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Waitohu Stream study

Hydraulic modelling

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Hydraulic Modelling of Waitohu Stream

Preface

A computer-based hydraulic model of the Waitohu Stream and the adjacent floodplain has been built with the aim of identifying flood hazard areas. The model extends from the Waterworks Bridge to the Tasman Sea. It also incorporates the Mangapouri Stream downstream of Convent Road and the lower reaches of the Ngatotara Stream. The Greenwood Boulevard area has not been included, although the runoff contribution from that subcatchment has been incorporated.

The model was substantially completed in 2003, but a flood on 12 February 2004 provided useful additional calibration data so that the model was refined early in 2004. A report was completed in mid-2004, but was not published at that stage.

Since the report was completed, three events of relevance have occurred.

Firstly, LIDAR data ("Light Detection and Ranging" data, obtained from an airborne laser scanner) for the floodplain has been purchased – giving a much more dense and reliable set of floodplain ground levels than was available previously

Secondly, 2-dimensional modelling software for floodplain modelling has begun to be adopted in New Zealand. This represents the "next generation" in floodplain modelling techniques. Greater Wellington now has access to such software. Using the LIDAR data, a more refined model could be built. The model could also be refined with a more detailed channel cross-section and bank level survey, and with a more refined hydrological model. A greater degree of confidence in predicted flood depths and extent on the floodplain would result.

However, such extra work is not appropriate for the scale of this study and the relative lack of risk to human safety and assets. Furthermore, until better calibration data and high flow gauging data are available, there is little point.

Finally, a flood occurred on 6 January 2005. Although this was a relatively small event according to flow estimates, localised areas of the floodplain suffered significant flooding. This flood highlighted the effect that changes in the stream bed (due to gravel movement, debris and vegetation obstructions) can have on channel capacity. Overflows were observed in some locations that had not been predicted by the model.

This document presents the original report of 2004 together with a file note regarding the January 2005 flood and photographs of that flood.

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1. Introduction

The Waitohu Stream, flowing from the Tararua Ranges to the Tasman Sea just north of Otaki, is a dynamic stream with a history of flooding and erosion problems. It has a catchment of 54km^2 and the steepest average slope of the Kapiti Coast rivers (WRC, 1994). Under the mandate of the Soil Conservation and Rivers Control Act 1941, erosion and flood mitigation work has been undertaken in the Waitohu Stream by the Flood Protection Group of Greater Wellington (the Wellington Regional Council) and its predecessor authorities (most notably, the Manawatu Catchment Board prior to 1989) since the inception of the Otaki Scheme in 1955.

Greater Wellington is undertaking a Waitohu Stream Study, commenced in 2002. One of the components of the study is the preparation of a computer-based hydraulic model of the Waitohu Stream and the adjacent floodplain, with the aim of identifying flood hazard areas. The model will also be of value in flood warning. This report describes the model and the results, and presents flood hazard maps.

In the early 1990s, as part of investigations for the Otaki River Floodplain Management Plan, a computer model of the Otaki River and floodplain was built. That model extended to the Waitohu Stream with connections between the Waitohu and the Mangapouri/Rangiuru catchments. It has to date been used for existing flood hazard maps of the Waitohu. However, that work focussed principally on flooding from the Otaki River, and was too broad in scale for a detailed assessment of the Waitohu flood hazard. The model described in this current report therefore supersedes the earlier one in the Waitohu floodplain. The earlier model is still relevant in the Rangiuru area however.

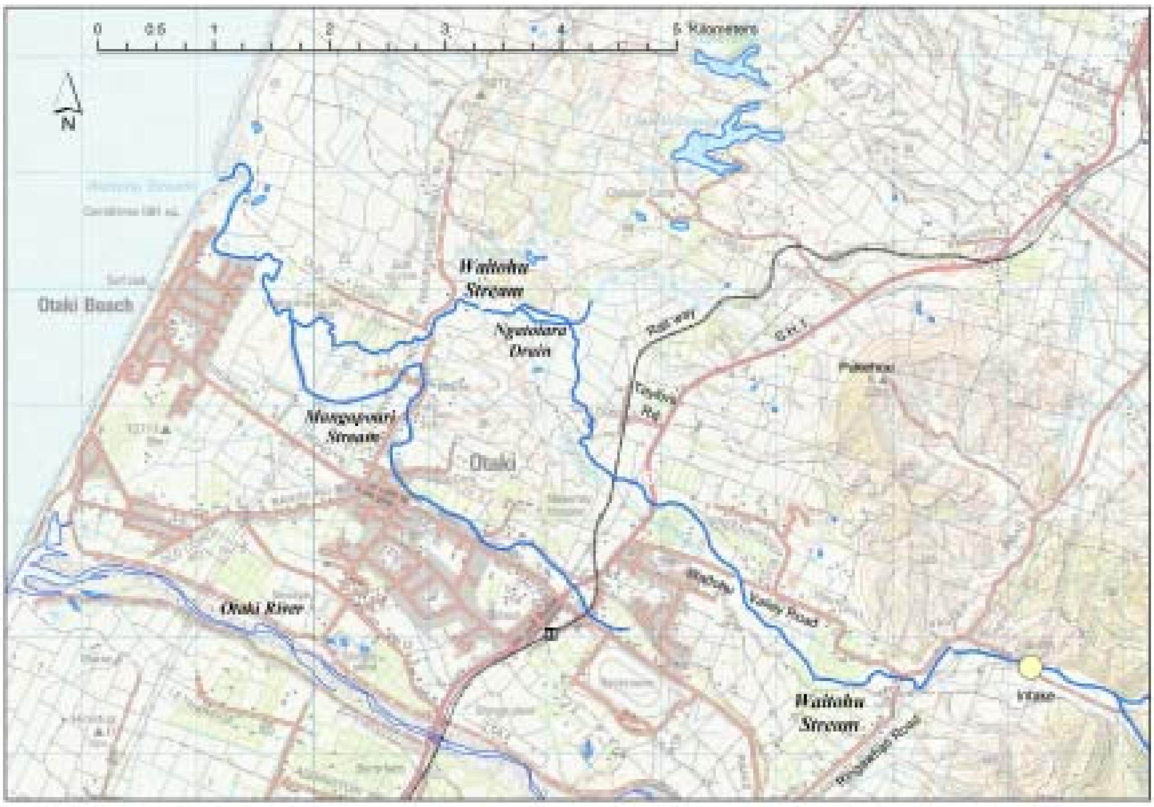

Figure 1 Waitohu Stream Location

2. Extent of model

The hydraulic model extends from immediately upstream of the Waterworks Bridge to the Tasman Sea, and covers the stream channel plus the adjacent floodplain. It also incorporates the Mangapouri Stream downstream of Convent Road and the lower reaches of the Ngatotara Stream (also referred to as the Ngatotara Drain). Overflow from the Mangapouri Stream via the Rangiuru Stream to the Otaki River has been allowed for. The Greenwood Boulevard area has not been included, although the runoff contribution from that subcatchment has been incorporated.

The stream mouth geometry varies depending on recent sea and stream conditions, and two versions of the model have been built: a short mouth and a long mouth version.

3. Model software

MIKE 11, a software program developed by DHI, has been used as the principal modelling tool. It has had extensive use around the world, and has been widely used in New Zealand, including by the Wellington Regional Council, for 15 years.

MIKE 11 uses the Saint-Venant one-dimensional unsteady flow equations to model open channel flow. It allows branched and looped networks of channels to be modelled (and thus can also model flood plain flow in a quasi two-dimensional manner if required). An unsteady state model is considered essential for this exercise, principally to model the effect of off-channel storage although also to allow any tidal effect to be incorporated

Weirs, culverts and other hydraulic structures can also be modelled with MIKE 11. Thus the Ngatotara siphon, various culverts and the small sections of stopbanks can all be represented within the model. Likewise the bridges over the Waitohu are included, using culverts as de facto bridges.

Flood maps have been produced using Greater Wellington’s in-house flood mapping software (based on ArcInfo).

4. Model layout

4.1 General

In developing the model, observations and comments from Greater Wellington staff were taken into account and site visits were made. Extensive use has been made of aerial photographs, flood photographs and various cross-section and topographical plans in building the model. The council’s GIS proved invaluable in this process.

Figure 2 shows the full extent of the model. (The location and chainage of Waitohu Stream cross-sections is given in Appendix II).

Figure 2 MIKE 11 Model Layout

4.2 Cross-section and topographical information

4.2.1 Waitohu Stream

A cross-section survey of the Waitohu Stream was undertaken between February and May of 2003. Other than around the new farm access bridge downstream of the railway (“Taylors” bridge), the cross-sections positions and alignment were as close as practical to the sections surveyed in 1992. The location of the Waitohu Stream cross-sections is given in Appendix II, while a list of the section names and their corresponding chainage in the MIKE 11 model is given in Appendix III. Information regarding the source of the cross-sections in the model is also stored in the “cross section ID” field of the MIKE 11 cross-section file *waitohu.xns11*.

Three additional cross-sections have been taken from a GPS survey of the stream bed, carried out during the autumn of 2003.

The last two downstream model sections in the “short mouth” model are artificial. The downstream section of the model, off-shore, has been made 300m wide and with an invert of –4m. The next section upstream is on the beach, and the assumed section has been based on site observation plus Greater Wellington staff comment, although in flood events there would be some scour and therefore uncertainty in the section dimensions. Predicted peak velocities are however only about 1m/s, suggesting that, at least at high tide, scour may not be enough to significantly enlarge the sections.

In the model, cross-sections have generally been truncated at the top of the stream bank.

4.2.2 Tributary cross-sections

In additional to the Waitohu Stream cross-sections, the 2003 survey also recorded sections at the downstream end of the Mangapouri Stream and in the Ngatotara Stream (downstream of the siphon). These sections have been used in the model.

Other sections in the Mangapouri have been taken from the 1987 survey carried out by the Manawatu Catchment Board. It is not expected that the Mangapouri sections will have significantly altered since that time, and in any case the effect of any changes will be small when considering overflows from the Waitohu Stream.

Other sections for the Ngatotara and the unnamed tributary from the Greenwood Boulevard area have been extracted from the digital terrain model (see below) held on the council’s GIS. It is likely that the sections will underestimate the cross-section area, as no raw photogrammetric data below water level would have been taken. Again, this is not likely to be significant, particularly given that farm culverts and flood debris will restrict capacity.

4.2.3 Floodplain channels and storage ponds

A network of floodplain channels (in which 1-D flow is assumed) and storage ponds (where water is more likely to pond rather than flow) has been developed to allow floodplain flow. The topographical data (i.e. cross-sections and storage-level relationships) have been derived from the two topographical models held by the council. Both are derived from 1990 aerial photogrammetry of the Otaki and Waitohu area. The first model is in the form of contoured aerial orthophotos. The second is a digital terrain model (DTM), developed from the original photogrammetric data, in the form of a TIN (triangular irregular network) stored in the council GIS. Because of the ease of extracting data, most of the floodplain sections and storage areas used in the hydraulic model have been taken from the TIN, although it is not as reliable as the orthophotos. Where obvious discrepancies between the orthophotos and the TIN exist, the former has been used, but in general the TIN is considered adequate for this exercise. For detailed flood risk assessment, say at a residential property scale, the TIN topographical data would need to be checked with a ground survey.

The floodplain cross-section locations are stored as the Arc shape file *Waitohuxs*. The storage ponds are stored as the Arc shape file *Area-contours*.

4.2.4 River – floodway – berm connections

Connections between the stream channel and floodplain channels or ponds have been treated as MIKE 11 "link channels". These treat the connection as a weir. In most instances, a simple geometry for the connections has been assumed. This geometry takes the level from the adjacent river cross-section that represents the boundary between the river and the berm or floodway channel and uses it as the minimum crest or low point of the "weir" (see Figure 3 for an example), or else the crest level has been estimated from the DTM. The weir width has been measured from the council GIS, and generally goes to either midway to the next cross-section (where a further link is specified if required) or to what is judged to be the physical end of the length of overflow weir.

This simple geometry assumes that the level of the crest is parallel to the stream water surface over its length. However the weir crest has been given some small arbitrary "dish" shape so as to improve the computational stability of the model.

In a few instances, a more refined geometry has been assumed. The ground or bank topography along the length of the connection has been extracted from the DTM, and rotated to be relative to the adjacent channel water surface. This is the case for the following link channels: 0110RB, link2, link3, link5, link11, link0240LB, and SH1_link. A 1996 survey by Connell Wagner was used to generate profiles for linkM-P and linkM-D.

In general a roughness of n = 0.050 was used for the links. In several locations however, aerial photographs or site inspections suggested a higher roughness would be required and n values of up to 0.150 were used as considered appropriate.

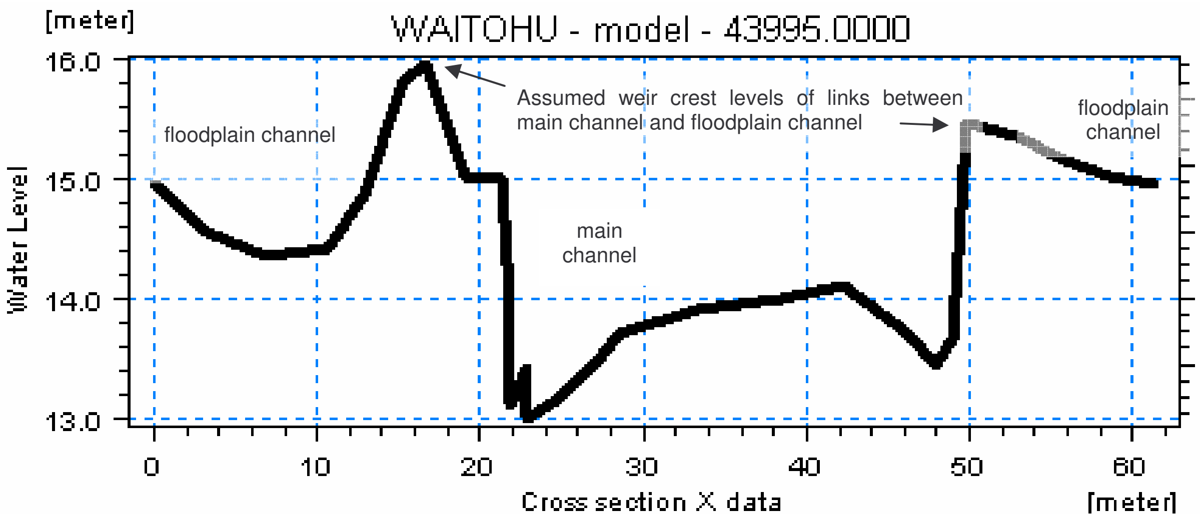

Figure 3 Example of links between parallel channels (Waitohu Section 170)

4.3 Superelevation

Superelevation of the water surfaces occurs around bends, and strictly some adjustment should be made for this. As the model assumes a constant water surface across a cross-section, one method to allow for superelevation is to lower the bank crest levels on the outside of the bank by an amount equal to the expected rise in water surface.

In this study, no such adjustment has been made. The large number of bends, along with the amount of superelevation being a function of velocity (i.e. flow), makes this impractical. A more reasonable approach is to include sufficient freeboard in design flood levels to allow for superelevation effects.

5. Calibration

5.1 Calibration events and data

Calibration information is limited. Until February 2004, the best information came from a few photographs taken during the 1-2 October 2000 event. (Figures 4 and 5). This event is also the largest in recent years and so was initially taken as the calibration event.

A small flood (estimated return period of approximately 50% AEP[1]) occurred on 12 February 2004, and some peak flood levels were recorded and general observations as to overflow points were made. This event now forms the primary calibration event. (Refer to file N/6/30/05 for photos and field notes from this flood).

Figure 4 Floodwaters, Convent Rd, October 2000

[1] By definition, there is a 1% chance of getting a 1% Annual Exceedence Probability (AEP) flood or a larger flood in any one year. This is more commonly known as the “1 in 100 year” flood, or more simply as the “100 year” flood. Likewise there is a 50% chance of getting a 50% AEP flood (“a 2 year flood”) or larger in any one year.

Figure 5 Floodwaters, Entrance to Winterburn Property, Convent Rd, October 2000

5.2 Calibration assumptions

5.2.1 Inflows

Greater Wellington operates a flow recorder at the Water Supply Intake on the Waitohu Stream (Figure 1), above the upstream end of the model. Estimates of the flow hydrographs are available for both the October 2000 and February 2004 events, and have been used as the upstream boundary condition for the calibration simulation. (Note however, that the Waitohu has never been gauged at flood flows, and thus there is some uncertainty in the flow hydrographs).

In 2003, as part of investigations into the flood hydrology of the catchment, a rainfall-runoff model was developed (Greater Wellington, 2003). In calibrating that model, hydrographs for the runoff from sub-catchments were generated for a number of storms, including the 1-2 October 2000 storm. These have been used as boundary conditions in the hydraulic model calibration simulation of that event.

Similarly, the February 2004 storm was run through the rainfall-runoff model to generate inflow hydrographs for key subcatchments. However, the Mangapouri hydrograph has been scaled back by 0.5, reflecting the likelihood that the Mangapouri channel restrictions and culverts will lead to some of the inflow spilling out of the channel before it reaches the upstream end of the model. This gives a peak flow of approximately 7.5m^3/s. Healy (1998) in his Table 6 estimated that the crossings in the Mangapouri would typically convey approximately 10m^3/s (via culvert and weir flow), although it is unclear how much of the weir flow he assumed would return to the main channel. (Note also that the recorded peak flow is less than the hydrological model peak flow for the Waitohu Stream at the Water Supply Intake: in that case the ratio is approximately 0.8). Regardless, reducing the Mangapouri inflow made little difference to the lower end of that stream as the levels were predicted to be controlled by the Waitohu backwater.

In both simulations, the Otaki River has been given a constant inflow of 50m3/s and the Rangiuru Stream a constant inflow of 0.1m3/s. Both these have no effect on results in the Waitohu floodplain. Other inflows in the model are set to zero.

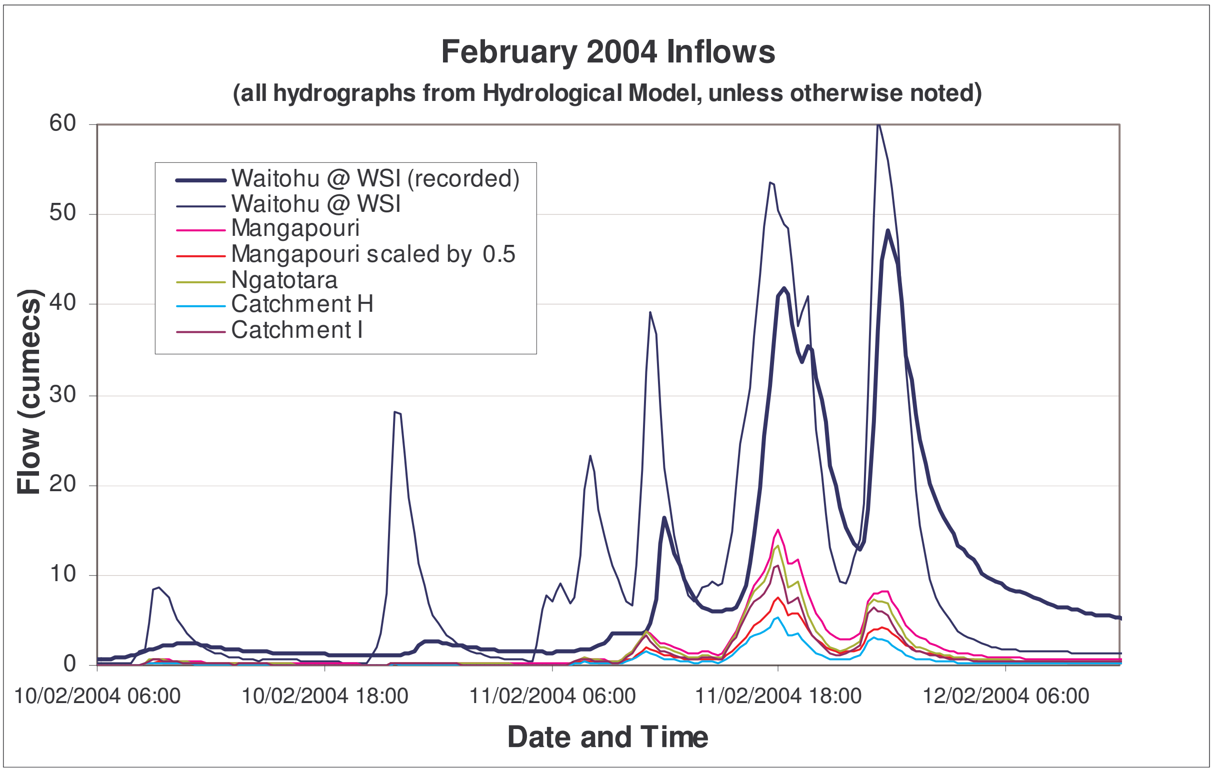

Figure 6 February 2004 Inflows

5.2.2 Tide level

NIWA has developed a model for New Zealand coastal waters, providing predictions of maximum and minimum tide levels[2]. For the period 1-2 October 2000, maximum and minimum tide levels were predicted at approximately 1.2m above and below mean sea level respectively. A storm surge of 500mm has been assumed for the duration of the event (allowing for wave set up from the north-west gales of the time[3] plus a 10mm rise in sea level for every 1hPa fall below 1014hPa). (The difficulty in predicting storm surge was noted in WRC (1992). That report also indicated that the storm surge in 1976, estimated at 0.7m, was regarded as an extreme event.)

A simple sinusoidal time series with a period of 12 hours, a peak level of 1.7m and a minimum level of 0.7m has been assumed. The timing has been taken from the NIWA predictions.

For the period 10-12 February 2004, maximum and minimum tide levels were predicted at approximately 0.85m above and below mean sea level respectively. High water marks on the beach appeared close to the base of the sand dunes, which according to the aerial orthophotos are at around 2m RL. Taking into account some runup, a storm surge of 500mm has been assumed, giving a peak sea level of 1.35m.

A sensitivity test was run with no storm surge added and with 750mm added. Results upstream of cross-section 40 did not differ significantly.

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[2] http://www.niwa.co.nz/services/tides/

[3] http://www.metservice.co.nz/severe_weather/Spring00_MAIN.asp

5.2.3 Mannings n

Central channel resistance values adopted for the Waitohu after calibration are as plotted in Figure 7. Water levels in the calibration simulation did not vary markedly with resistance. Nonetheless, a sensitivity test with Mannings values 0.05 higher was performed (section 6).

Note that roughness is often higher at smaller flows (although it tends to then increase again with larger flows). (See for example, Hicks and Mason (1991)). Thus calibration with this February 2004 event may have led conservative resistance values being adopted for design floods.

Additional resistance was applied to berms in many instances. Resistance values for the floodplain channels were selected after consulting Chow (1958).

5.2.4 Bridges

Each bridge has generally been modelled with MIKE 11 as a parallel weir and culvert. Bridges modelled this way have more impact on higher flows, and at lower flows they may overestimate losses through the bridge. In the February 2004 event, water levels through the Waterworks and Ringawhati Bridges were low, and the simulation for that event has been run with no culvert or weir at those sites. This improved the predictions at the upstream side of these bridges. No such adjustment was made for the October 2000 simulation.

5.3 Results and discussion

2004

The calibration results are summarised in Table 1 and Figures 7 and 8.

The model appears to underpredict water levels at the State Highway bridge, despite the use of reasonably high resistance values in the vicinity.

The model also appears to overpredict water levels in the lower Mangapouri Stream, as the overflow to the south predicted was not known to occur. (Note that the peak occurred during the night, and some floodwaters may have drained away before they were seen.) Likewise, the predicted overflow between the Waitohu and the lower Mangapouri was unlikely to have occurred.

As noted above, results were not sensitive to the size of the Mangapouri inflow. Adjusting the mouth geometry and the tidal conditions made no difference, while adjusting channel resistances had only minor effect.

Bank levels in the vicinity of the Waitohu/Mangapouri confluence were also reconsidered in an attempt to prevent the model predicting these overflows. The left bank Mangapouri levels were surveyed in 1996, and no modifications to the bank have been made since then. Thus that survey has been used as the basis for the model link between the Mangapouri Stream and the land to the south, even though it allows overflow relatively early. Levels for the left bank of the Waitohu in the area (i.e. around cross-section 80) were taken from the TIN. As these are only approximate, they were raised sufficiently to prevent any significant overflow from the Waitohu. No changes were made to the Mangapouri right bank as to raise that would mean more water over the Mangapouri left bank. Further attempts to improve the predictions in this area have not been made, and in any case the design scenarios modelled assume that the Mangapouri left bank is raised for the proposed Waitohu South stopbank.

Despite the shortcomings of the prediction, the calibration is considered satisfactory. The average difference between measured and predicted water levels is 18cm. Further survey work could be carried out, for example additional cross-sections in the main channels, and of bank levels. For the scale and timing of this exercise, such additional work is not justified, particularly given the uncertainty over the rating curve at the water supply intake (WSI) and the size of tributary inflows.

Location	Peak Flood Level (m) Measured	Model Prediction	Nearest Model Location	Difference (m)
Waterworks Bridge u/s	81.566	81.618	39242	-0.052
Ringawhati Bridge	76.65	77.041	39507	-0.348
		76.955	39514	
Waitohu Valley Rd Bridge	44.6	44.758	41485	-0.158
SH1 - 25m upstream	29.715	29.386	42521	0.329
SH1 - immediately d/s	28.951	28.732	42576	0.219
Railway	23.14	23.309	43006	-0.169
Convent Rd - 10m u/s	6.674	6.547	46320	0.127
Convent Rd - u/s face	6.56	6.547	46320	0.013
average absolute error				**0.184**

Table 1 Calibration Summary, February 2004 Flood

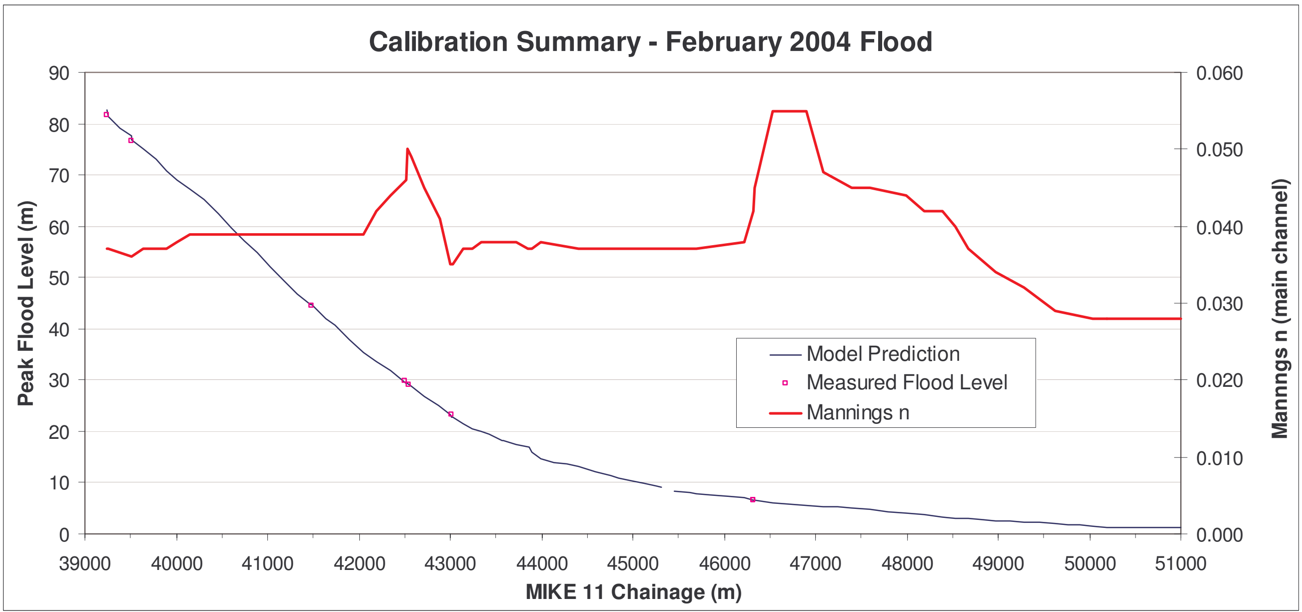

Figure 7 Calibration Results, February 2004 Flood, Long-section Profile Waitohu Stream

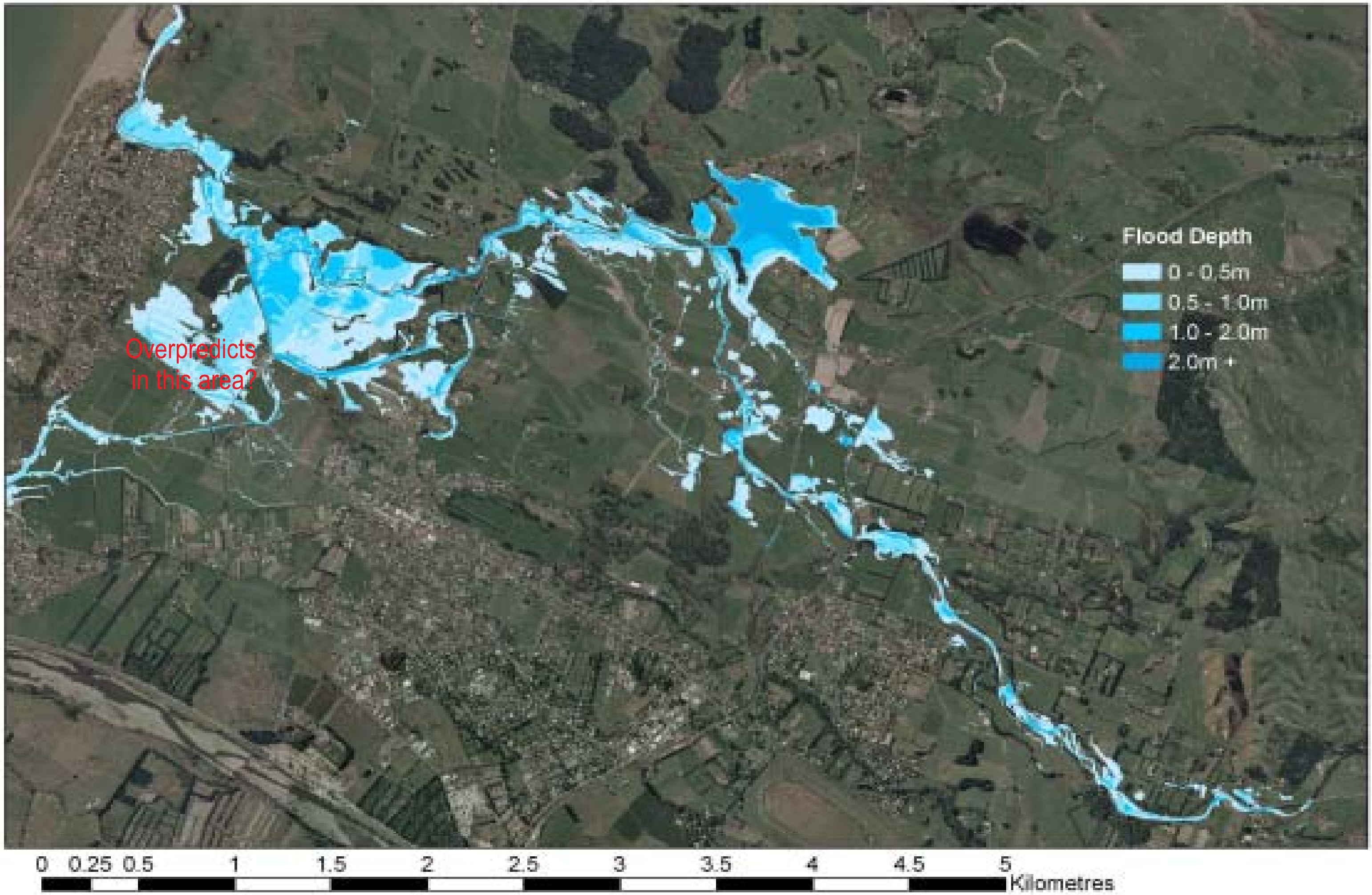

Figure 8 Modelled February 2004 Flood Extent

2000

Figure 9 shows the extent of the flood as predicted by the model.

The model predictions compared satisfactorily with the limited records of the flood extent (Figure 4). However, comments from landowners indicate that the model overpredicts the extent (and therefore the depths) of water adjacent to the Ngatotara Stream (Figure 9). A sensitivity test was run with no Ngatototara inflows, resulting in water levels lowered by 1.5m. Thus the model results are sensitive to the Ngatotara inflows. It is possible that the hydrological model does not adequately deal with the lakes and wetlands in the subcatchment, leading to overestimates of the inflow. Further work is needed to confirm this, and in the interim the model has been left as is.

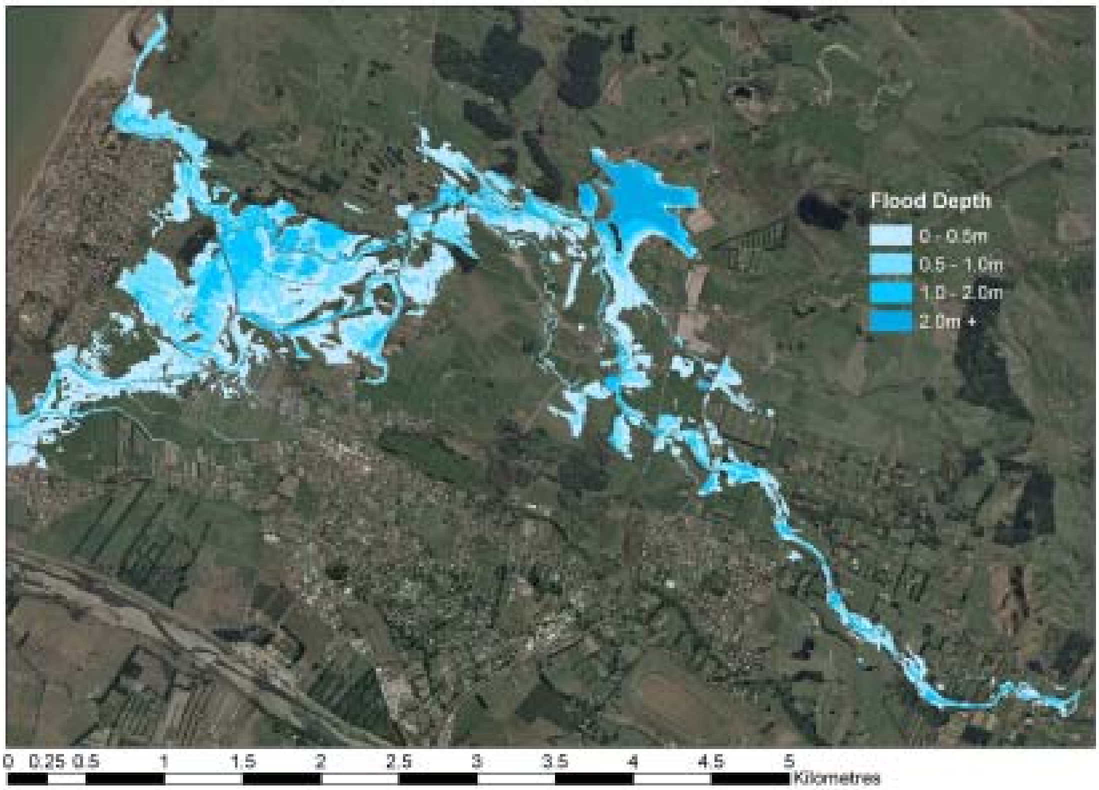

Figure 9 Modelled October 2000 Flood Extent

6. Sensitivity tests

Several sensitivity tests were carried out in developing the model. These have included sensitivity to the following parameters:

6.1 Channel roughness (Mannings n)

During the calibration process, numerous trial Mannings n profiles (versus river chainage) were trialled. The W_{50} and W_{100} design scenarios (refer to Table 2 for a key to the shorthand nomenclature for the scenarios) have been run with the final adopted profile and then with all Mannings n values increased by 0.005, to show the sensitivity of results to Mannings n. Results are given in Appendix III. For the $W_{50,}$ the largest difference (between the as-calibrated and the increased Mannings n cases) in the main channel is 190mm around section 170. The largest difference in the floodplain is 270mm in the golf course. In the W_{100} scenario, the largest main channel difference is 140mm (section 200), and the largest floodplain difference is 500mm (again in the golf course).

6.2 Mouth geometry and storm surge

Trials were also carried out to assess the impact of different storm surge and mouth geometry assumptions. For calibration event, the difference in results diminished upstream to 1cm by section 40. Given the limit effect, no such trials were carried out for larger flood scenarios.

In the case of the W_{100} event, the long mouth geometry raised water levels by a maximum of only 3mm over the short mouth layout.

6.3 Mangapouri inflow

The February 2004 event was also run with a nominal constant 0.1 m^3/s inflow into the Mangapouri, rather than the scaled hydrological model output (see section 5.2.1 above). Results indicate the water levels in the lower end of the Mangapouri are more controlled by the Waitohu levels and that the Mangapouri inflows do not have a significant effect downstream of Convent Rd. Results from design scenarios also indicate that the Waitohu has a noticeable effect up to around Convent Rd.

6.4 Ngatotara inflow

As noted above, running the October 200 event with the Ngatotara inflows as predicted by the hydrological model and then with no Ngatotara inflows indicates that model results are sensitive to the Ngatotara inflows.

7. Design simulations

7.1 Model layout

The design model layout differs from that used in the calibration model in that the proposed South Waitohu stopbank is included, preventing overflows into the Rangiuru area from the Waitohu and lower Mangapouri Streams. The Waterworks Access and Ringawhati Road bridges have been modelled as culverts/weirs, as in the October 2000 simulation.

7.2 Design hydrological conditions

The design sea level condition assumed is that used in previous Otaki modelling; that is, a tide oscillating between a peak of 2.5m RL and a trough of 0.7m RL, with a period of 12 hours. The timing of the tide has been set so that the peak tide approximately coincides with the arrival of the flood peak.

The flow scenarios modelled are as in Table 2. Hydrographs for each sub-catchment have been taken from the hydrological model outputs. For all events, a duration of 2 hours rainfall has been assumed, as this gave the highest peak flows.

Scenario		Subcatchment (refer to Hydrology report)			
Shorthand Notation (as referred to in text)	(RES file)	Waitohu @ WSI	Mangapouri	Ngatotara	Greenwood
W_2	W2SHORTMOUTH	2 year (50%AEP)	2 year	2 year	2 year
W_{10}	W10SHORTMOUTH	10 year (10%AEP)	2 year	2 year	2 year
W_{20}	W20SHORTMOUTH	20 year (5%AEP)	2 year	2 year	2 year
W_{50}	W50SHORTMOUTH	50 year (2%AEP)	20 year	20 year	20 year
W_{100}	W100SHORTMOUTH	100 year (1%AEP)	20 year	20 year	20 year
W_{200}	W200SHORTMOUTH	200 year (0.5%AEP)	20 year	20 year	20 year
M_{100}	M100SHORTMOUTH	20 year (5%AEP)	100 year	20 year	20 year
NG_{100}	NG100SHORTMOUTH	20 year (5%AEP)	20 year	100 year	100 year

Table 2 Combination of Subcatchment Flows for Design Scenarios

For each scenario, as with the calibration events, the Otaki River has been given a constant inflow of $50m^3/s$ and the Rangiuru Stream a constant inflow of $0.1m^3/s$. (For analysis of flooding originating in or via the Rangiuru Stream, refer to previous Otaki floodplain modelling, for example WRC (1995).) Other inflows in the model are set to zero.

7.3 Design water level results

Selected design water level profiles for the Waitohu Stream are plotted in Figures 10 and 11. A full set of results for each design scenario is tabulated in III.

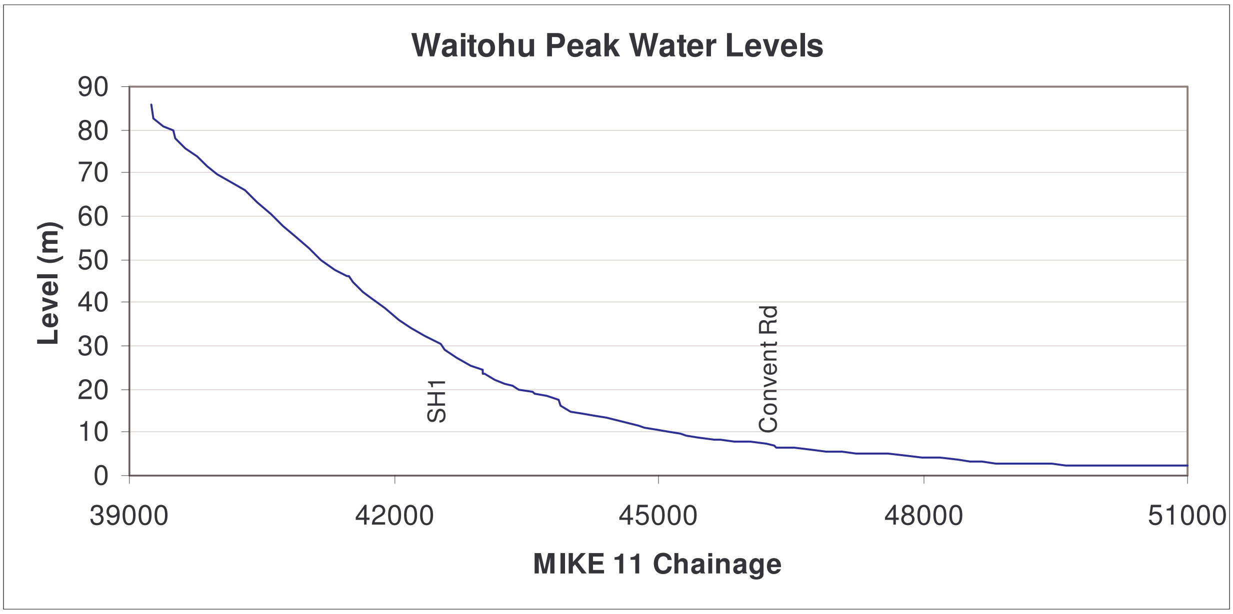

Figure 10 Predicted W_{100} Peak Water Level, Waitohu Stream (No Freeboard Allowance)

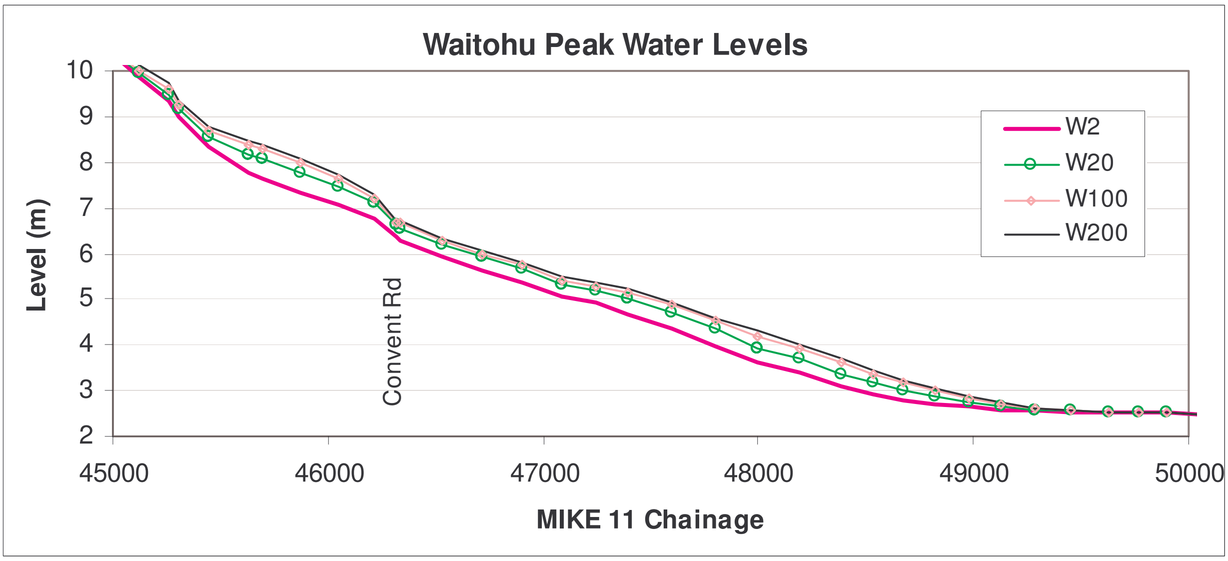

Figure 11 Design Flood Levels, Lower Waitohu Stream (No Freeboard Allowance)

7.4 Design velocity results

Main channel velocities have been estimated at selected sections for each of the W_2, W_{10}, W_{20}, and W_{50} scenarios (Appendix IV). MIKE 11 provides average velocity output for an entire channel width at each cross-section, so estimating the central channel velocity has required some back-calculation of results taking into account the variation in roughness across a section. Figure 12 shows the Waitohu W_{20} mean central channel velocity profile.

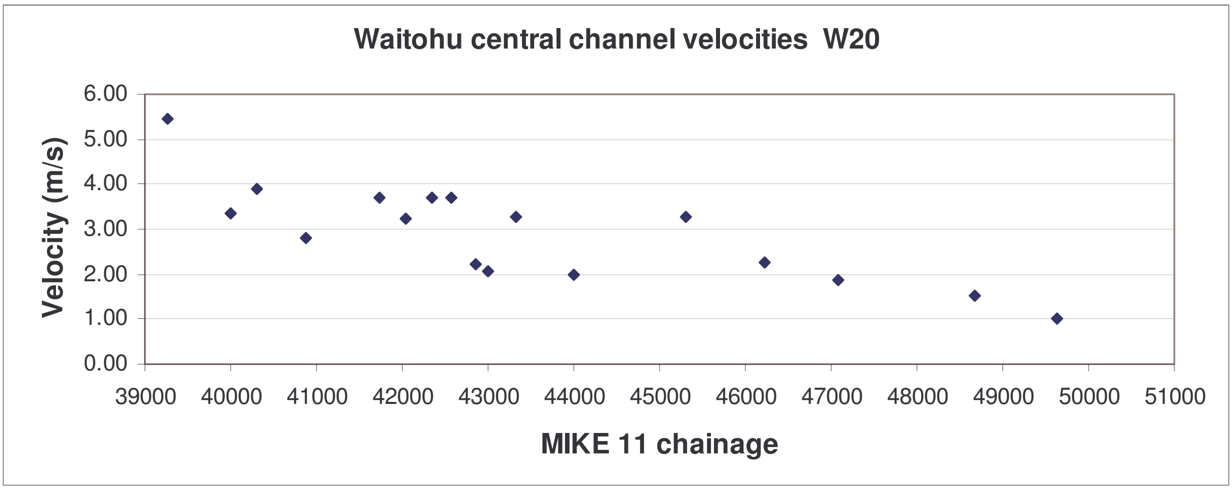

Figure 12 Waitohu W20 mean central channel velocity profile.

7.5 Flood extents

Floodmaps for several of the design scenarios have been produced. Illustrated below is the 1% AEP floodmap (Figure 13). This map is actually a composite, taking the highest water level of the 1% AEP Waitohu, the 1% AEP Mangapouri and the 1%AEP Ngatotara/Greenwood scenarios. (The 1% AEP Waitohu gave the highest water levels in almost all areas, the exceptions only being in the upper cross-sections of the Mangapouri, Ngatotara and Greenwood branches). The high resistance models of the 1% AEP scenario and the 0.5% AEP scenario do not show a significantly greater extent of flooding than the standard 1% AEP flooding.

Figure 14 compares the flood extents for various design scenarios. Each colour represents the additional area flooded compared to the next lowest flood scenario. It can be seen that even in a 50% AEP flood event, the flood extent is not insignificant, while there is not a significant increase in flood extent between a 2% AEP event and a 0.5% AEP event.

Figures 13 and 14 show the extent and depths of flooding without freeboard. Figure 15, on the otherhand, shows the extent with 300mm freeboard added to all flood levels. This is intended to account for various uncertainties (e.g. channel changes, uncertainties in model parameters, debris build-up and waves). It should also be noted that in the past the stream has occasionally changed course through its middle reaches, either through bank erosion or excessive gravel deposition, and there remains a possibility that this would happen again in the event of a large flood. Analysis of such a possibility is beyond the scope of this exercise, but nonetheless the possibility needs to be recognised.

Some areas are shown as being dry in this exercise that were shown as floodable in the previous modelling work. Although this current model is a significant refinement, the various uncertainties discussed above mean that it would be prudent to at least show those areas as being “possibly flooded” or “fringe flooding” or some such term. The latter has been used in Figure15. At the least, these areas will be subject to ponding from local runoff.

Thus, Figure 15 should be seen as the best available hazard map.

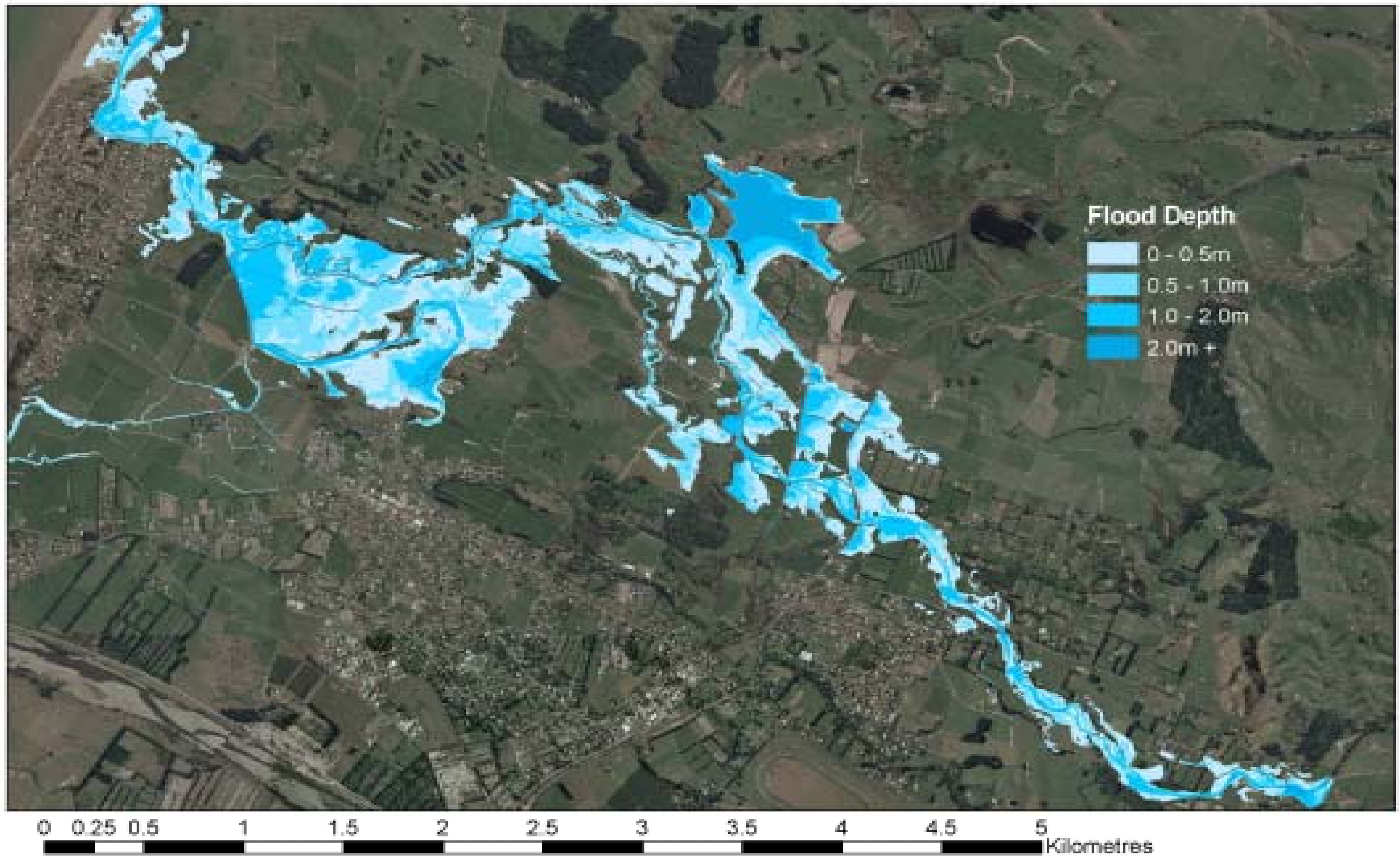

Figure 13 1% AEP Flood Map (without freeboard)

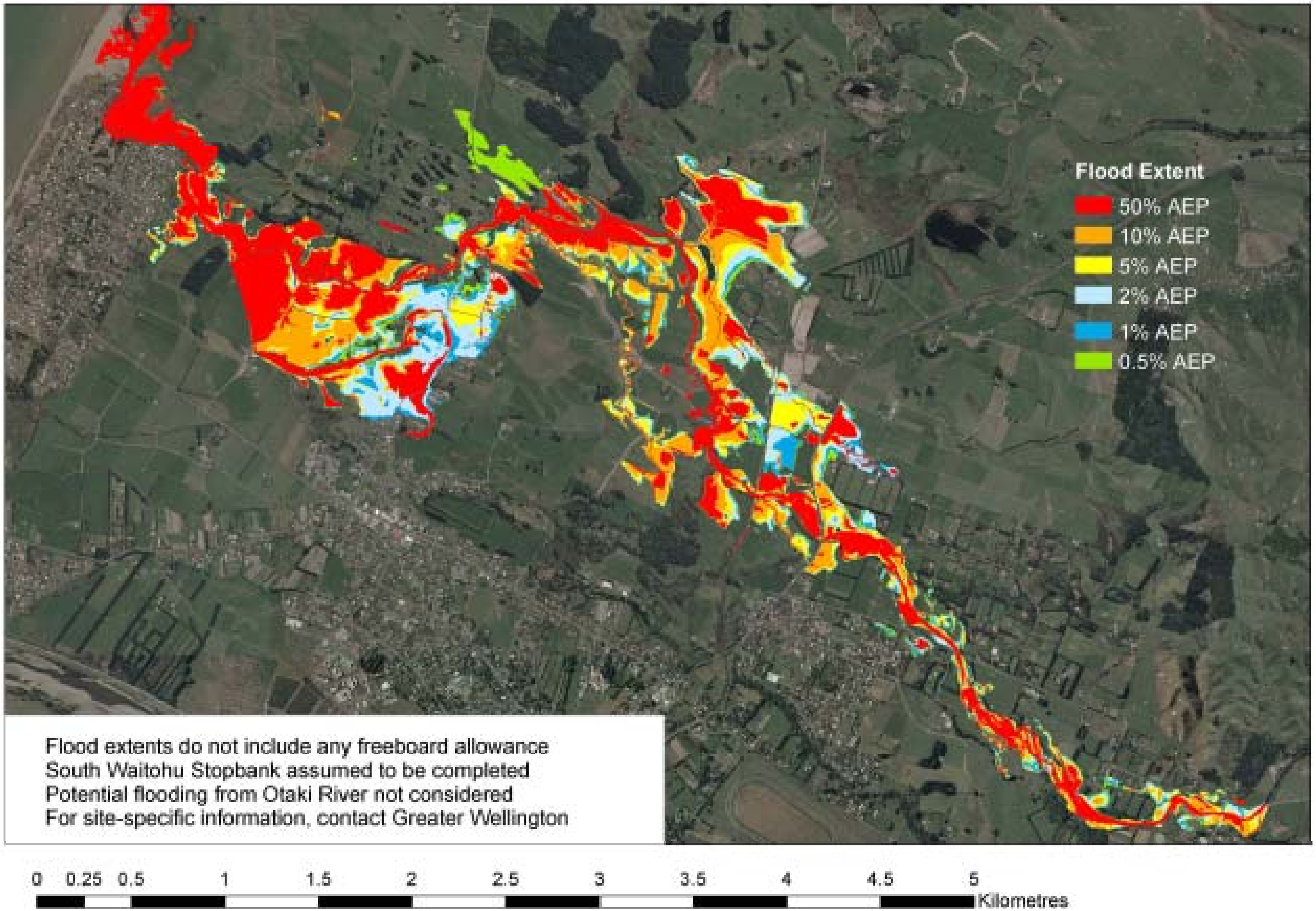

Figure 14 Flood Map – Various Scenarios (all without freeboard)

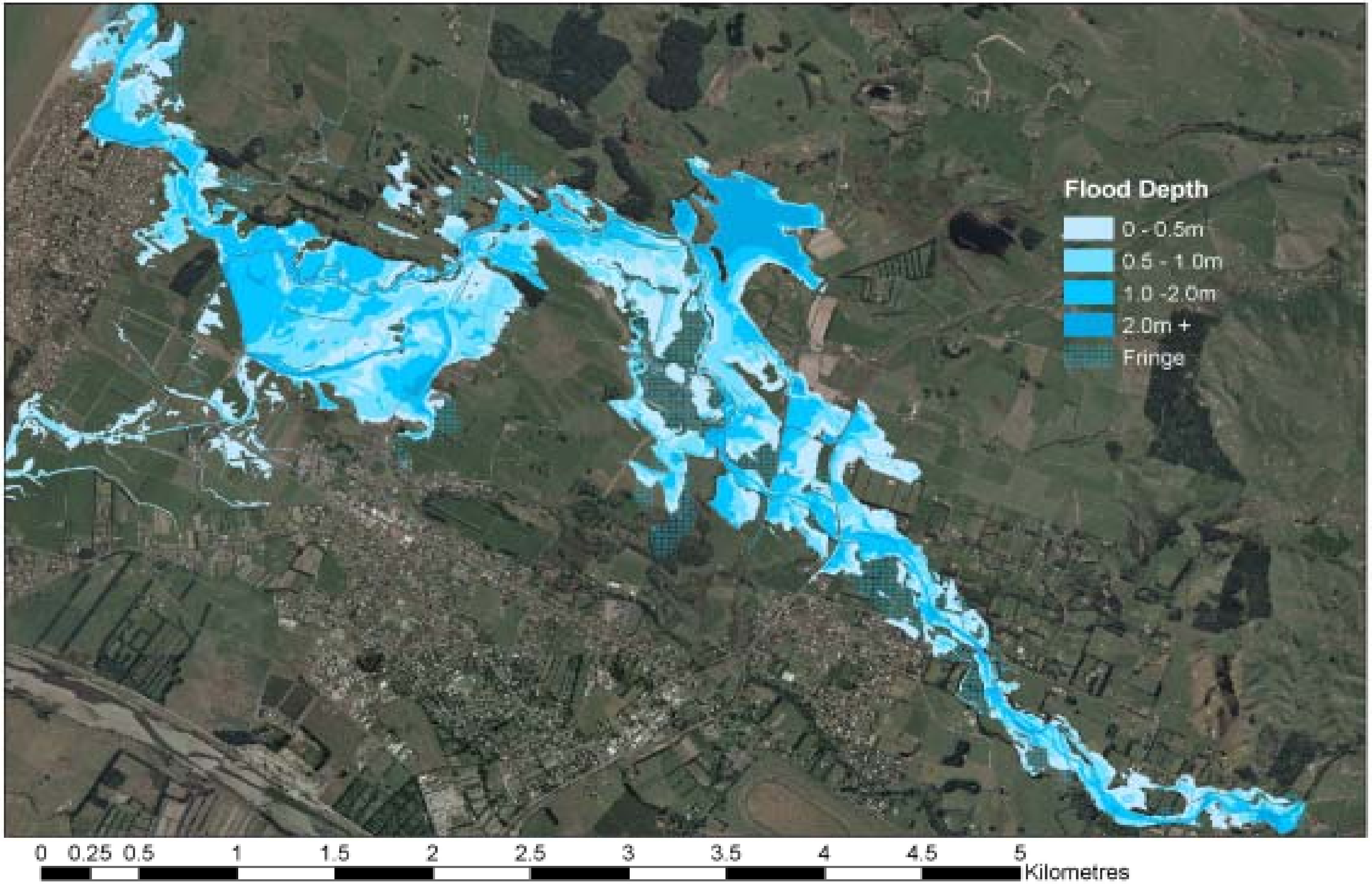

Figure 15 1% AEP Flood Hazard Map

8. Conclusions

The calibration has highlighted the difficulty in modelling a small stream. Without defined stopbanks, bank levels are somewhat variable. A good estimate of bank levels – essential to defining the overflow – cannot be provided without a detailed survey. Such a survey is not appropriate for the scale of this study and the relative lack of risk to human safety and assets. Instead, estimates have been made with the aid of the TIN.

Furthermore, with the degree of meandering of the stream channel, a greater number of stream cross-sections would have been desirable. Again, additional survey would be difficult to justify however.

The floodplain has been difficult to schematise as a network of one-dimensional flow channels. Future modelling should be done with a two-dimensional model, as this would give a greater degree of confidence in flood depths and extent on the floodplain.

For these reasons, any design advice or building levels for particular sites should not rely solely on the results of this study. Further on-site investigations will be required, to check ground levels and potential flow paths from the stream to the site.

Nonetheless, the investigations have provided a useful and updated indication of the flood depths and flood extent for various design scenarios. An updated 1% AEP Flood Hazard Map has been produced, and design levels and velocities produced.

8.1 Reporting and documentation

All models and associated files (e.g. spreadsheets) are stored on the Greater Wellington computer network. Appendix I lists the most relevant files, including the MIKE 11 model and result files.

References

Chow V. T (1959): Open Channel Hydraulics. McGraw-Hill, Tokyo.

Hicks, D.M. and Mason, P.D. (1991); Roughness Characteristics of New Zealand Rivers. Water Resources Survey, DSIR Marine and Freshwater.

Greater Wellington (2003); Waitohu Stream Flood Hydrology. Prepared by Mike Harkness. Report GW/RINV-T-03/06.

Greater Wellington Flood Protection Photograph Archive – Sets 268, 356, 542, 543, 544.

Wellington Regional Council (1992); Kapiti Coast Floodplain Management Plans: Review of Design Storm Surge Levels. Report WRC/RI-T-92/43.

Wellington Regional Council (1995); Otaki Floodplain Management Plan: Phase Two and Three Investigations – Hydraulic Modelling. Prepared by Sharon Manssen. Report WRC/RI-T-95/16.

Wellington Regional Council (1998); Otaki Floodplain Management Plan: Mangapouri Stream Upgrade – Hydraulic Modelling Report. Prepared by M. O. Healy, Report WRC/RI-T-97/48.

Appendix I – Files Used

All are stored in the directory J:\Strategy & Assets\Mike 11 Files\Waitohu\PhilW\

Scenario	.BS11	.sim11	.nwk11	.xns11	.bnd11	.HD11	.RES11
Hotstart File (used to provide initial conditions)		February2004HS	waitohu-ShortMouth	waitohu4	February2004	waitohu2	FEBRUARY2004HS
Hotstart File (used to provide initial conditions)		waitohuLongMouthHS	waitohu-LongMouth	waitohu4	February2004LMHS	waitohuLongMouth	W100LONGMOUTHHS
Hotstart File (used to provide initial conditions)		February2004NoWWRBridgesHS	waitohu-ShortMouth-NoWaterworks_or_RingaBridges	waitohu4	February2004		FEBRUARY2004NOWWRBRIDGESHS
October 2000 flood	Calibration		waitohu-ShortMouth	waitohu4	October2000	waitohu2	OCTOBER2000
February 2004 flood	Calibration		waitohu-ShortMouth	waitohu4	February2004	waitohu2	FEBRUARY2004
February 2004 flood (alternative representation of Waterworks and Ringawhati Bridges)	Calibration		waitohu-ShortMouth-NoWaterworks_or_RingaBridges	waitohu4	February2004	waitohu2	FEBRUARY2004NOWWRBRIDGES
50%AEP Waitohu & tributaries (W_2), short mouth	designruns		waitohu-ShortMouthDesign	waitohu4	Q2	waitohu2	W2SHORTMOUTH
10%AEP Waitohu & 50%AEP tributaries (W_{10}) , short mouth	designruns		waitohu-ShortMouthDesign	waitohu4	Q10	waitohu2	W10SHORTMOUTH
5%AEP Waitohu & 50%AEP tributaries (W_{20}), short mouth	designruns		waitohu-ShortMouthDesign	waitohu4	Q20	waitohu2	W20SHORTMOUTH
2%AEP Waitohu & 5%AEP tributaries (W_{50}), short mouth	designruns		waitohu-ShortMouthDesign	waitohu4	Q50	waitohu2	W50SHORTMOUTH
Q100 Waitohu & 5%AEP tributaries (W_{100}), short mouth	designruns		waitohu-ShortMouthDesign	waitohu4	Q100	waitohu2	W100SHORTMOUTH
Q200 Waitohu & 5%AEP tributaries (W_{200}),, short mouth	designruns		waitohu-ShortMouthDesign	waitohu4	Q200	waitohu2	W200SHORTMOUTH
5%AEP Waitohu & tributaries (W_{20}), long mouth	designruns		waitohu-LongMouthDesign	waitohu4	Q20-longmouth	waitohuLongMouth	W20LONGMOUTH
5%AEP Waitohu & tributaries (W_{100}), long mouth	designruns		waitohu-LongMouthDesign	waitohu4	Q100-longmouth	waitohuLongMouth	W100LONGMOUTH
2%AEP Waitohu & 5%AEP tributaries (W_{50}), short mouth, resistance raised by 0.005	designruns		waitohu-ShortMouthDesign	waitohu4	Q50	waitohuHighResistance	W50SHORTMOUTH-HIGHRESISTANCE
1%AEP Waitohu & 5%AEP tributaries (W_{100}), short mouth, resistance raised by 0.005	designruns		waitohu-ShortMouthDesign	waitohu4	Q100	waitohuHighResistance	W100SHORTMOUTH-HIGHRESISTANCE
5%AEP Waitohu, Ngatotara & Greenwood, Q100 Mangapouri, (M_{100}), short mouth	designruns		waitohu-ShortMouthDesign	waitohu4	Mangapouri100	waitohu2	M100SHORTMOUTH
5%AEP Waitohu & Mangapouri, 1%AEP Ngatotara & Greenwood, (NG_{100}), short mouth	designruns		waitohu-ShortMouthDesign	waitohu4	NgaGreen100	waitohu2	NG100SHORTMOUTH

Associated Files

Spreadsheets

Feb2004.xls	Results from calibration. Sensitivity tests
DesignResults.xls	Full results and graphs from design simulations (Powerdocs #203760)

Arc shape & apr/mxd files, etc

Shape files :	*area-contours*	The extent of the ponding (no flow) areas
	gravelsurvey2003	spot heights surveyed by GPS in channel downstream of the railway
	faultlinesalt	Divisions between channels for flood mapping routine
	waitohuxspwalt	Model cross-section locations, modified for flood mapping
	Waitohuxs	Model cross-section locations
	february_2004-edited	Flood Map for February 2004 event (simulated, no Ringawhati or Waterworks Bridges in model)
	october_2000-edited	Flood Map for October 2000 event (simulated)
	max-q100-july-edited	Flood Map for envelope of flooding from W_{100} (high resistance), M_{100} and NG_{100} scenarios
	max-q100-july_w_fb-edited	Flood Map for envelope of flooding from W_{100} (high resistance), M_{100} and NG_{100} scenarios, with 300mm freeboard added
	q2_shortmouth-july-edited	Flood Map for flooding from W_2
	q10_shortmouth-july-edited	Flood Map for flooding from W_{10}
	q20_shortmouth-july	Flood Map for flooding from W_{20}
	q50_shortmouth-july-edited	Flood Map for flooding from W_{50}
	q200_shortmth-july-edited	Flood Map for flooding from W_{200}
	q200_shortmth_july_w_fbd-edited	Flood Map for flooding from W_{200} with 300mm freeboard added
	otaki_flood_hazard_map_modified_for_chrystalls-waitohu_area	Flood Map from earlier Otaki modelling, cropped to cover the Waitohu area

Waitohu.mxd	Working ArcMap file
Waitohu.apr	Working ArcView project file

Appendix II – Waitohu Cross-Section Location and MIKE 11 Chainages

Appendix III – Design Levels

Note that all levels are in metres, and without freeboard. For design purposes or for setting appropriate building levels, further freeboard should be added to design levels given in this report. A minimum of 300mm is suggested. Refer to Appendix II for the location of the Waitohu Stream sections and to the MIKE 11 network files for the location of the other sections..

Branch	MIKE 11 chainage	Cross-section	Q2Waitohu + Q2 tributaries	Q10Waitohu + Q2 tributaries	Q20Waitohu + Q2 tributaries	Q50Waitohu + Q20 tributaries (High Resistance)	Q50Waitohu + Q20 tributaries	Q100Waitohu + Q20 tributaries	Q200Waitohu + Q20 tributaries	Q100Waitohu + Q20 tributaries (High Resistance)	Q100Mangapouri + Q20 Waitohu & tributaries	Q100Ngatotara & Greenwood + Q20 Waitohu & Mangapouri	Q100Waitohu + Q20 trib (Long Mouth)
WAITOHU	39242	400	82.68	84.10	84.72	85.37	85.37	85.73	86.05	85.73	84.72	84.72	85.73
WAITOHU	39262	390	81.40	81.98	82.25	82.55	82.67	82.71	82.86	82.84	82.25	82.25	82.71
WAITOHU	39384.5		79.22	79.87	80.22	80.63	80.70	80.87	81.07	80.94	80.22	80.22	80.87
WAITOHU	39507	380	77.53	78.39	78.91	79.59	79.59	79.96	80.27	79.96	78.91	78.91	79.96
WAITOHU	39514	370	76.96	77.44	77.64	77.85	77.95	77.97	78.07	78.08	77.64	77.64	77.97
WAITOHU	39644		75.03	75.43	75.59	75.75	75.83	75.84	75.92	75.92	75.59	75.59	75.84
WAITOHU	39774	360	73.02	73.36	73.49	73.62	73.69	73.70	73.76	73.76	73.49	73.49	73.70
WAITOHU	39889		70.87	71.22	71.36	71.50	71.56	71.57	71.64	71.64	71.36	71.36	71.57
WAITOHU	40004	350	69.05	69.42	69.57	69.73	69.80	69.81	69.89	69.88	69.57	69.57	69.81
WAITOHU	40154		67.21	67.57	67.71	67.85	67.92	67.93	68.00	68.00	67.71	67.71	67.93
WAITOHU	40304	340	65.28	65.61	65.73	65.86	65.91	65.93	65.99	65.98	65.73	65.73	65.93
WAITOHU	40454		62.42	62.72	62.84	62.97	63.03	63.05	63.11	63.10	62.84	62.84	63.05
WAITOHU	40604	330	59.65	59.96	60.09	60.22	60.28	60.30	60.36	60.36	60.09	60.09	60.30
WAITOHU	40744		57.17	57.41	57.51	57.62	57.67	57.68	57.73	57.73	57.51	57.51	57.68
WAITOHU	40884	320	54.87	55.08	55.17	55.26	55.30	55.31	55.35	55.35	55.17	55.17	55.31
WAITOHU	41034		52.14	52.40	52.48	52.58	52.62	52.63	52.66	52.66	52.48	52.48	52.63
WAITOHU	41184	310	49.39	49.71	49.81	49.92	49.97	49.99	50.05	50.04	49.81	49.81	49.99
WAITOHU	41329		46.80	47.10	47.23	47.37	47.41	47.46	47.54	47.50	47.23	47.23	47.46
WAITOHU	41474	300	44.78	45.39	45.73	46.09	46.10	46.32	46.52	46.32	45.73	45.73	46.32
WAITOHU	41485		44.76	45.36	45.69	46.04	46.03	46.25	46.44	46.25	45.69	45.69	46.25
WAITOHU	41536	290	43.69	44.10	44.29	44.48	44.58	44.59	44.68	44.69	44.29	44.29	44.59
WAITOHU	41638.5		42.02	42.29	42.43	42.58	42.66	42.66	42.74	42.75	42.43	42.43	42.66
WAITOHU	41741	280	40.58	40.82	40.93	41.06	41.12	41.13	41.19	41.20	40.93	40.93	41.13
WAITOHU	41896		38.01	38.25	38.36	38.48	38.54	38.55	38.61	38.61	38.36	38.36	38.55
WAITOHU	42051	270	35.47	35.72	35.83	35.95	36.02	36.02	36.09	36.09	35.83	35.83	36.02

WAITOHU	42196		33.54	33.83	33.97	34.11	34.17	34.19	34.26	34.25	33.97	33.97	34.19
WAITOHU	42341	260	31.80	32.16	32.31	32.45	32.50	32.53	32.60	32.57	32.31	32.31	32.53
WAITOHU	42521	250	29.38	29.93	30.16	30.33	30.32	30.41	30.49	30.40	30.16	30.16	30.41
WAITOHU	42536		29.37	29.93	30.17	30.34	30.30	30.42	30.50	30.38	30.17	30.17	30.42
WAITOHU	42576	240	28.73	29.03	29.14	29.23	29.26	29.27	29.31	29.30	29.14	29.14	29.27
WAITOHU	42721		26.79	27.03	27.13	27.20	27.23	27.23	27.26	27.26	27.13	27.13	27.23
WAITOHU	42866	230	24.95	25.17	25.27	25.35	25.36	25.39	25.41	25.40	25.27	25.27	25.39
WAITOHU	43006	220 (u/s rail)	23.31	23.81	24.10	24.32	24.31	24.46	24.56	24.41	24.10	24.10	24.46
WAITOHU	43006		23.31	23.81	24.10	24.32	24.31	24.46	24.56	24.41	24.10	24.10	24.46
WAITOHU	43016		22.80	23.18	23.37	23.50	23.61	23.56	23.59	23.64	23.37	23.37	23.56
WAITOHU	43026	210	22.72	23.11	23.31	23.43	23.51	23.49	23.52	23.54	23.31	23.31	23.49
WAITOHU	43136		21.49	21.92	22.13	22.25	22.30	22.30	22.33	22.34	22.13	22.13	22.30
WAITOHU	43246		20.49	20.90	21.11	21.25	21.38	21.30	21.34	21.44	21.11	21.11	21.30
WAITOHU	43336	200	20.00	20.39	20.57	20.71	20.83	20.75	20.79	20.88	20.57	20.57	20.75
WAITOHU	43426		19.37	19.71	19.89	20.03	20.08	20.07	20.11	20.13	19.89	19.89	20.07
WAITOHU	43566	190	18.31	18.86	19.09	19.26	19.34	19.31	19.35	19.39	19.09	19.09	19.31
WAITOHU	43586	180 (new location)	18.13	18.66	18.90	19.06	19.13	19.12	19.16	19.19	18.90	18.90	19.12
WAITOHU	43723.25		17.39	17.86	18.07	18.22	18.26	18.27	18.30	18.32	18.07	18.07	18.27
WAITOHU	43860.49		17.01	17.30	17.40	17.47	17.41	17.49	17.49	17.45	17.40	17.40	17.49
WAITOHU	43860.49		17.01	17.30	17.40	17.47	17.41	17.49	17.49	17.45	17.40	17.40	17.49
WAITOHU	43866		17.01	17.28	17.38	17.44	17.38	17.46	17.46	17.41	17.38	17.38	17.46
WAITOHU	43900		15.91	16.05	16.10	16.13	16.33	16.26	16.27	16.34	16.10	16.10	16.26
WAITOHU	43995	170	14.59	14.71	14.75	14.78	14.95	14.89	14.90	14.97	14.75	14.75	14.89
WAITOHU	44136.48		13.94	14.07	14.11	14.13	14.30	14.22	14.23	14.31	14.11	14.11	14.22
WAITOHU	44136.48		13.94	14.07	14.11	14.13	14.30	14.22	14.23	14.31	14.11	14.11	14.22
WAITOHU	44271.24		13.61	13.72	13.74	13.74	13.86	13.75	13.78	13.88	13.74	13.74	13.75
WAITOHU	44406	160	13.06	13.12	13.14	13.15	13.19	13.19	13.19	13.20	13.14	13.14	13.19
WAITOHU	44585.08		12.25	12.31	12.32	12.33	12.38	12.37	12.38	12.38	12.32	12.32	12.37
WAITOHU	44764.16		11.40	11.44	11.45	11.45	11.48	11.47	11.48	11.48	11.45	11.45	11.47
WAITOHU	44764.16		11.40	11.44	11.45	11.45	11.48	11.47	11.48	11.48	11.45	11.45	11.47
WAITOHU	44846	150	10.98	11.00	11.01	11.01	11.01	11.07	11.15	11.09	11.01	11.01	11.07
WAITOHU	44983.31		10.44	10.46	10.47	10.47	10.47	10.53	10.62	10.55	10.47	10.47	10.53
WAITOHU	45120.61		9.89	9.93	9.94	9.95	9.97	10.02	10.13	10.06	9.94	9.94	10.02
WAITOHU	45257.92		9.33	9.46	9.49	9.51	9.56	9.59	9.73	9.67	9.49	9.49	9.59
WAITOHU	45257.92		9.33	9.46	9.49	9.51	9.56	9.59	9.73	9.67	9.49	9.49	9.59
WAITOHU	45310	140	9.01	9.13	9.15	9.18	9.21	9.24	9.36	9.29	9.15	9.15	9.24
WAITOHU	45448.63		8.35	8.49	8.55	8.62	8.72	8.69	8.80	8.77	8.55	8.56	8.69
WAITOHU	45629		7.78	8.06	8.18	8.31	8.44	8.39	8.48	8.49	8.19	8.19	8.39
WAITOHU	45697	130	7.65	7.95	8.07	8.20	8.33	8.29	8.39	8.39	8.08	8.08	8.29

WAITOHU	45870.33		7.35	7.65	7.77	7.89	8.01	7.98	8.07	8.07	7.77	7.78	7.98
WAITOHU	46043.67		7.07	7.37	7.47	7.57	7.68	7.64	7.72	7.73	7.47	7.47	7.64
WAITOHU	46217	120	6.78	7.06	7.12	7.18	7.26	7.20	7.27	7.29	7.12	7.12	7.20
WAITOHU	46320		6.35	6.60	6.63	6.69	6.72	6.69	6.73	6.71	6.63	6.63	6.68
WAITOHU	46340	110	6.29	6.52	6.55	6.61	6.63	6.69	6.73	6.71	6.56	6.56	6.61
WAITOHU	46530		5.92	6.18	6.22	6.27	6.22	6.28	6.35	6.27	6.22	6.22	6.28
WAITOHU	46720	100	5.62	5.89	5.93	5.99	5.94	5.99	6.07	6.00	5.93	5.94	5.99
WAITOHU	46905		5.37	5.63	5.66	5.72	5.68	5.74	5.82	5.75	5.68	5.68	5.74
WAITOHU	47090	90	5.07	5.27	5.32	5.39	5.37	5.42	5.48	5.43	5.34	5.34	5.41
WAITOHU	47243.5		4.93	5.12	5.19	5.27	5.23	5.29	5.36	5.30	5.22	5.21	5.29
WAITOHU	47397	80	4.66	4.91	5.01	5.11	5.07	5.14	5.22	5.15	5.05	5.05	5.14
WAITOHU	47597		4.34	4.59	4.71	4.83	4.80	4.87	4.94	4.88	4.77	4.76	4.87
WAITOHU	47797		3.98	4.25	4.34	4.47	4.46	4.52	4.59	4.54	4.42	4.40	4.52
WAITOHU	47997	70	3.62	3.87	3.94	4.10	4.14	4.19	4.30	4.24	4.06	4.03	4.19
WAITOHU	48192		3.38	3.62	3.68	3.83	3.88	3.92	4.02	3.97	3.80	3.77	3.92
WAITOHU	48387	60	3.11	3.31	3.38	3.52	3.57	3.60	3.69	3.65	3.49	3.46	3.60
WAITOHU	48530		2.93	3.11	3.16	3.28	3.34	3.36	3.44	3.41	3.26	3.23	3.35
WAITOHU	48673	50	2.80	2.95	3.00	3.10	3.15	3.16	3.24	3.22	3.08	3.06	3.16
WAITOHU	48825.5		2.71	2.83	2.86	2.94	2.98	2.99	3.05	3.03	2.93	2.91	2.99
WAITOHU	48978		2.64	2.72	2.74	2.80	2.83	2.83	2.88	2.87	2.79	2.78	2.83
WAITOHU	49130.5		2.58	2.63	2.65	2.69	2.71	2.71	2.73	2.72	2.68	2.67	2.71
WAITOHU	49283	40	2.55	2.57	2.58	2.61	2.61	2.61	2.62	2.62	2.60	2.60	2.61
WAITOHU	49455.5		2.53	2.55	2.55	2.57	2.58	2.57	2.58	2.58	2.56	2.56	2.57
WAITOHU	49628	30	2.52	2.52	2.52	2.53	2.54	2.53	2.54	2.55	2.53	2.53	2.53
WAITOHU	49763.67		2.51	2.52	2.52	2.53	2.53	2.53	2.53	2.54	2.53	2.52	2.53
WAITOHU	49899.33		2.51	2.51	2.51	2.51	2.52	2.52	2.52	2.52	2.51	2.51	2.52
WAITOHU	50035	20	2.50	2.50	2.50	2.50	2.51	2.50	2.50	2.51	2.50	2.50	2.50
WAITOHU	50190		2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50
WAITOHU	50345		2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50
WAITOHU	50500		2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50
WAITOHU	50666.67		2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50
WAITOHU	50833.33		2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50
WAITOHU	51000		2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50
WAITOHU	51175												2.50
WAITOHU	51350												2.50
WAITVALLEYRD	1000		81.75	81.75	81.75	81.75	81.75	81.75	81.75	81.75	81.75	81.75	81.75
WAITVALLEYRD	1080		80.21	80.21	80.21	80.21	80.21	80.21	80.21	80.21	80.21	80.21	80.21
WAITVALLEYRD	1190		77.55	77.55	77.55	77.55	77.55	77.55	77.55	77.55	77.55	77.55	76.55
WAITVALLEYRD	1340		75.45	76.08	76.26	76.46	76.56	76.55	76.63	76.66	76.26	76.26	74.86

WAITVALLEYRD	1540	72.69	73.05	73.25	73.47	73.57	73.56	73.63	73.66	73.25	73.25	73.56
WAITVALLEYRD	1590	72.69	73.05	73.25	73.47	73.57	73.56	73.63	73.66	73.25	73.25	73.56
WAITVALLEYRD	1704	71.74	71.84	71.90	71.99	72.05	72.05	72.10	72.12	71.90	71.90	72.05
WAITVALLEYRD	1903	67.45	68.21	68.58	68.94	69.15	69.14	69.29	69.33	68.58	68.58	69.14
WAITVALLEYRD	2138	66.55	66.87	67.03	67.16	67.24	67.24	67.31	67.33	67.03	67.03	67.24
WAITVALLEYRD	2410	65.64	65.82	65.91	66.00	66.06	66.05	66.09	66.11	65.91	65.91	66.05
WAITVALLEYRD	2680	63.47	63.60	63.67	63.73	63.77	63.77	63.80	63.81	63.67	63.67	46.32
WAITVALLEYRD	2820	61.29	61.44	61.56	61.68	61.76	61.75	61.82	61.84	61.56	61.56	82.71
STREAMLET	1000	81.75	81.75	81.75	81.75	81.75	81.75	81.75	81.75	81.75	81.75	81.75
STREAMLET	1135	76.96	77.44	77.64	77.85	77.95	77.97	78.07	78.08	77.64	77.64	76.55
STREAMLET	1270	75.45	76.08	76.26	76.46	76.56	76.55	76.63	76.66	76.26	76.26	44.53
STREAMLET	1346.83	44.78	45.39	45.73	46.09	46.10	46.32	46.52	46.32	45.73	45.73	46.32
STREAMLET	1430	48.38	48.38	48.41	48.55	48.66	48.70	48.79	48.79	48.41	48.41	47.04
STREAMLET	1635	46.94	46.94	46.95	47.03	47.10	47.12	47.20	47.20	46.95	46.95	45.57
STREAMLET	1785	44.90	44.90	44.91	45.02	45.10	45.13	45.24	45.23	44.91	44.91	45.03
STREAMLET	1900	44.36	44.36	44.37	44.53	44.59	44.61	44.69	44.68	44.37	44.37	44.53
STREAMLET	2110	44.36	44.36	44.37	44.53	44.59	44.61	44.69	44.68	44.37	44.37	44.53
STREAMLET	2240	43.13	43.13	43.14	43.41	43.51	43.54	43.67	43.66	43.14	43.14	43.41
STREAMLET	2240	41.23	41.23	41.23	41.45	41.55	41.57	41.68	41.67	41.23	41.23	39.51
STREAMLET	2360	41.23	41.23	41.23	41.45	41.55	41.57	41.68	41.67	41.23	41.23	36.09
STREAMLET	2560	31.85	31.85	31.85	31.88	31.91	31.93	31.94	31.94	31.85	31.85	31.88
STREAMLET	2700	29.00	30.52	30.68	30.76	30.78	30.80	30.83	30.82	30.68	30.68	27.66
STREAMLET	2720	29.00	30.52	30.68	30.76	30.78	30.80	30.83	30.82	30.68	30.68	27.66
PLUNKET	1000	24.28	24.70	24.90	25.07	25.12	25.15	25.21	25.20	24.90	24.90	25.15
PLUNKET	1100	24.28	24.70	24.90	25.07	25.12	25.15	25.21	25.20	24.90	24.90	24.63
PLUNKET	1140	23.41	23.96	24.30	24.52	24.49	24.63	24.69	24.55	24.30	24.30	24.46
PLUNKET	1240	29.00	30.52	30.68	30.76	30.78	30.80	30.83	30.82	30.68	30.68	30.80
PLUNKET	1320	29.38	29.93	30.16	30.33	30.32	30.41	30.49	30.40	30.16	30.16	30.41
PLUNKET	1420	29.02	29.35	29.55	29.72	29.75	29.79	29.85	29.82	29.55	29.55	29.79
GREENWOOD	1000	27.85	28.01	28.12	28.27	28.30	28.33	28.40	28.37	28.12	28.12	28.33
GREENWOOD	1220	26.53	27.11	27.60	27.94	28.01	28.08	28.19	28.15	27.60	27.60	28.08
GREENWOOD	1420	26.53	27.11	27.60	27.94	28.01	28.08	28.19	28.15	27.60	27.60	27.52
GREENWOOD	1620	26.42	26.83	27.15	27.41	27.47	27.52	27.62	27.58	27.15	27.15	26.54
GREENWOOD	1670	25.05	25.06	25.21	25.55	25.60	25.77	25.99	25.81	25.25	25.26	25.77
GREENWOOD	1810	32.12	32.12	32.12	32.25	32.27	32.25	32.25	32.27	32.25	32.30	32.25
GREENWOOD	1935	29.23	29.23	29.23	29.36	29.38	29.36	29.36	29.38	29.36	29.41	29.36
GREENWOOD	1990	26.59	26.59	26.59	26.81	26.82	26.81	26.81	26.82	26.81	26.86	26.81
GREENWOOD	2055	25.05	25.06	25.21	25.55	25.60	25.77	25.99	25.81	25.25	25.26	25.77
GREENWOOD	2080	25.05	25.06	25.21	25.55	25.60	25.77	25.99	25.81	25.25	25.26	25.77

GREENWOOD	2120	23.91	23.94	24.24	24.42	24.46	24.49	24.56	24.53	24.27	24.28	24.49
GREENWOOD	2165	21.97	21.99	22.22	22.41	22.45	22.50	22.60	22.54	22.26	22.26	22.50
GREENWOOD	2250	19.58	19.65	20.59	21.18	21.25	21.51	21.84	21.58	20.75	20.76	19.92
GREENWOOD	2345	18.12	18.14	18.65	19.79	19.83	19.92	20.05	19.95	19.63	19.64	19.92
GREENWOOD	2555	16.68	16.71	16.93	17.99	18.13	18.45	19.03	18.59	17.36	17.39	17.73
GREENWOOD	2695	16.56	16.67	16.91	17.61	17.68	17.73	17.83	17.78	17.29	17.31	16.33
GREENWOOD	2815	14.45	14.47	14.64	15.21	15.28	15.34	15.45	15.41	14.88	14.89	14.27
GREENWOOD	3030	13.42	13.49	13.70	14.16	14.21	14.27	14.37	14.34	13.86	13.88	14.27
GREENWOOD	3135	11.85	11.98	12.16	12.61	12.66	12.73	12.84	12.80	12.30	12.32	12.19
GREENWOOD	3190	11.30	11.69	11.85	12.10	12.15	12.19	12.38	12.25	11.86	11.88	12.09
GREENWOOD	3225	9.48	10.59	11.01	11.80	11.81	12.09	12.38	12.12	11.16	11.39	12.09
GREENWOOD	3250	9.44	10.58	10.99	11.80	11.81	12.09	12.38	12.12	11.16	11.39	12.09
GREENWOOD	3290	9.44	10.66	11.09	11.80	11.81	12.09	12.38	12.12	11.16	11.39	12.09
GREENWOOD	3490	9.43	10.65	11.08	11.78	11.79	12.05	12.31	12.08	11.14	11.37	9.66
GREENWOOD	3680	9.43	10.65	11.08	11.78	11.79	12.05	12.31	12.08	11.14	11.37	9.66
SH1_LINK	1000	9.36	9.55	9.59	9.62	9.69	9.71	9.86	9.80	9.59	9.59	9.71
SH1_LINK	1045	9.36	9.55	9.59	9.62	9.69	9.71	9.86	9.80	9.59	9.59	9.71
DRAINAGE	1000	9.34	9.47	9.50	9.52	9.57	9.60	9.74	9.68	9.50	9.50	9.60
DRAINAGE	1130	9.33	9.46	9.49	9.51	9.56	9.59	9.73	9.67	9.49	9.49	9.59
DRAINAGE	1310	31.80	32.16	32.31	32.45	32.50	32.53	32.60	32.57	32.31	32.31	32.53
DRAINAGE	1375	29.02	29.35	29.55	29.72	29.75	29.79	29.85	29.82	29.55	29.55	29.79
OLDCHANNEL	925	26.53	27.11	27.60	27.94	28.01	28.08	28.19	28.15	27.60	27.60	28.08
OLDCHANNEL	1000	25.92	25.99	26.01	26.04	26.05	26.05	26.06	26.06	26.01	26.01	26.05
OLDCHANNEL	1130	21.73	21.73	21.95	22.22	22.33	22.28	22.33	22.37	21.95	21.95	22.28
OLDCHANNEL	1365	20.42	20.91	21.11	21.25	21.39	21.31	21.35	21.45	21.11	21.11	21.31
OLDCHANNEL	1660	20.42	20.90	21.11	21.25	21.39	21.30	21.35	21.45	21.11	21.11	21.31
OLDCHANNEL	1660	20.49	20.90	21.11	21.25	21.38	21.30	21.34	21.44	21.11	21.11	21.30
OLDCHANNEL	1920	18.19	18.47	18.55	18.61	18.66	18.63	18.65	18.68	18.55	18.55	18.63
OLDCHANNEL	2280	16.34	16.77	16.84	16.92	16.97	16.95	16.96	16.99	16.84	16.84	16.95
OLDCHANNEL	2280	15.34	15.80	15.93	16.01	16.07	16.04	16.07	16.10	15.93	15.93	16.04
OLDCHANNEL	2560	13.91	14.52	14.75	14.88	14.94	14.91	14.94	14.98	14.75	14.75	14.91
OLDCHANNEL	2825	12.33	12.92	13.16	13.32	13.44	13.39	13.44	13.51	13.16	13.16	13.39
OLDCHANNEL	3035	12.33	12.92	13.16	13.32	13.44	13.39	13.44	13.51	13.16	13.16	13.39
DRAINAGE2	1000	10.85	11.31	11.52	11.66	11.75	11.71	11.75	11.81	11.52	11.52	11.71
DRAINAGE2	1200	9.21	9.80	9.97	10.02	10.07	10.05	10.07	10.10	9.97	9.97	10.05
DRAINAGE2	1200	9.21	9.80	9.97	10.02	10.07	10.05	10.07	10.10	9.97	9.97	10.05
DRAINAGE2	1280	8.45	9.00	9.20	9.29	9.34	9.32	9.35	9.38	9.20	9.20	9.32
DRAINAGE2	1280	7.82	8.18	8.32	8.44	8.55	8.51	8.55	8.60	8.32	8.32	8.51
DRAINAGE2	1420	7.78	8.06	8.18	8.31	8.44	8.39	8.48	8.49	8.19	8.19	8.39

DRAINAGE2	1420	16.77	16.77	16.77	16.77	16.77	16.77	16.77	16.77	16.77	16.77	16.77
DRAINAGE2	1645	15.06	15.06	15.06	15.06	15.06	15.06	15.06	15.06	15.06	15.06	15.06
DRAINAGE2	1645	15.06	15.06	15.06	15.06	15.06	15.06	15.06	15.06	15.06	15.06	15.06
DRAINAGE2	1770	14.12	14.12	14.12	14.12	14.12	14.12	14.12	14.12	14.12	14.12	14.12
DRAINAGE2	1845	14.12	14.12	14.12	14.12	14.12	14.12	14.12	14.12	14.12	14.12	14.12
DRAINAGE2	2045	12.48	12.48	12.48	12.48	12.48	12.48	12.48	12.48	12.48	12.48	12.48
DRAINAGE2	2250	12.48	12.48	12.48	12.48	12.48	12.48	12.48	12.48	12.48	12.48	12.48
DRAINAGE2	2445	10.40	10.87	10.92	10.96	11.14	11.07	11.10	11.16	10.92	10.92	11.07
NEWCON	1000	8.35	8.49	8.55	8.62	8.73	8.69	8.80	8.77	8.56	8.56	8.69
NEWCON	1170	8.35	8.49	8.55	8.62	8.72	8.69	8.80	8.77	8.55	8.56	8.69
NEWCON	1390	12.33	12.92	13.16	13.32	13.44	13.39	13.44	13.51	13.16	13.16	13.39
NEWCON	1390	14.12	14.12	14.12	14.12	14.12	14.12	14.12	14.12	14.12	14.12	14.12
NEWCON	1470	9.21	9.80	9.97	10.02	10.07	10.05	10.07	10.10	9.97	9.97	10.05
NEWCON	1470	10.40	10.87	10.92	10.96	11.14	11.07	11.10	11.16	10.92	10.92	11.07
NEWCON	1530	7.08	7.08	7.08	7.08	7.18	7.17	7.20	7.19	7.08	7.08	7.17
NEWCON	1600	5.03	5.66	6.01	6.29	6.56	6.56	6.71	6.68	6.03	6.03	6.55
NEWCON	1645	4.93	5.86	6.09	6.28	6.56	6.56	6.71	6.68	6.09	6.10	6.56
DAIRY	47210	4.93	5.86	6.09	6.28	6.56	6.56	6.71	6.68	6.09	6.10	6.56
DAIRY	47400	4.62	5.54	5.79	6.00	6.14	6.15	6.23	6.21	5.80	5.80	6.15
DAIRY	47615	4.62	5.54	5.79	6.00	6.14	6.15	6.23	6.21	5.80	5.80	6.15
DAIRY	47785	4.25	5.01	5.27	5.47	5.65	5.66	5.74	5.72	5.29	5.30	5.65
DAIRY	47890	3.79	4.44	4.85	5.04	5.19	5.22	5.36	5.31	5.20	4.91	5.20
DAIRY	48140	3.79	4.13	4.78	4.93	5.13	5.16	5.33	5.27	5.20	4.91	5.14
PADDOCK	47590	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
PADDOCK	47735	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
PADDOCK	47920	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
RANGIURU	47205	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
RANGIURU	47475	1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.66
RANGIURU	47475	1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.66
RANGIURU	47820	2.59	2.59	2.59	2.59	2.59	2.59	2.59	2.59	2.59	2.59	2.59
RANGIURU	48140	2.59	2.59	2.59	2.59	2.59	2.59	2.59	2.59	2.59	2.59	2.59
RANGIURU	48140	2.59	2.59	2.59	2.59	2.59	2.59	2.59	2.59	2.59	2.59	2.59
RANGIURU	48455	3.59	3.59	3.59	3.59	3.59	3.59	3.59	3.59	3.59	3.59	3.59
RANGIURU	48775	2.59	2.59	2.59	2.59	2.59	2.59	2.59	2.59	2.59	2.59	2.59
RANGIURU	48900	2.59	2.59	2.59	2.59	2.59	2.59	2.59	2.59	2.59	2.59	2.59
RANGIURU	49140	1.67	1.67	1.67	1.67	1.67	1.67	1.67	1.67	1.67	1.67	1.67
RANGIURU	49340	1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.66
RANGIURU	49340	1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.66
RANGIURU	49510	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65

RANGIURU	49510	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65
RANGIURU	49750	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65
RANGIURU	49840	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
CULVERTRANGI	49340	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	2.70
CULVERTRANGI	49510	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	2.56
DVRTBANK	1000	2.52	2.52	2.52	2.52	2.53	2.52	2.52	2.53	2.52	2.52	2.52
DVRTBANK	1170	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50
FOOTHILLS	1000	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50
FOOTHILLS	1200	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50
FOOTHILLS	1200	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50
FOOTHILLS	1440	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50
FOOTHILLS	1580	11.30	11.69	11.85	12.10	12.15	12.19	12.38	12.25	11.86	11.88	12.19
NEARMOUTH	1000	9.44	10.66	11.09	11.80	11.81	12.09	12.38	12.12	11.16	11.39	12.09
NEARMOUTH	1130	4.33	4.91	5.01	5.11	5.07	5.14	5.22	5.15	5.06	5.05	5.14
NEARMOUTH	1265	4.34	4.91	5.01	5.11	5.07	5.14	5.22	5.15	5.06	5.05	5.14
NEARMOUTH	1390	4.34	4.91	5.01	5.11	5.07	5.14	5.22	5.15	5.06	5.05	5.14
NEARMOUTH	1450	4.47	4.91	5.01	5.11	5.07	5.14	5.22	5.15	5.05	5.05	5.14
MANGAPOURI	10000	4.66	4.91	5.01	5.11	5.07	5.14	5.22	5.15	5.05	5.05	5.14
MANGAPOURI	10167	2.55	2.57	2.58	2.61	2.61	2.61	2.62	2.62	2.60	2.60	2.61
MANGAPOURI	10240	2.54	2.56	2.57	2.58	2.59	2.59	2.60	2.60	2.58	2.58	2.59
MANGAPOURI	10270	2.53	2.55	2.56	2.58	2.58	2.58	2.59	2.59	2.57	2.57	2.58
MANGAPOURI	10276	2.51	2.52	2.52	2.53	2.54	2.53	2.54	2.54	2.53	2.53	2.54
MANGAPOURI	10469	2.50	2.50	2.50	2.50	2.51	2.50	2.50	2.51	2.50	2.50	2.50
MANGAPOURI	10469	6.16	6.16	6.16	6.98	7.11	6.98	6.98	7.11	7.41	6.98	6.98
MANGAPOURI	10640	5.12	5.12	5.12	6.03	6.08	6.03	6.03	6.08	6.52	6.03	6.03
MANGAPOURI	10670	4.39	4.39	4.39	5.59	5.62	5.59	5.59	5.62	6.16	5.59	5.59
MANGAPOURI	10687	4.32	4.32	4.32	5.05	5.11	5.05	5.05	5.11	5.38	5.05	5.05
MANGAPOURI	10783	4.33	4.33	4.33	5.14	5.19	5.14	5.14	5.19	5.51	5.14	5.14
MANGAPOURI	10952	3.79	3.88	3.98	4.92	4.98	4.92	4.92	4.98	5.35	4.92	4.92
MANGAPOURI	11110	3.79	3.88	3.98	4.92	4.98	4.92	4.92	4.98	5.35	4.92	4.92
MANGAPOURI	11357	3.63	3.87	3.95	4.61	4.67	4.61	4.64	4.67	5.05	4.61	4.61
MANGAPOURI	11357	3.62	3.86	3.94	4.11	4.17	4.22	4.32	4.27	4.09	4.04	4.21
MANGAPOURI	11750	3.62	3.86	3.94	4.11	4.18	4.22	4.33	4.28	4.16	4.04	4.22
MANGAPOURI	11988	3.62	3.86	3.94	4.11	4.17	4.22	4.32	4.27	4.07	4.04	4.21
MANGAPOURI	11988	3.62	3.86	3.94	4.10	4.16	4.21	4.31	4.26	4.07	4.04	4.19
MANGAPOURI	12140	3.62	3.86	3.94	4.10	4.15	4.20	4.31	4.25	4.07	4.03	4.19
STORAGE	0	9.43	10.65	11.08	11.78	11.79	12.05	12.31	12.08	11.14	11.37	12.05
STORAGE	75	9.79	10.42	10.61	10.92	10.93	11.08	11.18	11.10	10.61	10.61	11.08
NGATOTARA	980	9.79	10.42	10.61	10.92	10.93	11.08	11.18	11.10	10.61	10.61	11.08

NGATOTARA	1000	10.98	11.00	11.01	11.01	11.01	11.07	11.15	11.09	11.01	11.01	11.07
NGATOTARA	1080	11.40	11.44	11.45	11.45	11.48	11.47	11.48	11.48	11.45	11.45	14.22
NGATOTARA	1180	9.36	9.52	9.55	9.58	9.65	9.66	9.79	9.75	9.55	9.55	12.48
DIVGRNCON	1680	14.59	14.71	14.75	14.78	14.95	14.89	14.90	14.97	14.75	14.75	14.89
DIVGRNCON	1800	15.06	15.06	15.06	15.06	15.06	15.06	15.06	15.06	15.06	15.06	15.06
DIVGRNCON	1904.16	14.59	14.71	14.75	14.78	14.95	14.89	14.90	14.97	14.75	14.75	14.89
DIVGRNCON	1904.16	14.80	15.14	15.24	15.36	15.34	15.37	15.40	15.38	15.24	15.24	15.37
DIVGRNCON	1910	13.06	13.12	13.14	13.15	13.19	13.19	13.19	13.20	13.14	13.14	13.19
CONVENTDRAIN	1000	15.38	15.38	15.38	15.38	15.38	15.38	15.38	15.38	15.38	15.38	15.38
CONVENTDRAIN	1050	13.42	13.49	13.73	14.16	14.21	14.27	14.37	14.34	13.86	13.88	14.27
CONVENTDRAIN	1050	13.42	13.49	13.73	14.16	14.21	14.27	14.37	14.34	13.86	13.88	14.27
CONVENTDRAIN	1160	13.42	13.49	13.70	14.16	14.21	14.27	14.37	14.34	13.86	13.88	14.27
CONVENTDRAIN	1200	4.93	5.86	6.09	6.28	6.56	6.56	6.71	6.68	6.09	6.10	6.56
CONVENTDRAIN	1280	6.35	6.60	6.63	6.69	6.72	6.69	6.73	6.71	6.63	6.63	6.68
CONVENTDRAIN	1340	6.11	6.11	6.11	6.11	6.11	6.11	6.11	6.11	6.11	6.11	6.11
SH1-WAKAPUA	875	40.58	40.82	40.93	41.06	41.12	41.13	41.19	41.20	40.93	40.93	41.13
SH1-WAKAPUA	925	41.23	41.23	41.23	41.45	41.55	41.57	41.68	41.67	41.23	41.23	41.46
SH1-WAKAPUA	1000	73.02	73.36	73.49	73.62	73.69	73.70	73.76	73.76	73.49	73.49	73.70
SH1-WAKAPUA	1125	72.69	73.05	73.25	73.47	73.57	73.56	73.63	73.66	73.25	73.25	73.56
SH1-WAKAPUA	1125	23.31	23.81	24.10	24.32	24.31	24.46	24.56	24.41	24.10	24.10	24.46
SH1-WAKAPUA	1160	20.85	20.89	21.00	21.72	21.64	22.48	22.55	22.46	21.00	21.00	22.48
SH1-WAKAPUA	1190	25.92	25.99	26.01	26.04	26.05	26.05	26.06	26.06	26.01	26.01	26.05
SH1-WAKAPUA	1190	25.48	25.54	25.60	25.65	25.66	25.66	25.68	25.68	25.60	25.60	25.66
SH1-WAKAPUA	1240	24.59	24.64	24.67	24.70	24.71	24.72	24.73	24.73	24.67	24.67	24.72
SH1-WAKAPUA	1290	20.85	20.89	21.00	21.72	21.64	22.48	22.55	22.46	21.00	21.00	22.48
SH1-WAKAPUA	1340	20.85	20.89	21.00	21.72	21.64	22.48	22.55	22.46	21.00	21.00	22.48
SH1-WAKAPUA	1360	20.01	20.06	20.31	21.72	21.64	22.48	22.54	22.45	20.31	20.31	22.48
SH1-WAKAPUA	1380	20.01	20.06	20.29	20.53	20.56	20.68	20.78	20.68	20.29	20.29	20.68
SH1-WAKAPUA	1480	20.01	20.06	20.29	20.53	20.56	20.68	20.78	20.68	20.29	20.29	20.68
SH1-WAKAPUA	1560	20.01	20.06	20.10	20.33	20.34	20.48	20.57	20.46	20.10	20.10	20.48
SH1-WAKAPUA	1560	19.51	19.56	19.64	19.94	19.94	20.13	20.33	20.07	19.63	19.63	20.13
SH1-WAKAPUA	1635	19.04	19.25	19.54	19.88	19.86	20.09	20.32	20.01	19.54	19.54	20.09
SH1-WAKAPUA	1635	19.00	19.15	19.48	19.83	19.82	20.02	20.16	19.95	19.48	19.48	20.02
SH1-WAKAPUA	1720	18.75	18.78	18.84	19.08	19.08	19.20	19.28	19.18	18.84	18.84	19.20
SH1-WAKAPUA	1720	17.13	17.15	17.22	17.39	17.39	17.45	17.49	17.44	17.22	17.22	17.45
SH1-WAKAPUA	1800	16.40	16.42	16.50	16.71	16.71	16.78	16.84	16.77	16.50	16.50	16.79
SH1-WAKAPUA	1910	16.40	16.42	16.50	16.71	16.71	16.78	16.84	16.77	16.50	16.50	16.79
SH1-WAKAPUA	2000	16.00	16.27	16.37	16.51	16.48	16.53	16.55	16.54	16.37	16.37	16.53
SH1-WAKAPUA	2080	16.00	16.27	16.37	16.51	16.48	16.53	16.55	16.54	16.37	16.37	16.53

RAIL-WAKAPUA	1230	14.80	15.14	15.24	15.36	15.34	15.37	15.40	15.38	15.24	15.24	15.37
RAIL-WAKAPUA	1240	14.80	15.14	15.24	15.36	15.34	15.37	15.40	15.38	15.24	15.24	15.37
RAIL-WAKAPUA	1430	14.14	14.38	14.46	14.56	14.55	14.57	14.60	14.58	14.46	14.46	14.57
RAIL-WAKAPUA	1430	12.77	13.37	13.44	13.54	13.53	13.55	13.56	13.56	13.44	13.44	13.55
RAIL-WAKAPUA	1470	11.92	12.41	12.51	12.64	12.63	12.66	12.68	12.67	12.51	12.51	12.66
RAIL-WAKAPUA	1530	11.30	11.69	11.85	12.10	12.15	12.19	12.38	12.25	11.86	11.88	12.19
RAIL-WAKAPUA	1600	20.01	20.06	20.29	20.53	20.56	20.68	20.78	20.68	20.29	20.29	20.68
RAIL-WAKAPUA	1600	19.61	19.61	19.61	19.67	19.76	20.04	20.23	20.04	19.61	19.61	20.05
RAIL-WAKAPUA	1650	18.03	18.74	19.13	19.20	19.26	19.21	19.15	19.27	19.13	19.13	19.21
RAIL-WAKAPUA	1650	18.03	18.74	19.13	19.20	19.26	19.21	19.15	19.27	19.13	19.13	4.20
RAIL-WAKAPUA	1700	18.50	18.59	18.69	18.77	18.79	18.78	18.78	18.80	18.69	18.69	4.20
GOLF1	0	3.62	3.86	3.94	4.10	4.15	4.19	4.30	4.24	4.06	4.03	4.19
GOLF1	100	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
GOLF2	0	10.98	11.00	11.01	11.01	11.01	11.07	11.15	11.09	11.01	11.01	11.07
GOLF2	150	9.36	9.55	9.59	9.62	9.69	9.71	9.86	9.80	9.59	9.59	9.71
GOLF3	0	6.78	7.06	7.12	7.18	7.26	7.20	7.27	7.29	7.12	7.12	7.20
GOLF3	150	6.00	6.07	6.45	6.77	7.03	6.88	7.16	7.25	6.47	6.48	6.88
GOLF4	0	6.00	6.07	6.45	6.77	7.03	6.88	7.16	7.25	6.47	6.48	6.15
GOLF4	100	6.05	6.05	6.05	6.05	6.05	6.05	6.05	6.64	6.05	6.05	5.44
WAIORONGOMAIRD	0	18.13	18.66	18.90	19.06	19.13	19.12	19.16	19.19	18.90	18.90	19.12
WAIORONGOMAIRD	100	16.77	16.77	16.77	16.77	16.77	16.77	16.77	16.77	16.77	16.77	16.77
CHICKEN	0	7.65	7.95	8.07	8.20	8.33	8.29	8.39	8.39	8.08	8.08	8.29
CHICKEN	100	8.16	8.38	8.42	8.48	8.56	8.60	8.77	8.67	8.42	8.43	8.60
WAIORONGOMAI	0	0.00	0.00	0.00	0.00	0.00	0.82	8.57	8.43	0.00	0.00	0.81
WAIORONGOMAI	200	7.93	7.93	7.93	7.93	7.93	7.93	8.57	8.26	7.93	7.93	7.93

Appendix IV – Waitohu Stream Central Channel Velocities

MIKE 11 Chainage	Scenario			
	W_2	W_{10}	W_{20}	W_{50}
49628	0.73	0.93	1.01	1.16
48673	1.28	1.48	1.53	1.66
47090	1.63	1.87	1.87	1.89
46217	1.87	2.10	2.26	2.43
45310	3.00	3.24	3.28	3.31
43995	1.79	1.94	1.98	2.01
43336	2.31	2.94	3.25	3.48
43006	1.55	1.95	2.08	2.16
42866	2.03	2.21	2.23	2.26
42576	2.71	3.42	3.69	3.93
42341	2.50	3.37	3.69	4.16
42051 (Left channel)	2.56	3.04	3.22	3.38
42051 Right channel)	1.75	2.34	2.57	2.78
41741	3.07	3.48	3.69	3.92
40884	2.17	2.60	2.82	3.05
40304	3.06	3.84	3.89	4.14
40004	2.66	3.11	3.35	3.64
39262	4.04	5.21	5.45	5.84

Appendix V – Other Flood Photographs

Looking west across SH1 towards the Ngatotara/Waitohu confluence

FILE NOTE

DATE 16 March 2005

AUTHOR Philip Wallace

SUBJECT Waitohu MIKE 11 Model - January 2005 Flood

FILE NUMBER N/06/30/08

I have rerun the MIKE 11 hydraulic model with the January 2005 flood.

Firstly, I ran the model with inflow data from the WSI recorder (main Waitohu branch) plus data from the hydrologic model (Ngatotara, catchments H & I, Greenwood Boulevard (assumed same as I), and Mangapouri). Tide data was based on the max/min tide levels and timing from the NIWA tide model, with 0.5m added for storm surge.

The model predicted a level of 12.42m in the Ngatotara drain area – compared to a level of 10.57m surveyed by Gilbert Kimberly (of Taylors Rd). I still think that the hydrological model doesn't account for the storage within the Ngatotara catchment (wetlands, railway embankment etc), so I took that inflow out. That resulted in a predicted level of 11.8m, ie still too high. So then I ran it with no inflows from catchment H & I. This gave a level of 10.66m – ie close to the observed.

Note that the residents suggested that little flow was coming into the Ngatotara/Taylors Rd via the Ngatotara catchment, but rather from the Greenwood catchment (which was being fed also by over from the Waitohu upstream of the rail bridge).

Indicates need to refine the hydrological model, in the Ngatotara catchment.

The hydraulic model link0220RB does allows some overflow from the Waitohu upstream of the railway, but the overflow that was observed was not envisaged at the time of model setup. Overflow was observed near section 42866 shown on the attached diagrams. It is also inferred that water backed up behind the railway so that it joined the Greenwood branch that runs through the triangular block near the railway crossing on Taylors Rd (Figure 2).

It could be refined, but the stream section changes (gravel accumulation) are such that the model could just as quickly become out of date.

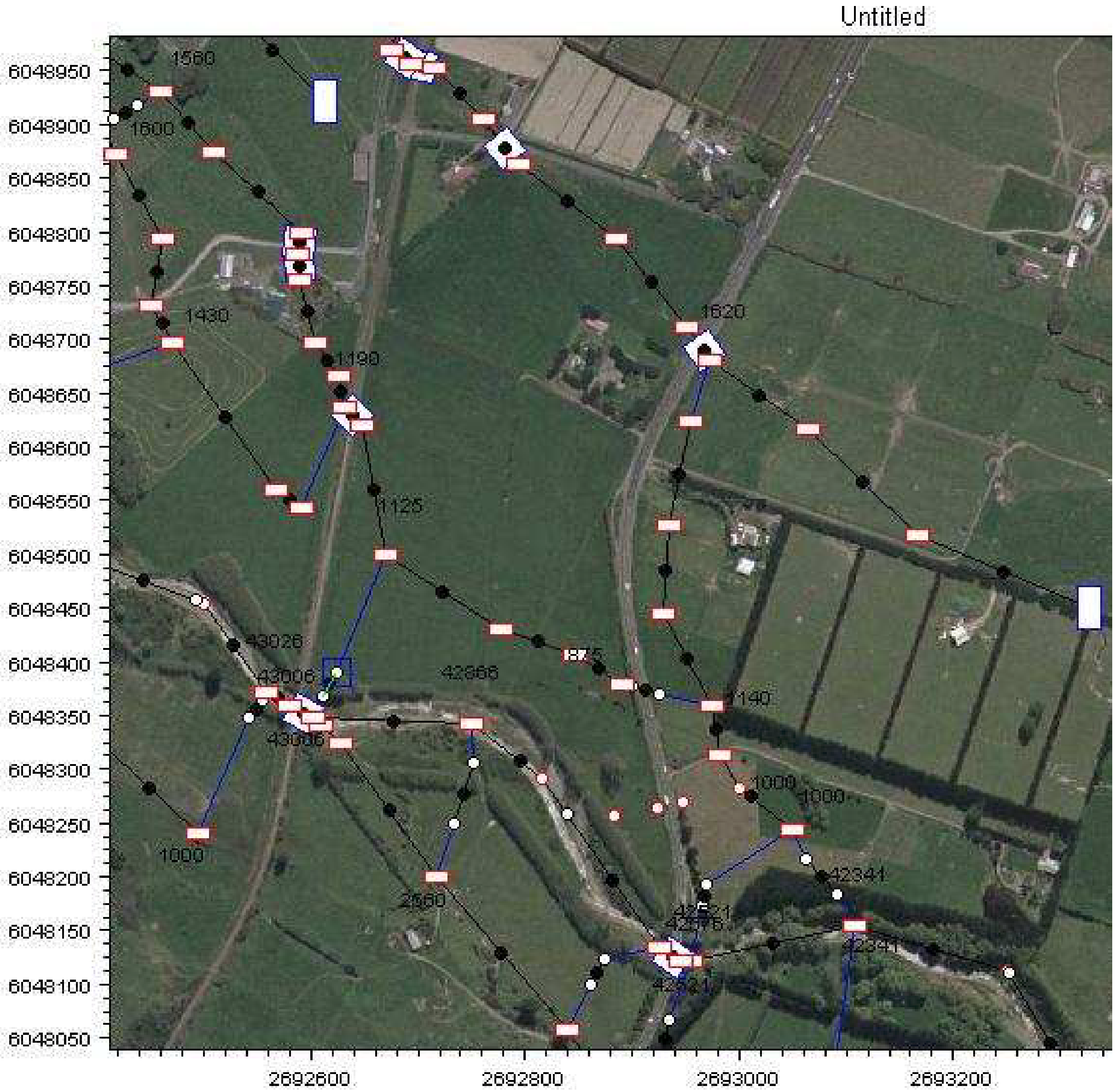

Figure 1 – Existing Model Layout at Railway/Taylors Rd

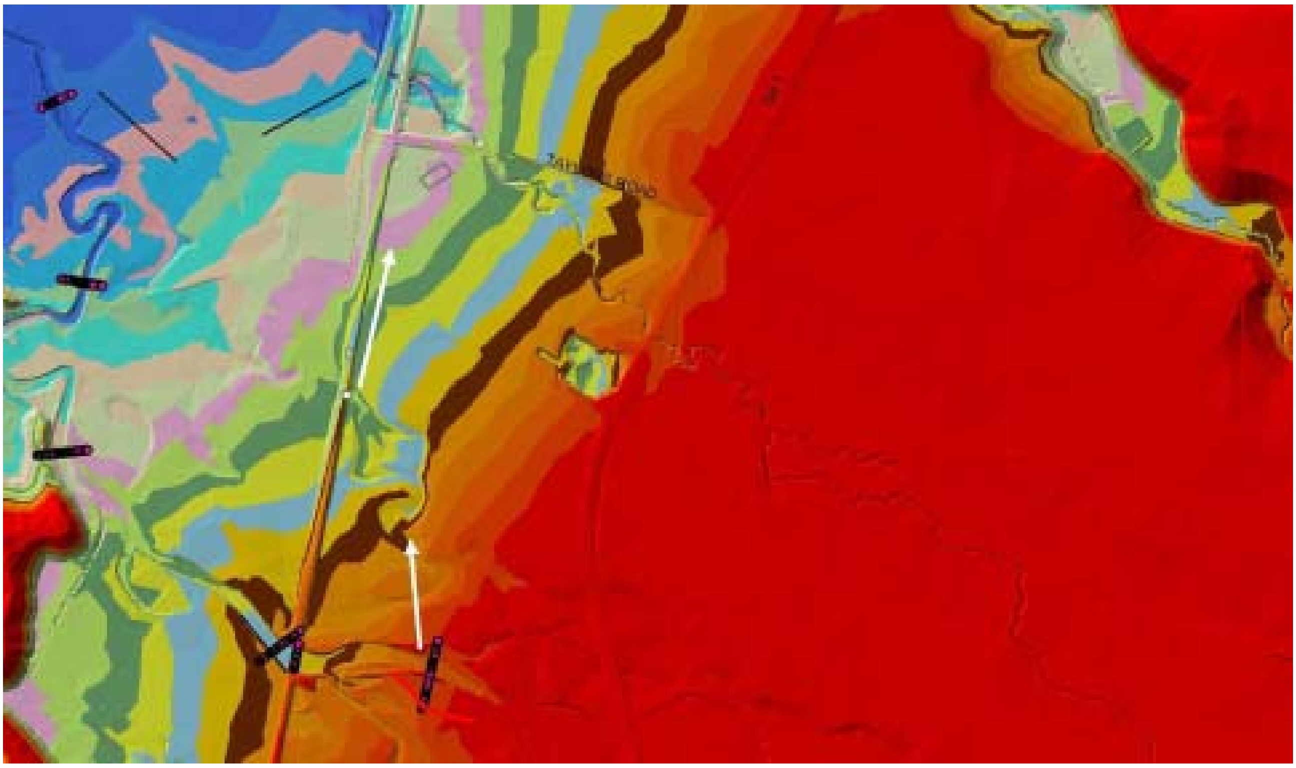

Figure 2 Inferred Flow Paths (white arrows) in event, to the house at 27 Taylors Rd (grey rectangle). Model could be refined to insert links at these arrows.

Files – J/strategy&assets/mike11/waitohu/philw

January2005.sim11

January2005-noNgaInflow.sim11

Philip Wallace

6 January 2005 Flood, Bennetts Rd (Mangapouri Stream)

Silt deposited by overflows in 6 January 2005 Flood, Waitohu Stream, right bank between SH1 and Rail bridges