 10%		
2012	24.4684	Assumed = Depot St flow + 10%		

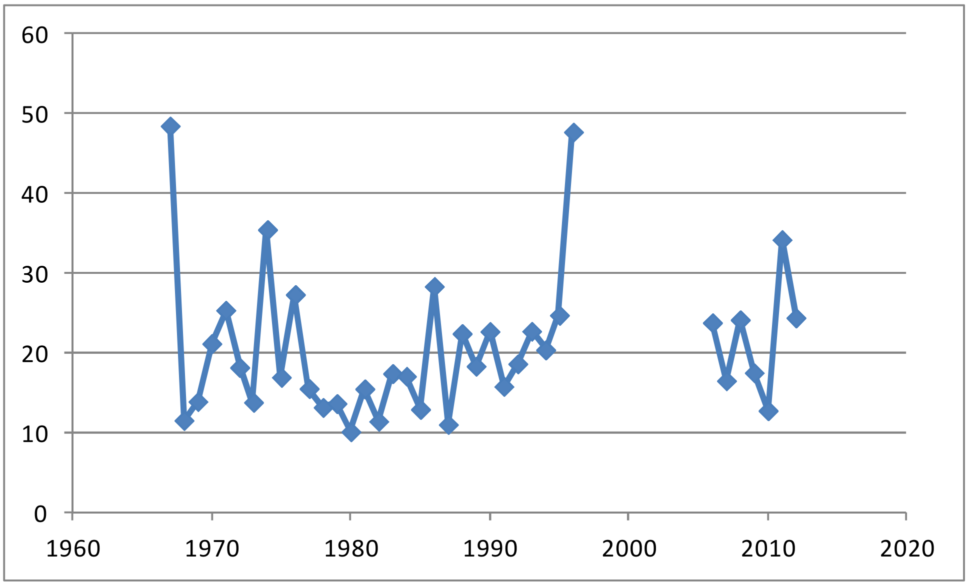


Figure C.1 Annual maxima flows for Utuhina Stream at Lake Rd (assumed for 2006-2012)

Table C.2 Analysis of annual maxima using Log-Pearson III

n = 37

Q(1) = 48.5; Q(2) = 11.615; Q(3) = 13.982; Q(4) = 21.243; Q(5) = 25.418; Q(6) = 18.241; Q(7) = 13.881; Q(8) = 35.509; Q(9) = 17.017; Q(10) = 27.383; Q(11) = 15.6; Q(12) = 13.251; Q(13) = 13.733; Q(14) = 10.196; Q(15) = 15.569; Q(16) = 11.498; Q(17) = 17.493; Q(18) = 17.149; Q(19) = 12.993; Q(20) = 28.403; Q(21) = 11.1; Q(22) = 22.488; Q(23) = 18.408; Q(24) = 22.759; Q(25) = 15.874; Q(26) = 18.702; Q(27) = 22.79; Q(28) = 20.454; Q(29) = 24.785; Q(30) = 47.746; Q(31) = 23.8568; Q(32) = 16.5781; Q(33) = 24.2132; Q(34) = 17.5802; Q(35) = 12.8337; Q(36) = 34.2606; Q(37) = 24.4684.

skew coefficient [of the logarithms] C_s = 0.61

OUTPUT:

i	Return period T (yr)	Probability P (percent)	Frequency factor K	y = log (Q)	Flood discharge Q (m^3/s)
1	1.05	95.2	-1.454	1.042	11
2	1.11	90.1	-1.198	1.085	12
3	1.25	80	-0.857	1.142	14
4	2	50	-0.101	1.267	18
5	5	20	0.799	1.416	26
6	10	10	1.328	1.504	32
7	25	4	1.942	1.606	40
8	50	2	2.364	1.676	47
9	100	1	2.762	1.743	55
10	200	0.5	3.142	1.806	64

(from http://ponce.sdsu.edu/onlinepearson.php)

Appendix D Alternative Flood Frequency Distribution (Robert Monk)

Analysis of the 2011 flood event hydrology by Robert Monk of Sigma Consultants, outlined in email correspondence between Robert Monk and Philip Wallace. Selected attachments to these emails are reproduced here (Figures D.1 and D.2).

From: Robert Monk [robertm@sigmaconsult.co.nz]
Sent: Wednesday, 11 May 2011 6:15 p.m.
To: Philip Wallace
Subject: RE: 29 Jan 2011 Utuhina Stream Flood - Return Period Confirmation
Attachments: Utuhina Hydrographs.pdf

Hello Philip,

As a start to understanding the issue of a flood with a high peak flow having a flood level lower than a flood with a lower peak flow, I phoned Paul Andrews to discuss his confidence in the flood debris levels he measured after each flood. We also discussed his observations of the flows coming out of each subcatchment in the two storms. This discussion was very helpful in providing a starting point for the development of the analysis explained in the following excerpt from my draft report. The hydrographs are attached.

Two storms in late January caused the Utuhina Stream to flood. Storm rainfall recorded at Whakarewarewa rain gauge station on the southern edge of Rotorua city and Oturoa and Rotorua Airport to the northwest and east respectively are summarised as follows:

Rainfall Period	Raingauge	Total Rainfall	Maximum Intensity
2200 hrs, 22 Jan – 2200 hrs, 23 Jan	Oturoa	190.5mm	16.5mm/hr
	Whakarewarewa	206mm	17.5mm/hr
	Rotorua Airport	193.6mm	18.2mm/hr
2200 hrs, 28 Jan – 0600 hrs, 29 Jan	Oturoa	111.5mm	20mm/hr
	Whakarewarewa	129mm	26mm/hr
	Rotorua Airport	146.2mm	35.4mm/hr

In both storms, there is less than an hour's difference between when the heavy rain started and when it stopped at each of the raingauges, although the intensities peaked at different times. Maximum intensities increased from west to east. Because of the relatively short duration of the second storm, its total rainfall was also significantly higher in the east.

In the first storm, peak intensity was reached first at Whakarewarewa. Rainfall at the other two stations peaked six hours later, when there was also a secondary peak at Whakarewarewa. On the first of the appended flood hydrographs measured at the Depot Street gauging site, individual flood peaks from the three major subcatchments, the Otamatea, the Mangakakahe and the upper Utuhina, can clearly be seen occurring in sequence, accentuated by the pattern of peaks in the rainfall intensity. Separating the component hydrographs indicates that the flood peaks from the individual subcatchments were approximately as follows.

Otamatea	Mangakakahi	Upper Utuhina
3.8 m^3/sec	12.5 m^3/sec	16.2 m^3/sec

The upper Utuhina subcatchment was the dominant source contributing to the maximum recorded flow of 26.2 m^3/sec, which is expected to occur about once every four years on average in the future, allowing for climate change. However, had the flood peaks reached Depot Street simultaneously, the total flow would have been about 32m^3/sec, which has a future return period of about 8 years on average. The future return period of the dominant upper Utuhina component could be expected to be a little higher, perhaps 9 or 10 years on average.

Comparison of the rainfall depths recorded in the second storm with a depth-duration-frequency analysis of the Whakarewarewa rainfall record suggests that the future return period of this event will be approximately 14 years on average, taking into account the effect of climate change. .

In the second rainstorm, peak intensity was reached first at Oturoa Road, an hour later at Whakarewarewa and three hours later at the airport. It was different from the first storm in that it affected the total catchment in such a way that the flood peaks from the three subcatchments reached the Depot Street gauging site simultaneously, producing a combined peak flow of 34.8m^3/sec. This flow can be expected to occur about once every 11 – 12 years in future, which is consistent with the above return period estimate for the rainstorm. However, the peak flow from the upper Utuhina subcatchment was observed to be less in this flood than the 16.2 m^3/sec believed to have occurred in the first flood, and the peak flows from the other two subcatchments were proportionately greater. Thus peak flood levels measured from flood debris in the vicinity of Malfroy Road were 0.1 – 0.5m lower after the second storm than after the first.

I hope the above will help clarify matters for you.

Regards,

Robert Monk.
Sigma Consultants Ltd.

From: Philip Wallace [mailto:philip.wallace@riveredge.co.nz]
Sent: 10 May 2011 3:34 p.m.
To: Robert Monk
Subject: RE: 29 Jan 2011 Utuhina Stream Flood - Return Period Confirmation

Hi Robert,
Thanks for your call earlier this afternoon.
In short, I would be interested in your thoughts on the Whakarewarewa RF analysis and the 23rd vs 29th flood levels.
Note that the work I'm doing is for EBOP rather than Peter Dine, but he has a real interest in my findings as it impacts upon the Lake Rd bridge proposals. I'm still grappling with some of the issues, so happy to hear of anything you might add.

Regards

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Mob 021 238 7515

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From: Robert Monk [robertm@sigmaconsult.co.nz]
Sent: Wednesday, 11 May 2011 5:49 p.m.
To: Philip Wallace
Subject: FW: January Flood Levels, Utuhina Stream
Attachments: January Storm Rainfall Summaries.doc; Oturoa Rainfall, 22 - 29 Jan 2011.pdf; Rotorua Airport Rainfall, 22 - 29 Jan 2011.pdf; Gumbel 1.pdf; Gumbel 2.pdf; Gumbel 3.pdf; Gumbel 4.pdf; Gumbel 5 .pdf

Hello Philip,

Below is a copy of the information I sent to Peter Dine at RDC. He was not satisfied with my comparison between the measured rainfall at Whakarewarewa and HIRDS predictions for the same site.

Regards,

Robert Monk.
Sigma Consultants Ltd

From: Robert Monk
Sent: 10 May 2011 12:53 p.m.
To: 'Peter Dine'
Subject: RE: January Flood Levels, Utuhina Stream

Hello Peter,

I did not have enough up-to-date raw data to quickly provide an accurate estimate of the return period of the January rainstorms. Having obtained and analysed some of the data I needed, I can now provide you with a belated reply.

Before I do, I should confirm that, although I cannot vouch for all the flood debris levels Paul Andrews measured after the January storms, I have made independent checks using debris still visible immediately downstream of the two highest he measured some distance downstream of the Malfroy Rd Bridge and have found them to be about 0.1m different to my levels.

I have obtained rainfall data for the two January storms from the Oturoa and Airport raingauges as well as the one at Whakarewarewa. They are summarised in the attached table. The raw data from the additional raingauges is also attached.

In both storms, there is less than an hour's difference between when the heavy rain started and when it stopped at each of the raingauges, although the intensities peaked at different times. Maximum intensities increased from west to east. Because of the relatively short duration of the second storm, its total rainfall was also significantly higher in the east.

In the first storm, peak intensity was reached first at Whakarewarewa. Rainfall at the other two stations peaked six hours later, when there was also a secondary peak at Whakarewarewa. In the second rainstorm, peak intensity was reached first at Oturoa Road, an hour later at Whakarewarewa and three hours later at the airport.

I have determined the two-part frequency distributions for annual maximum rainfall depths measured between 1984 and 2011at Whakarewarewa for durations of 3, 6, 12 and 24 hours. They are shown on the first of the attached Gumbel plots. The solid lines are lines of best fit through the measured data. The lines of best fit for 3, 6, and 12 hour durations are almost parallel to the 24 hour line of best fit.

The dashed lines have been drawn parallel to the 24 hour line of best fit when the daily data measured between 1900 and 2011 are included , as shown in the second Gumbel plot. They represent an estimate of how the frequency distributions will look 85 years hence, if climate change does not affect it as predicted. I have assumed that the relationship between the data for the different durations, as shown in the first Gumbel plot, will be retained as the record length increases. This assumption needs to be validated by repeating this analysis on the Rotorua Airport annual maxima.

In the third Gumbel plot, the estimated long term frequency distributions are compared with HIRDS version 3 estimates for Whakarewarewa and your District Council design curves, both with the climate change allowance removed. The HIRDS estimates are more widely spread than the estimates I have made, falling below the 3 hour duration dashed line and rising above the 24 hour line. I am surprised that NIWA have allowed their model to differ so much from the Whakarewarewa 24 hour data, since it is the longest record in the region. Maybe the Airport data will provide the reason. Being closely aligned to HIRDS version 1.5b estimates, which conform to an EV Type1 distribution, your District Council design curves also fall below the dashed line for 3 hours duration when the return period exceeds 10 years.

I have plotted the peak rainfall depths for 3, 4, 5 and 6 hour durations at the height of the two January storms on the estimated long term frequency distributions in the fourth Gumbel plot, and confirmed that the time of concentration for the Utuhina catchment is about 4 hours. This plot indicates that the return periods for the four hour periods of maximum intensity at Whakarewarewa on 23rd and 29th January are about 4 years and 14 years respectively. However, because of its twin peaks, the return period of the storm on 23rd January is much greater than 4 years for longer durations, culminating at 120 years for the 24 hour event.

Next is the question of what all this may mean in terms of the frequency distribution of Utuhina Stream flows measured at Depot St. On my amended frequency distribution for this gauging site, attached as Gumbel 5, I have dotted in the shape of the 3 hour rainfall frequency distribution for the 1984 – 2011 Whakarewarewa record. It fits closely with the amended flow distribution. This suggests that the long term frequency distribution for the flow record will probably be as indicated by the dashed line (long dashes), taken from the 1900 – 2011 record of 24 hour maximum rainfalls. When transposed on to this line, the long-term return period of the flow measured at Depot St appears to be about 23 years.

To validate the basic assumptions used above using Rotorua Airport data, I will first have to download semi processed and raw data from NIWA's CliFlo database, and then process it further. Not having used the database before, I am not sure how long this will take. Alternatively, Met Service is willing to have their Consultant Meteorologist assemble the data for a fee of $400 plus GST.

Do you want me to go ahead with the Rotorua Airport data analysis?

Regards,

Robert Monk.
Sigma Consultants Ltd

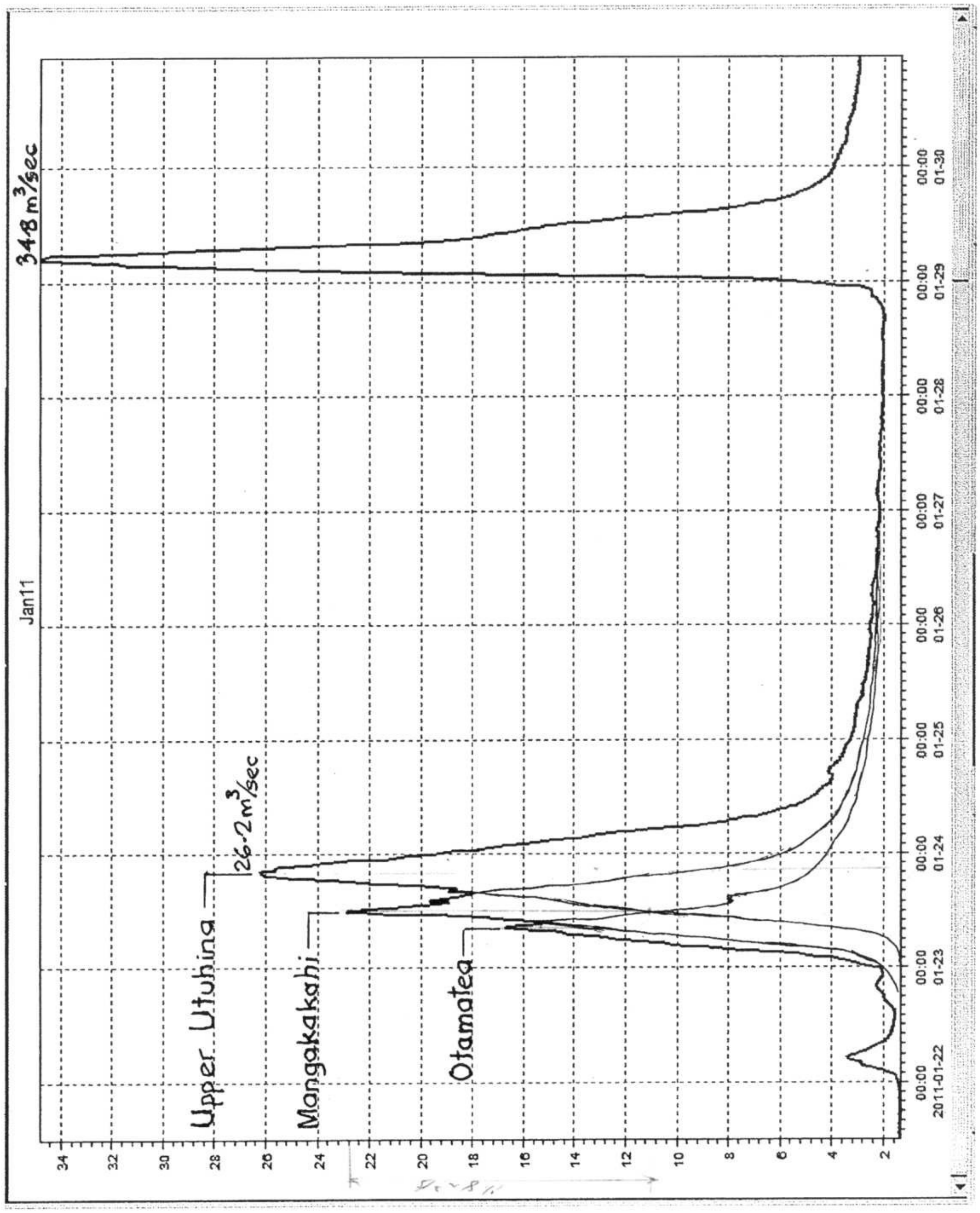

Figure D.1 Attachment "Utuhina Hydrograph.pdf" to Monk email of 11 May 2011 6:15pm.

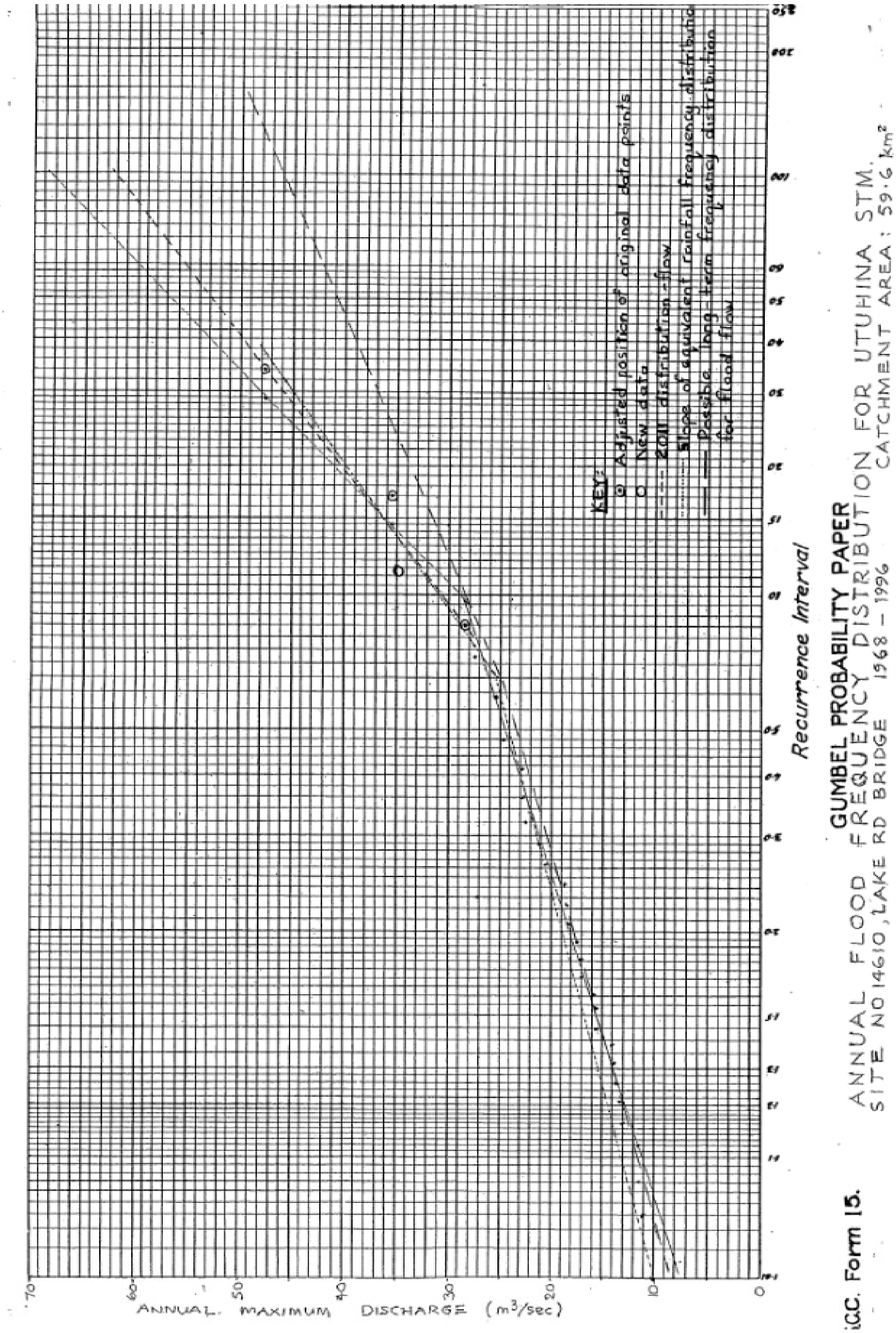

Figure D.2 Attachment "Gumbel 5" to Monk email of 11 May 2011 5:49pm.

Appendix E Lake Rotorua Level Summary (Post-Control, 1972-2010)

Bay of Plenty Regional Council
Post-Control Lake Level Summary

Site Number	14615		**Date compiled**	November 2012	
Lake	Rotorua		**Compiled by**	H MacKenzie	
Station name	Town Warf				
NZTM Reference	1885150	5775015	**NZMG Reference**	2795293	6336541
Catchment area (km²)	500		**Period of Summary**	Sept 1972 to 2010	

Post-Control Statistical Summary

Level - Moturiki Datum (mm)			
Minimum Level	279359	Maximum Level	280450
Mean Annual Minimum Level	279623	Mean Annual Maximum Level	280101
Mean Level	279815	Mean Summer Level	279765
Median Level	279803	Mean Autumn Level	279772
		Mean Winter Level	279876
		Mean Spring Level	279851
Low Level Distribution Fit	GEV	Peak Level Distribution Fit	GEV
7 day Low Level (Minimum)	279371	Peak Level (5 yr Return)	280203
7 Day Low Level (Mean Annual)	279637	Peak Level (10 yr Return)	280248
7 day Low Level (5 yr Return)	279586	Peak Level (20 yr Return)	280283
7 Day Low Level (10 yr Return)	279551	Peak Level (50 yr Return)	280319
		Peak Level (100 yr Return)	280340

Post-Control Annual Summaries

Year	Level - Moturiki Datum (mm)				Year	Level - Moturiki Datum (mm)		
	Minimum	Mean	Maximum			Minimum	Mean	Maximum
1985	279589	279794	280042		1998	279624	279873	280450
1986	279571	279799	280231		1999	279648	279844	280128
1987	279597	279782	279952		2000	279650	279843	280122
1988	279654	279806	280071		2001	279649	279837	280151
1989	279591	279885	280200		2002	279659	279785	280030
1990	279638	279837	280238		2003	279607	279789	280058
1991	279608	279797	280057		2004	279656	279861	280112
1992	279674	279832	280089		2005	279651	279877	280086
1993	279623	279757	280054		2006	279741	279912	280123
1994	279637	279844	280228		2007	279701	279846	280136
1995	279651	279904	280228		2008	279641	279861	280194
1996	279738	279915	280153		2009	279668	279830	280077
1997	279721	279857	280080		2010	279640	279846	280148

Post-Control Level Distribution

Level - Moturiki Datum (mm)

Percentiles	0	1	2	3	4	5	6	7	8	9
0	280450	280143	280098	280070	280052	280038	280027	280016	280005	279995
10	279985	279976	279969	279961	279954	279948	279942	279935	279929	279924
20	279919	279913	279908	279903	279898	279894	279889	279884	279880	279875
30	279871	279866	279862	279858	279854	279851	279847	279844	279841	279838
40	279834	279831	279828	279825	279822	279818	279815	279812	279809	279806
50	279803	279800	279798	279795	279792	279789	279786	279783	279780	279778
60	279775	279772	279770	279767	279764	279761	279758	279755	279751	279748
70	279744	279741	279738	279734	279731	279728	279724	279721	279717	279713
80	279710	279706	279703	279699	279694	279690	279685	279680	279676	279672
90	279667	279662	279657	279650	279641	279632	279620	279603	279581	279556
100	279359									

Appendix F Cross-section Locations

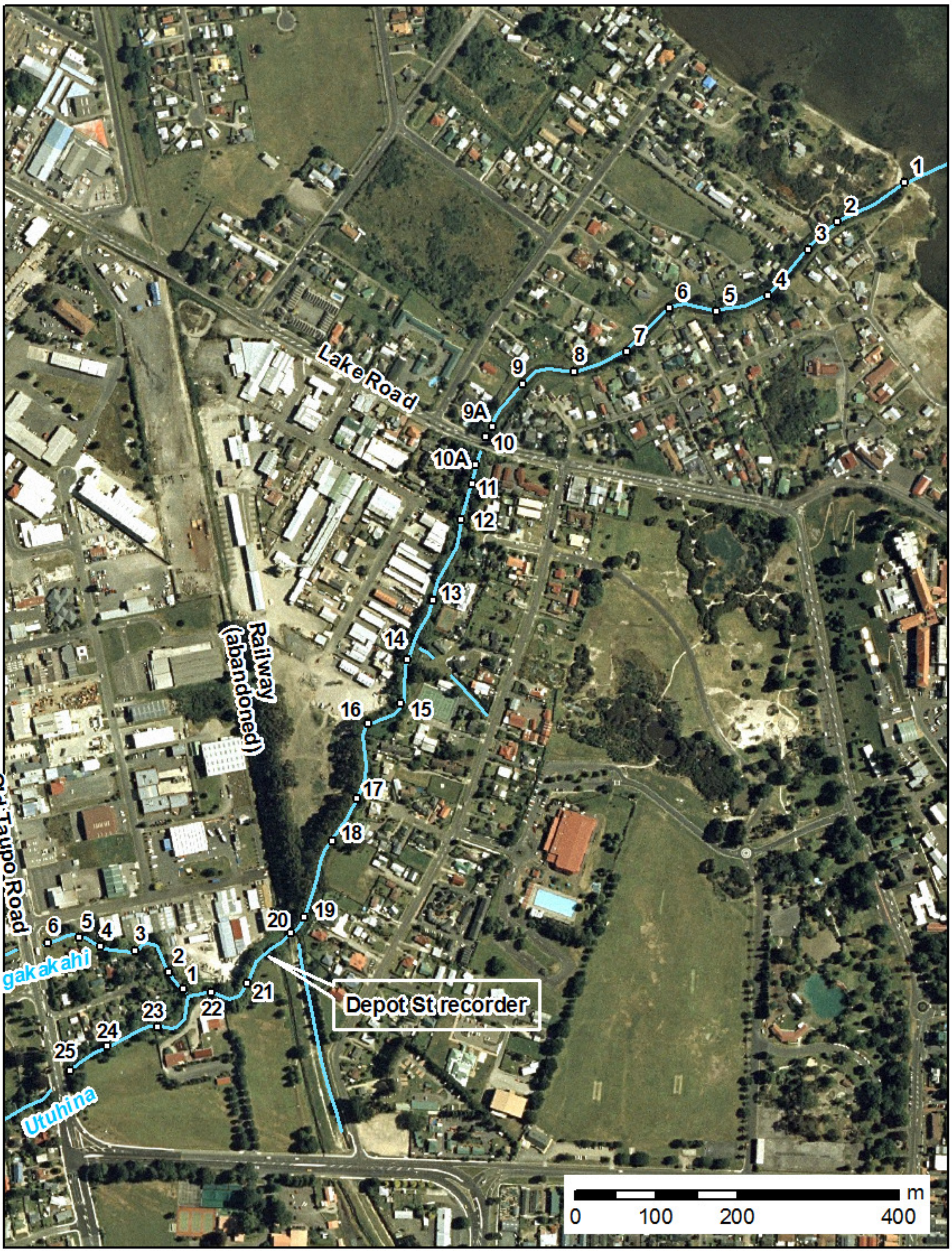

Figure F.1 Stream cross-section locations

Appendix G Scour Assumptions at Mouth

The Utuhina Stream mouth cross-section (cross-section 1) widened progressively between 2002 and 2013 (Figure 12). Aerial photographs also illustrate this, as well as an occasional tendency for a bar to develop (Figures G.1-G.6).

Figure G.1 Stream mouth, December 2012 (cross-section locations shown)

Figure G.2 Stream mouth, 28 May 2007

Figure G.3 Stream mouth, 14 March 2010

Figure G.4 Stream mouth, 9 September 2011

Figure G.5 Stream mouth, 2011

Figure G.6 Stream mouth, 12 May 2013

Some scour of the mouth could reasonably be expected in a design flood, and the 2006 modelling first introduced a scoured mouth section. Figure 12 shows how a similar assumption has been made in the current modelling.

Competent velocity theory argues that channel scour of cohesionless material occurs when velocity exceeds a critical value given by Figure G.7. No data are available on the sediment size in the lower stream, but data from the near-shore zone elsewhere in Lake Rotorua gives a median grain size of ranging from 0.2 mm to 0.7 mm, averaging out at 0.5 mm (Stephens et al, 2004). Channel depths peak at around 3m, indicating a competent velocity of around 1 m/s.

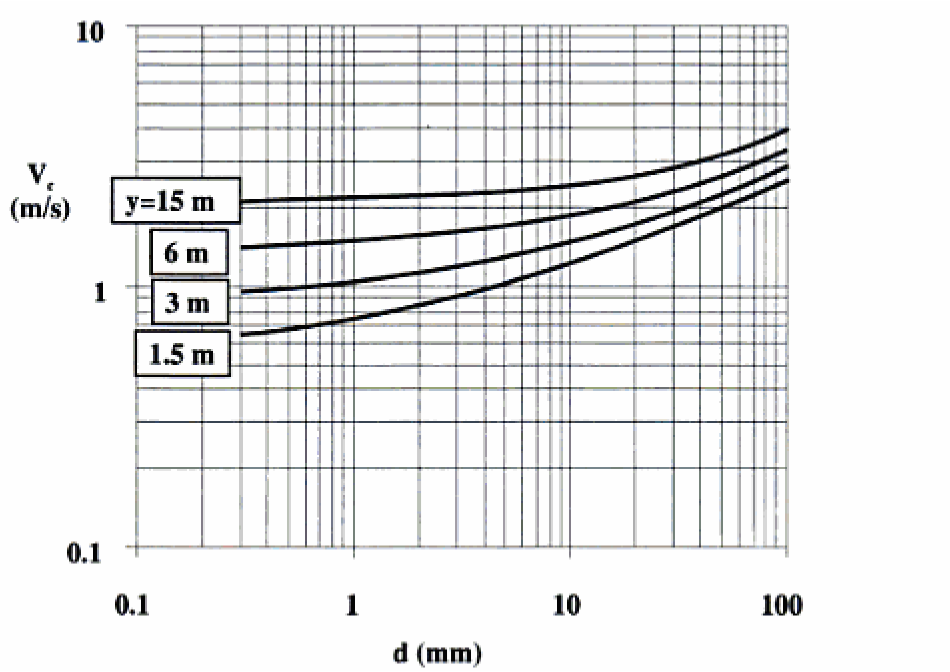

Figure G.7 Competent velocity chart for cohensionless sediment (reproduced in Melville and Coleman)

With unscoured section assumed for the calibration, the model predicts that the channel-averaged velocity peak would have been about 1.5 m/s in the lower reaches (Figure G.8). For the design runs, with the scoured section, the velocity peaked at around 1.8 m/s at section 1 but 2.7 m/s at section 2. Hence, it seems that some scour could reasonably have been assumed for the calibration runs and that the scour has been underpredicted for the design scenarios. In particular, scour at least as far as cross-section 3 could have been assumed. Model results as they stand are therefore likely to be conservative.

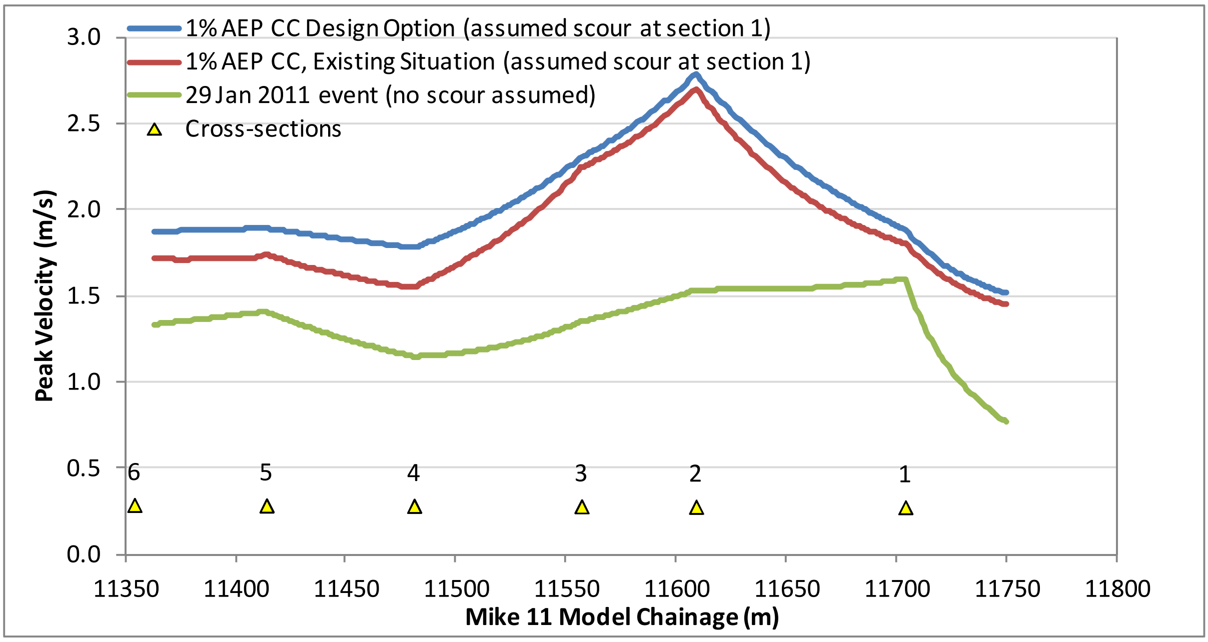

Figure G.8 Channel-average peak velocities, lower Utuhina Stream (model predictions)

It could be argued that the mouth cross-section would widen rather than deepen, but the impact on water levels is unlikely to be much different and furthermore such detail is beyond the scope of this exercise.

The sensitivity of the results to mouth scour has also been investigated, for the 1% AEP (climate change) scenario. If no scour is assumed, levels would be up to 300 mm higher in the lower stream channel compared to the case where scour is as assumed in Figure 12 (Figure G.9). Flood depths on the lower floodplain would generally be up to 150 mm higher (Figure G.10).

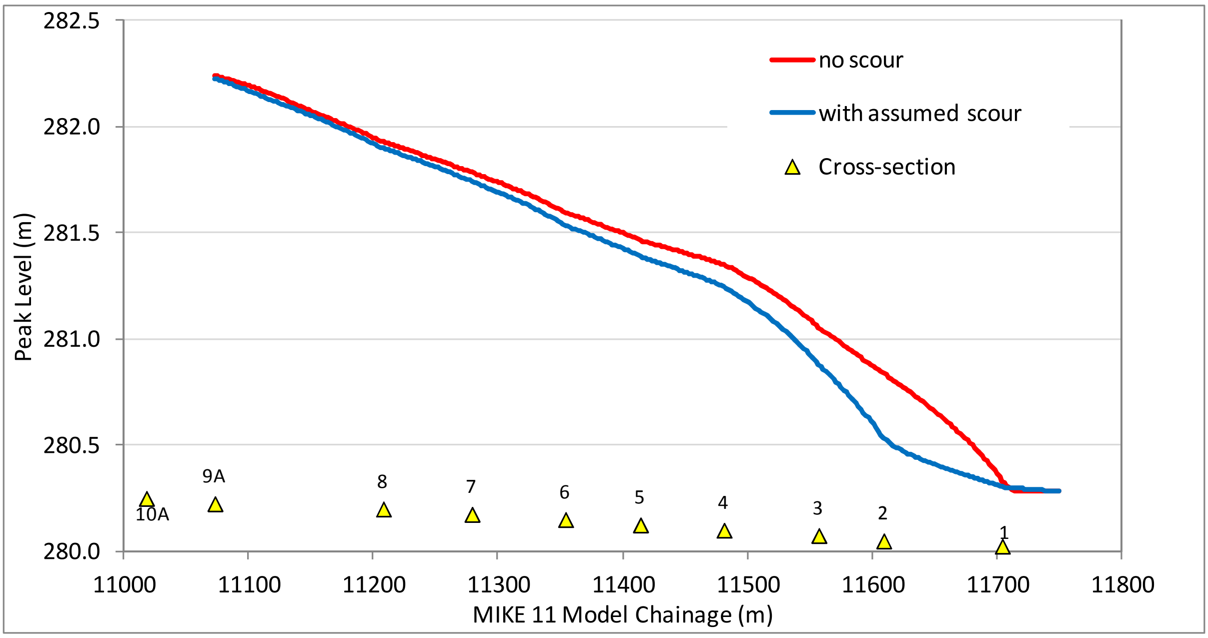

Figure G.9 Sensitivity of peak channel levels to scour assumptions, lower Utuhina Stream (1% AEP climate change, existing situation)

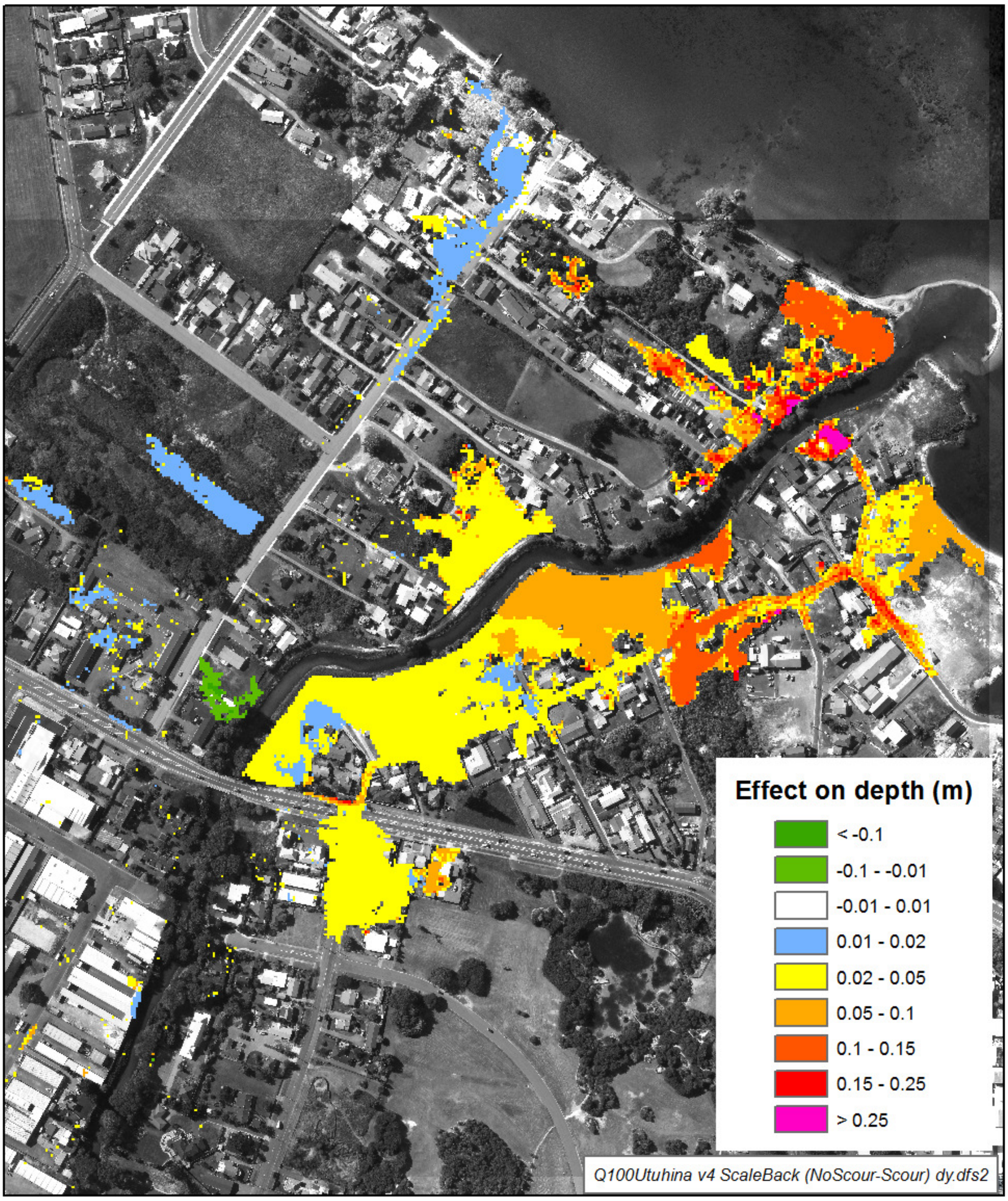

Figure G.10 Sensitivity of peak flood depths to scour assumptions, (1% AEP climate change, existing situation) (Note: positive values indicate an increase in depth if no scour occurred.)

Appendix H Model Results, Previous Flow Estimates

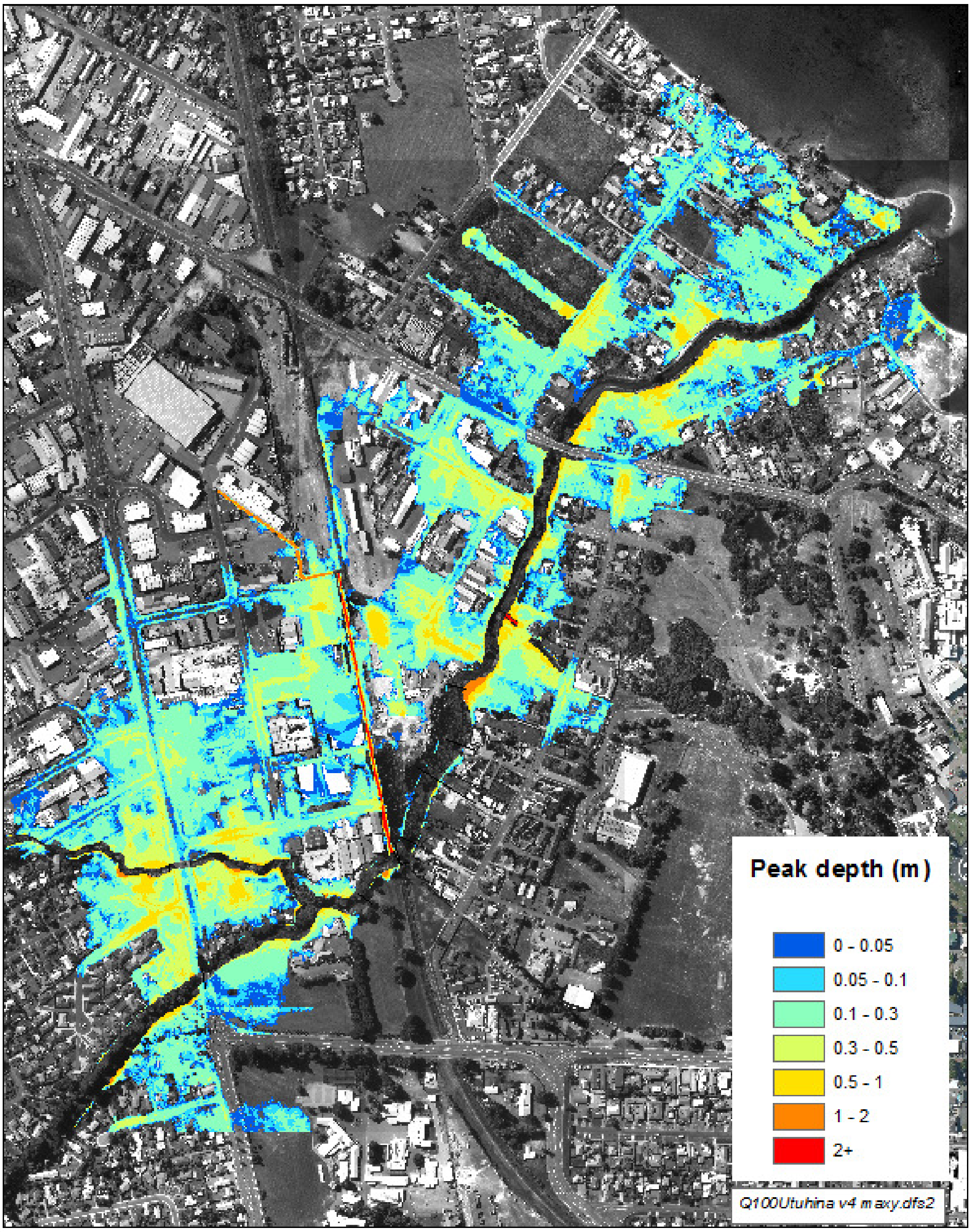

Figure H.1 Flood Extent, 1% AEP (climate change), previous flow estimates, existing situation

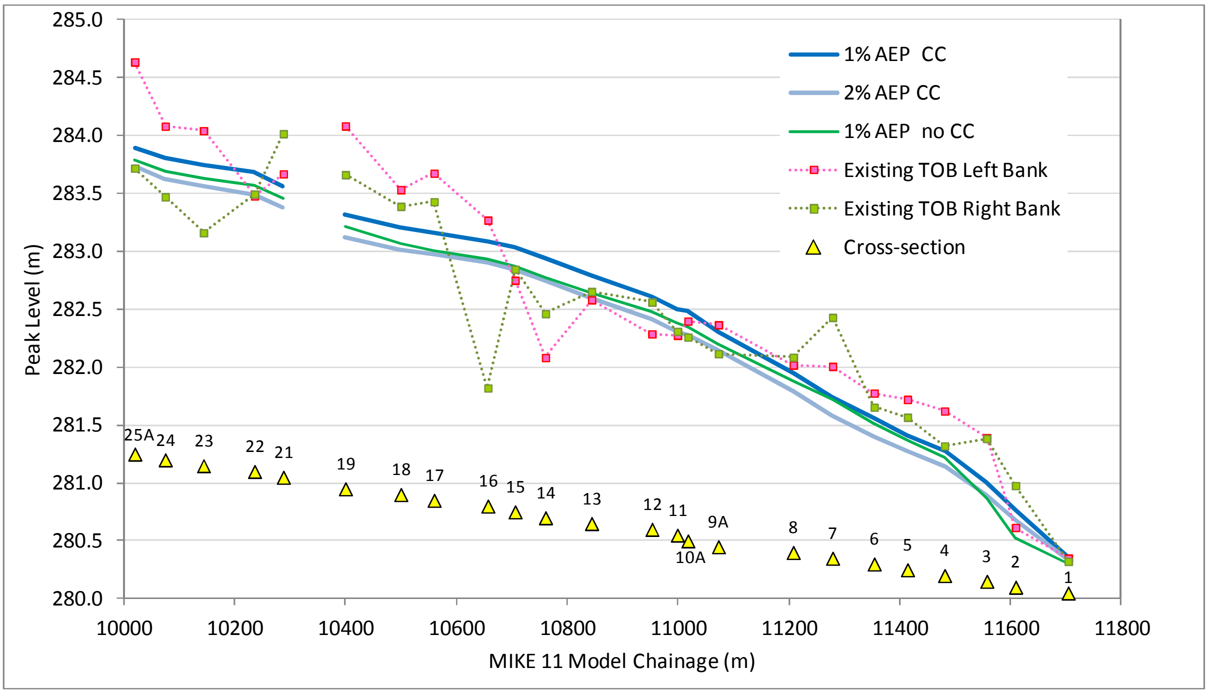

Figure H.2 Flood levels for Utuhina Stream, existing situation (previous design flows)

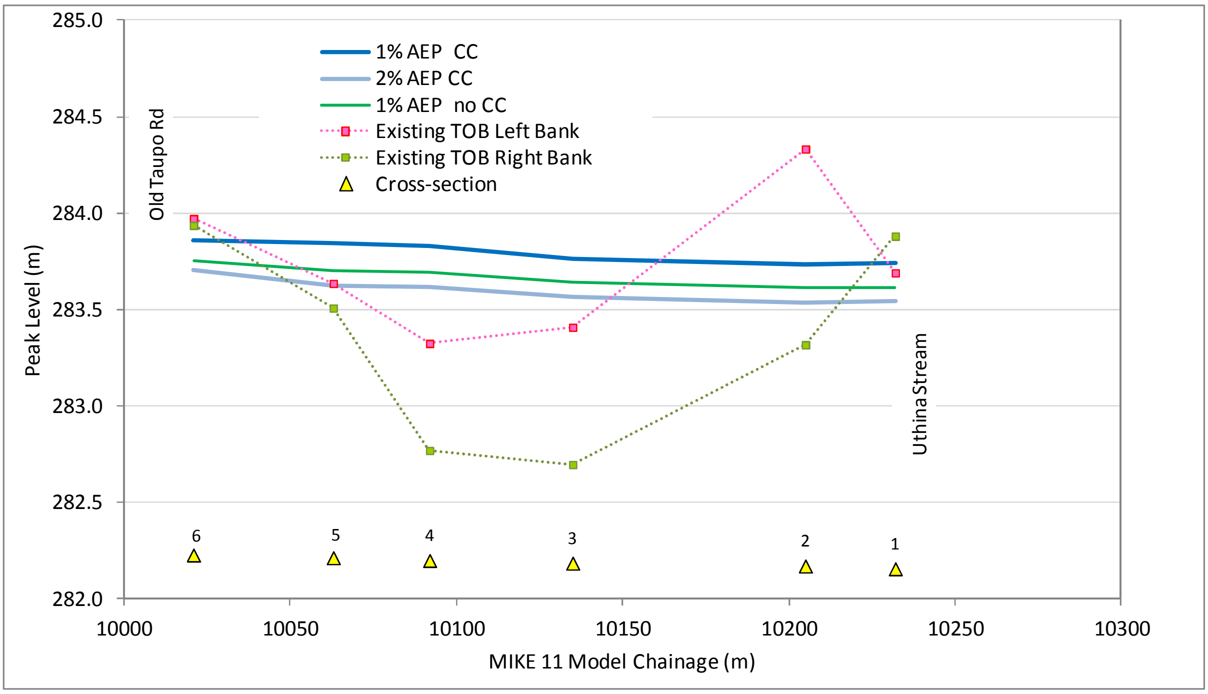

Figure H.3 Flood levels for Mangakakahi Stream, existing situation (previous design flows)

Appendix I Effect of Raising Mangakakahi Detention Dam

RDC had earlier modelled the effect of raising the Mangakakahi Detention Dam crest level (from 287.4 m RL to 288 m RL) on dam outflows. Results were extracted from the RDC modelling, and are shown in Figure H.1 (for a 1% AEP event, with climate change). The dam outflows were then used in the current MIKE FLOOD model to predict the effect of a raised dam on flood extents (Figure H.2).

(Note that the model was not the final version used – for instance it did not extend upstream of Old Taupo Road –and so the prediction for the existing case differs slightly from that shown in Figure G.1.)

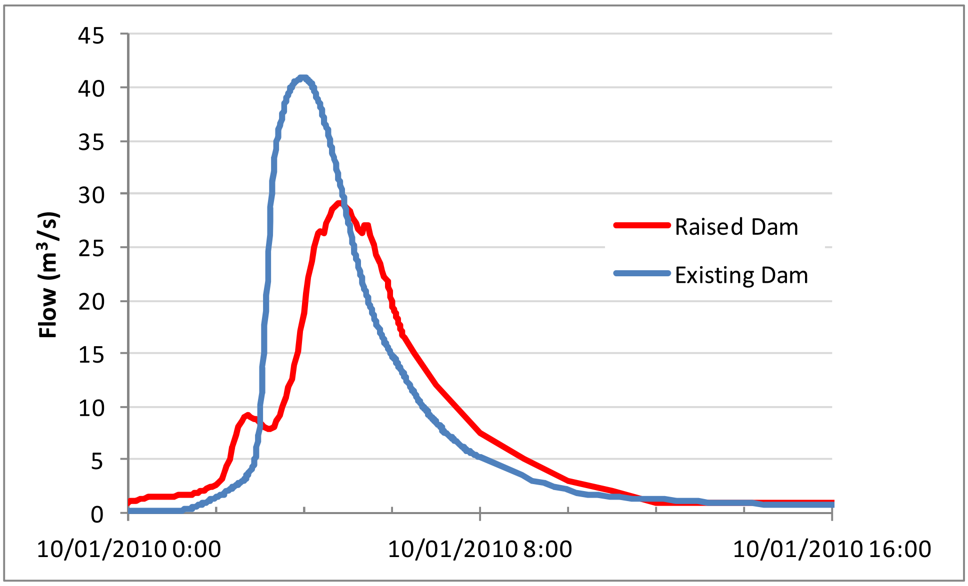

Figure I.1 Effect of raising Mangakakahi detention dam crest on dam outflows

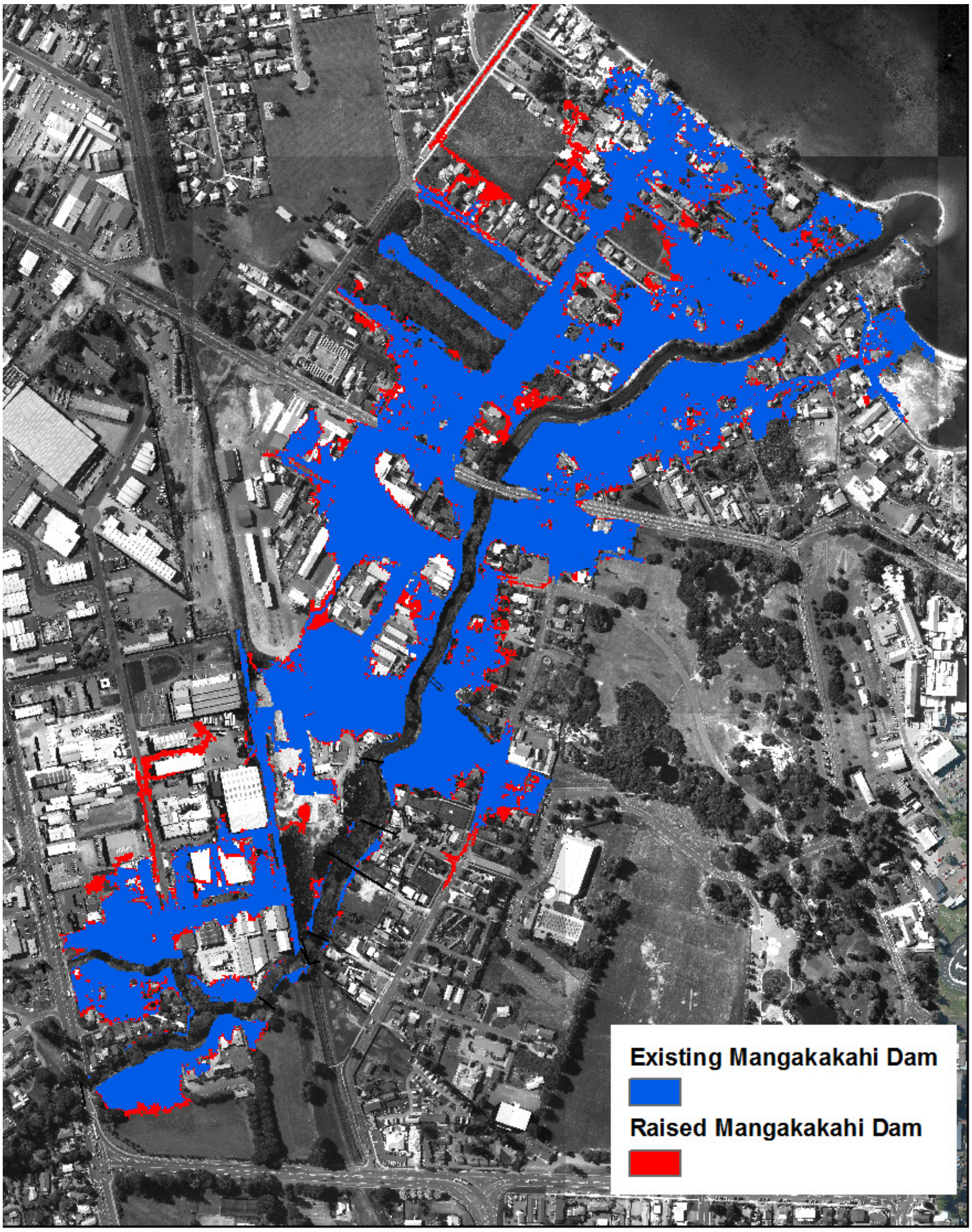

Figure I.2 Flood extents for 1% AEP (climate change, previous flow estimates) for existing and raised Mangakakahi Dam crest

Appendix J Bank Levels and Peak Flood Levels

Peak water level predictions at stream cross-sections are given in Tables J.1 (for the existing banks) and J.2 (for the design option modelled) for each model simulation. Table J.2 also includes levels incorporating freeboard ("+FB"). A freeboard of 500 mm is assumed for the design levels (as specified in the Rivers and Drainage Asset Management Plan).

Note that the Mangakakahi Stream cross-section labels are as for those surveyed in 2013 (rather than 2006) and shown in Appendix F.

Table J.1 Bank levels and peak flood levels (existing situation)

	Cross-section	Chainage	Existing Top of Bank		Peak flood levels (existing stopbanks/floodwalls)						
			Left Bank	Right Bank	2% AEP (no CC)	2% AEP (CC)	1% AEP (no CC)	1% AEP (CC)	2% AEP (CC)	1% AEP (no CC)	1% AEP (CC)
					Previous flows				Revised flows		
Utuhina	25A	10020	284.64	283.72	283.56	283.74	283.79	283.90	283.56	283.56	283.79
	24	10075	284.08	283.47	283.44	283.62	283.69	283.81	283.44	283.44	283.70
	23	10144	284.04	283.16	283.37	283.56	283.63	283.75	283.37	283.37	283.64
	22	10236	283.48	283.50	283.31	283.49	283.57	283.69	283.31	283.31	283.58
	21	10288	283.67	284.02	283.21	283.38	283.46	283.57	283.21	283.21	283.47
	20				283.01	283.14	283.24	283.35	283.01	283.01	283.28
	19	10400	284.08	283.66	282.99	283.13	283.21	283.32	282.99	282.99	283.25
	18	10500	283.53	283.39	282.85	283.01	283.07	283.20	282.85	282.85	283.11
	17	10560	283.68	283.43	282.78	282.98	283.01	283.16	282.78	282.78	283.04
	16	10657	283.27	281.82	282.71	282.90	282.93	283.09	282.71	282.71	282.97
	15	10706	282.75	282.85	282.66	282.84	282.87	283.03	282.66	282.66	282.91
	14	10761	282.08	282.46	282.56	282.75	282.78	282.94	282.56	282.56	282.82
	13	10844	282.58	282.65	282.42	282.60	282.64	282.79	282.42	282.42	282.68
	12	10953	282.29	282.56	282.27	282.41	282.48	282.61	282.27	282.27	282.52
	11	10999	282.28	282.31	282.16	282.30	282.38	282.50	282.16	282.16	282.42
	10A	11018	282.40	282.26	282.12	282.28	282.35	282.49	282.12	282.12	282.39
	9A	11073	282.37	282.12	282.02	282.14	282.20	282.30	282.02	282.02	282.23
	8	11208	282.02	282.09	281.70	281.79	281.88	281.94	281.70	281.70	281.90
	7	11279	282.01	282.43	281.53	281.59	281.72	281.75	281.53	281.53	281.74
	6	11354	281.78	281.66	281.31	281.40	281.51	281.56	281.31	281.31	281.53
	5	11414	281.72	281.57	281.18	281.27	281.37	281.41	281.18	281.18	281.39
	4	11481	281.62	281.32	281.04	281.15	281.22	281.28	281.04	281.04	281.25
	3	11557	281.39	281.38	280.73	280.90	280.86	281.01	280.73	280.73	280.88
	2	11609	280.62	280.98	280.44	280.67	280.52	280.76	280.44	280.44	280.53
	1	11704	280.35	280.32	280.29	280.34	280.30	280.36	280.29	280.29	280.30
Mangakakahi	6	10021	283.97	283.94	283.52	283.71	283.75	283.86	283.52	283.52	283.80
	5	10063	283.64	283.51	283.45	283.62	283.70	283.84	283.45	283.45	283.74
	4	10092	283.33	282.77	283.44	283.62	283.69	283.83	283.44	283.44	283.73
	3	10135	283.41	282.70	283.40	283.57	283.64	283.76	283.40	283.40	283.67
	2	10205	284.33	283.32	283.35	283.54	283.61	283.74	283.35	283.35	283.63
	1	10232	283.69	283.88	283.36	283.54	283.61	283.74	283.36	283.36	283.63

Table J.2 Existing bank levels and design peak flood levels for floodwalls/stopbanks

	Cross-section	Chainage	Existing Top of Bank		Design flood levels, with raised stopbanks/floodwalls					
			Left Bank	Right Bank	1% AEP CC	+FB	2% AEP CC	+FB	1% AEP CC (revised)	+FB
					Previous flows		Revised flows			
Utuhina	25A	10020	284.64	283.72	284.07	284.57	283.54	284.04	283.85	284.35
	24	10075	284.08	283.47	283.97	284.47	283.42	283.92	283.76	284.26
	23	10144	284.04	283.16	283.92	284.42	283.36	283.86	283.71	284.21
	22	10236	283.48	283.50	283.86	284.36	283.30	283.80	283.65	284.15
	21	10288	283.67	284.02	283.75	284.25	283.20	283.70	283.55	284.05
	20				283.55	284.05	283.00	283.50	283.34	283.84
	19	10400	284.08	283.66	283.52	284.02	282.97	283.47	283.31	283.81
	18	10500	283.53	283.39	283.40	283.90	282.83	283.33	283.18	283.68
	17	10560	283.68	283.43	283.33	283.83	282.77	283.27	283.11	283.61
	16	10657	283.27	281.82	283.27	283.77	282.70	283.20	283.05	283.55
	15	10706	282.75	282.85	283.20	283.70	282.65	283.15	282.99	283.49
	14	10761	282.08	282.46	283.10	283.60	282.55	283.05	282.89	283.39
	13	10844	282.58	282.65	282.97	283.47	282.39	282.89	282.75	283.25
	12	10953	282.29	282.56	282.81	283.31	282.23	282.73	282.58	283.08
	11	10999	282.28	282.31	282.72	283.22	282.12	282.62	282.48	282.98
	10A	11018	282.40	282.26	282.69	283.19	282.08	282.58	282.45	282.95
	9A	11073	282.37	282.12	282.46	282.96	281.98	282.48	282.28	282.78
	8	11208	282.02	282.09	282.12	282.62	281.66	282.16	281.94	282.44
	7	11279	282.01	282.43	281.93	282.43	281.48	281.98	281.75	282.25
	6	11354	281.78	281.66	281.70	282.20	281.28	281.78	281.54	282.04
	5	11414	281.72	281.57	281.54	282.04	281.15	281.65	281.39	281.89
	4	11481	281.62	281.32	281.40	281.90	281.02	281.52	281.25	281.75
	3	11557	281.39	281.38	281.03	281.53	280.73	281.23	280.91	281.41
	2	11609	280.62	280.98	280.65	281.15	280.45	280.95	280.57	281.07
	1	11704	280.35	280.32	280.32	280.82	280.29	280.79	280.31	280.81
Mangakakahi	6	10021	283.97	283.94	284.00	284.50	283.59	284.09	283.94	284.44
	5	10063	283.64	283.51	283.95	284.45	283.44	283.94	283.78	284.28
	4	10092	283.33	282.77	283.95	284.45	283.43	283.93	283.78	284.28
	3	10135	283.41	282.70	283.91	284.41	283.38	283.88	283.72	284.22
	2	10205	284.33	283.32	283.90	284.40	283.35	283.85	283.70	284.20
	1	10232	283.69	283.88	283.91	284.41	283.35	283.85	283.70	284.20

Appendix K Model Files

All model input and result files can be tracked via the following .couple files.

Table K.1 Model files

Scenario	.couple file
Calibration	
23rd January 2011 flood	23rdJan2011 Utuhinav5
29th January 2011 flood	29Jan2011 Utuhinav5
Design flows, existing situation	
2% AEP (previous flows), climate change	Q50 Utuhina v3
2% AEP (revised flows), climate change	Q50 Utuhina v4 ScaleBack
1% AEP (previous flows), climate change	Q100 Utuhina v4
1% AEP (revised flows), climate change	Q100 Utuhina v4 ScaleBackQ100
Design flows, existing situation, no scour assumption	
1% AEP (revised flows), climate change	Q100 Utuhina v4 ScaleBackQ100 NoScour
Design flows, raised stopbanks/floodwalls	
2% AEP (previous flows), climate change	*not modelled*
2% AEP (revised flows), climate change	Q50 Utuhina v4 DesignOption1 ScaleBack
1% AEP (previous flows), climate change	Q100 Utuhina v4 DesignOption1
1% AEP (revised flows), climate change	Q100 Utuhina v4 DesignOption1 ScaleBack
Design flows, raised Mangakakahi detention dam	
1% AEP (previous flows), climate change	Q100 Utuhina v3 TrialDam288

(Note: Greyed cells indicate preliminary version of model used)