Taupo District Flood Hazard Study

WHAREROA STREAM

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For: ***Environment Waikato and Taupo District Council***

June 2012

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Executive Summary

A flood hazard assessment of Whareroa Stream involves an analysis of the magnitude and frequency of known runoff events, consideration of how these may be affected by land use and climate change, and the interaction of these events with the landscape. Implicit in these analyses is the stationarity of data. This assumes that the same processes and runoff relationships that existed in the past will continue to apply in the future. This has particular implications when considering the long term effects of land use and climate change, and on-going ground deformation.

It is also necessary to consider how the flood interacts with human activities, and the effect that lake level may have on either exacerbating or moderating the flood. Any particular flood event is a function of both the flow in the river and the conditions on the lake at the time the flood peak reaches the river mouth. The conditions on the lake are a function of the static water level, and over the longer term tectonic deformation. The risk of flooding, and the extent and depth of inundation near the major tributaries, is therefore a multi-factor problem, with both temporal and spatial components.

Previous work has analysed the frequency and magnitude of variations in lake level, and how these might affect the extent and depth of flooding around Lake Taupo (McConchie *et al.* 2008). Those data are not discussed in detail, but are presented largely in summary form in this report. This report focuses on the extent and depth of flooding caused predominantly by large flows in Whareroa Stream.

The lack of a long term flow record for Whareroa Stream is a significant constraint on design flood estimation. However, a realistic long term synthetic flow series was derived using appropriately scaled data from the adjacent Kuratau catchment. The major flood which occurred in early 2004 and was measured in the Whareroa Stream appears typical of large flood events. This flood hydrograph was therefore used as the basis from which to scale various design flows which were used in hydraulic modelling

A range of extreme flood scenarios were analysed using a MIKE FLOOD one-dimensional and two-dimensional coupled hydraulic model of the lower Whareroa catchment. The lack of specific information relating to significant flood events and the resulting inundation made it difficult to calibrate the hydraulic model using empirical data. The MIKE FLOOD model can, however, be further calibrated when such information becomes available.

To recognise the various constraints on the flood hazard assessment, a conservative approach was taken. Consequently, the flood extents and depths of inundation are likely to be slightly greater than would actually occur during a major flood event of the magnitude modelled; but they are realistic. Such an approach is considered appropriate for a reconnaissance-scale flood assessment.

A significant proportion of the flat land adjacent to Whareroa Stream is not prone to flooding because of the incised nature of the river. The areas that are prone to flooding lie near the mouth of the river, and around the lake shore. These areas are also prone to flooding from high lake levels.

Flood waters that break out of the main channel flow across river bends and occupy low lying areas. A large volume of water can be accommodated by inundation to a relatively shallow depth. Likewise, once any flood water leaves the channel, the depth of flow is generally shallow and so friction slows the velocity dramatically. Consequently over most of the area that would potentially flood, the risk to life and property is low.

The areas subject to the greatest risk are within the main channel. Therefore, during the 100-year event, the hazard outside of the obvious channels and flow paths is generally low. A small portion of the 'urban area' near the mouth of the river is subject to a risk of flooding. However, while the cost of flooding and inconvenience may still be high, the actual risks to life and property are not great.

The flood hazard maps provide guidance as to what level of planning control might be appropriate, rather than restricting or denying specific activities. The maps also indicate where detailed, site-specific studies, might be required before any major capital works are undertaken.

The lack of calibration and validation data for the flood model is a major constraint. Priority therefore needs to be given to recording water levels and flood extents during any large event which affects the Whareroa catchment. While there are obviously a number of priorities during large floods, the value of accurate information regarding the extent and depth of flooding cannot be over-estimated.

The limited flow information available for Whareroa Stream is particularly problematic. Following the release of the updated regional flood estimation parameters the design flows should be reviewed, and if necessary the hydraulic model re-run using any revised hydrographs.

This study provides a consistent assessment of the flood hazard posed by Whareroa Stream given the current state of knowledge. However, should a large flood event occur, and calibration data become available, consideration should be given to updating the flood model and its results.

Contents

1 Overview

1.1 Purpose

Under the Resource Management Act (1991), regional councils and territorial authorities are required to develop provisions that avoid or mitigate the effects of natural hazards. Areas near Lake Taupo are vulnerable to flooding, particularly over the longer term, as a result of large river flows, high lake levels, big waves, on-going ground deformation, and the topography and geology of the surrounding area. Major tributaries to the lake also pose a flood risk which can be exacerbated when high lake levels impede flood drainage. Environment Waikato and the Taupo District Council are therefore investigating the combined flood risk in a holistic manner so that they can monitor and manage this hazard (Environment Waikato, 2005).

This study has been prompted by:

- Environment Waikato and the Taupo District Council being required, under sections 30 and 31 of the Resource Management Act (1991), to avoid and mitigate the effects of natural hazards;
- Section 35 of the Resource Management Act (1991) that requires Councils to monitor the environment, and maintain records of natural hazards;
- The need to provide definition, justification, description, and interpretation of the flood hazard area rules in the District Plan;
- Central Government's review of flood management in New Zealand; and
- Environment Waikato's Project Watershed which aims to address flood protection, soil conservation, and river management in the Waikato River catchment.

The primary objective of this phase of the *Taupo District Flood Hazard Study* was to assess the flood risk to land adjacent to Whareroa Stream. Of particular concern is the flood risk near the mouth of the river and for 1km upstream where future expansion of Whareroa Village may take place on the flood plain. The flood risk was assessed using detailed hydrometric analysis and a two-dimensional computational hydraulic model.

2 Whareroa catchment

2.1 Description

Whareroa Stream flows generally eastwards, draining the slopes of the Pureora Forest Park and Pukepoto Forest to Lake Taupo. The catchment is 58.8km² in area and contains three main tributaries; the Otarua, Ngatokotoko, and Whareroa Streams (Figure 2.1).

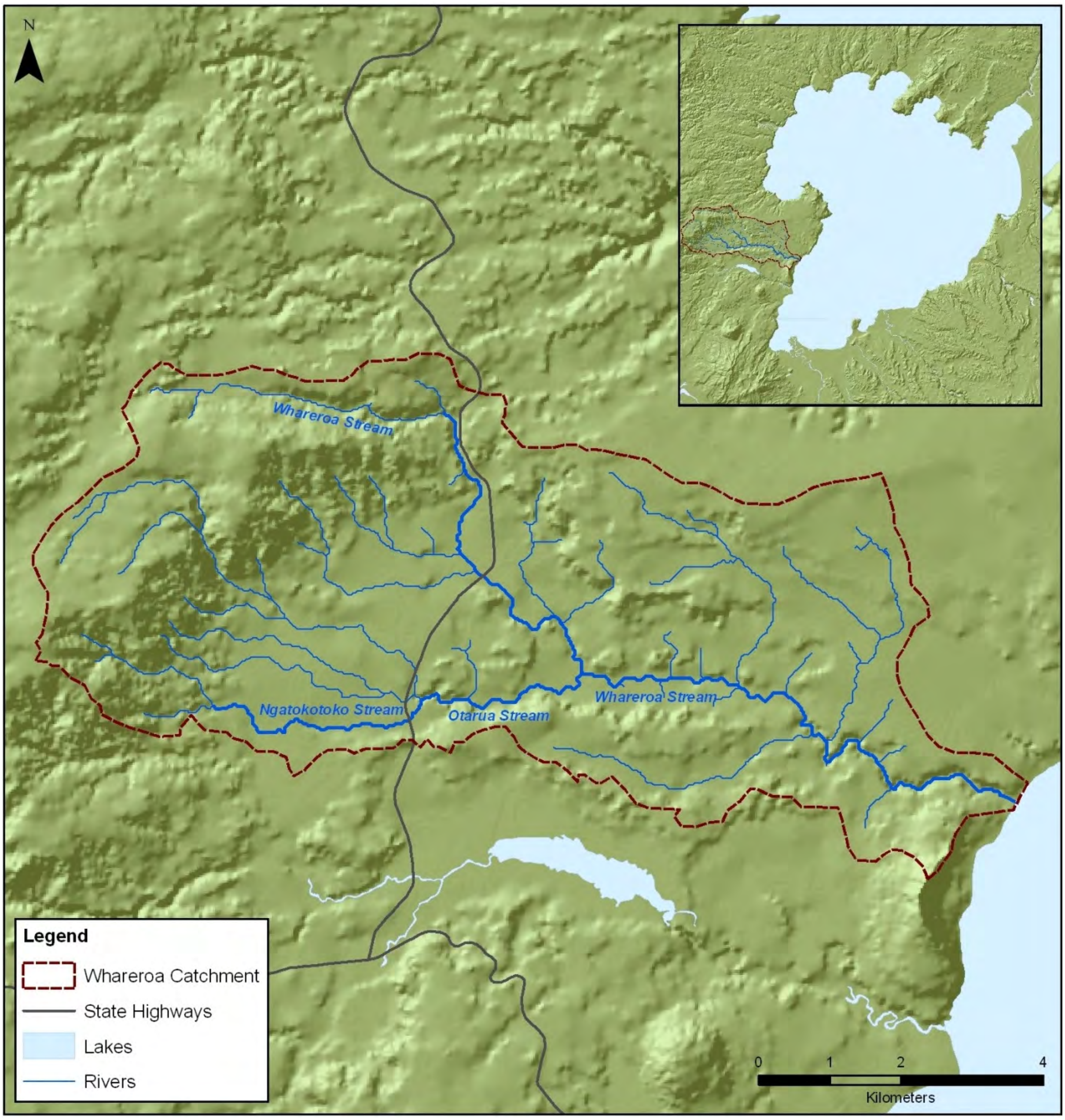


Figure 2.1: Location of the Whareroa catchment.

The majority of the Whareroa catchment is eroded into Kaharoa and Taupo ashes (62%), and Taupo and Kaharoa breccias and pumiceous alluvium (36%). These materials are composed of fragments of rock cemented together, or reshaped by water and deposited in valley basins. The northern part of the catchment is the only area underlain with lava and welded ignimbrite. The eastern, lower elevation, area is predominantly Quaternary breccias, older than the Taupo breccias. Lavas and welded ignimbrites, and Quaternary breccias underlie 1% and 2% of the catchment respectively. All these rocks originate from volcanic activity in the Taupo Volcanic Zone which runs from Mt Ruapehu in the south to White Island in the Bay of Plenty in the north (Figure 2.2).

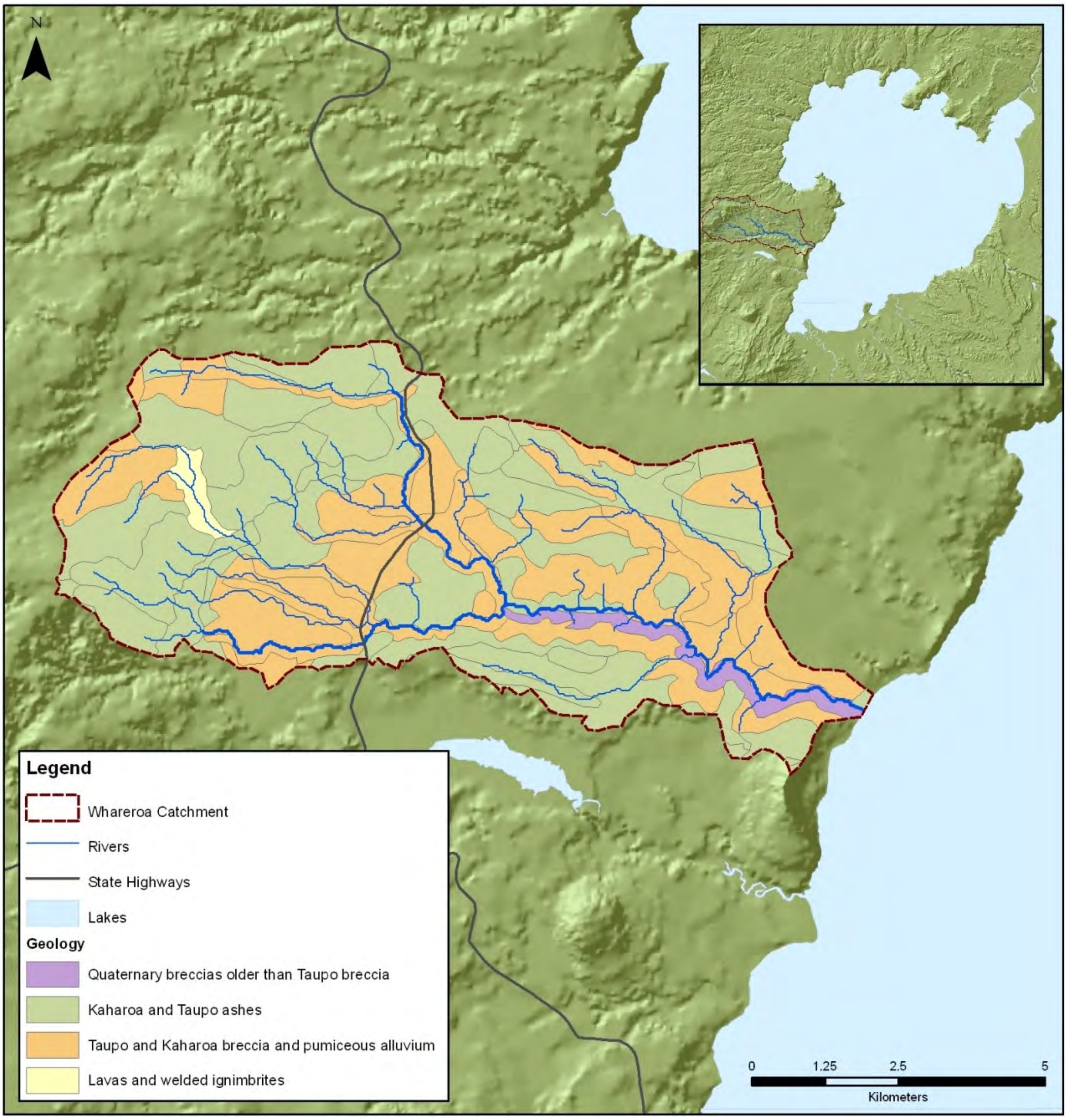


Figure 2.2: Catchment geology of the Whareroa Stream.

Pumice soils are the dominant soil type in the Whareroa catchment; with immature orthic pumice soils covering the greatest area (43.2%). These soils have low clay content and are mostly gravelly or pumice sand. The soils have low natural and disturbed strength, high macroporosity, and deep rooting depth. The soils on the slopes of the upper catchment are predominately humose orthic podzols (12.2%). Podzol soils often occur in areas of high rainfall, and have low fertility, low base saturation, and are strongly acidic. Welded impeded pumice soils (8.4%) occur where there is a subsoil layer that restricts the movement of water and roots. Allophanic soils are also found in the Whareroa catchment; typic orthic (2.7%), and acidic orthic (4.6%). These soils are dominated by allophane minerals and are predominantly found in volcanic ash and weathered volcanic rocks. The soil is porous with a low density structure and weak strength (Figure 2.3).

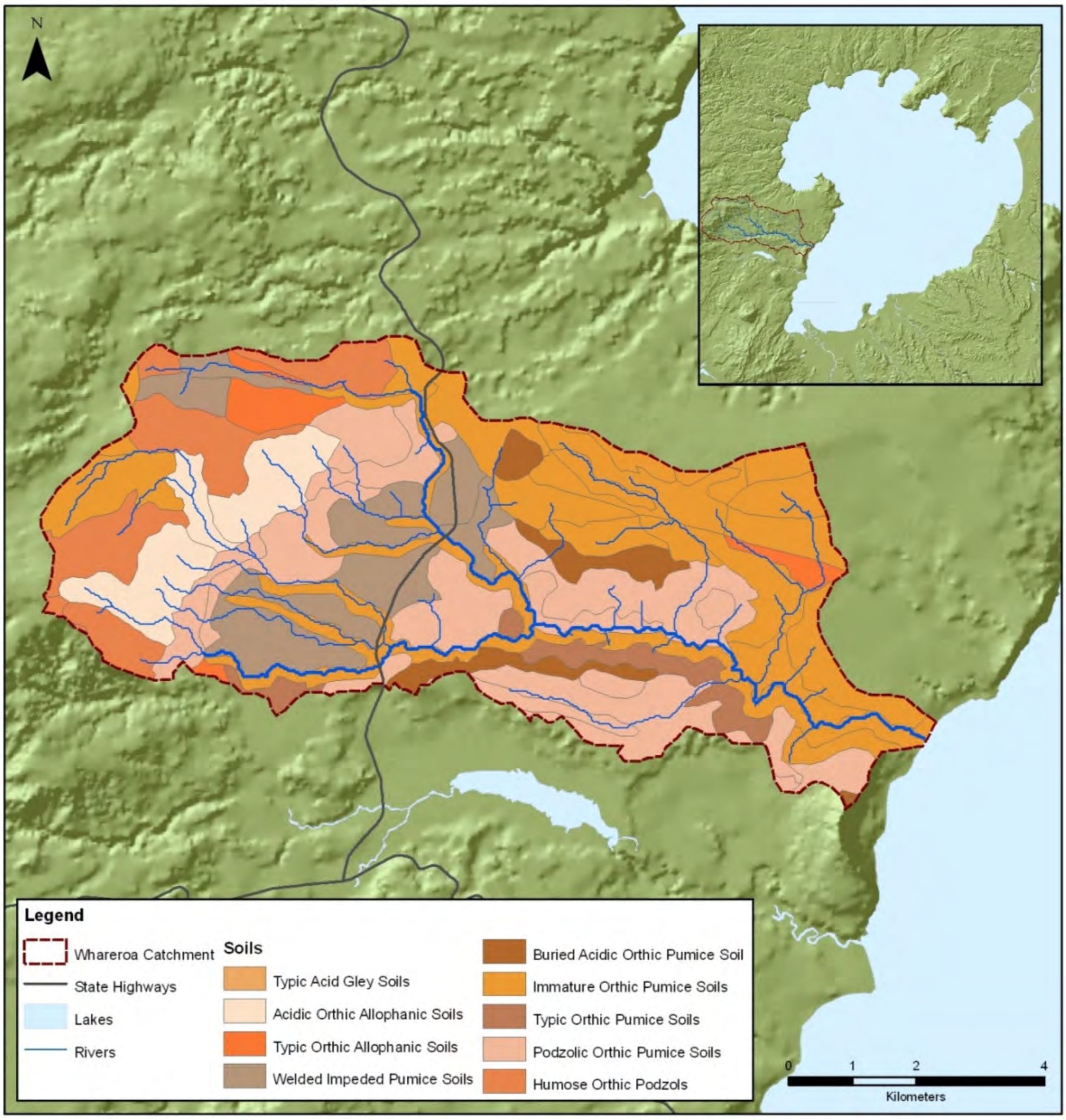


Figure 2.3: **Soils of the Whareroa catchment.**

The Whareroa Stream lies in a well-defined depression eroded into various volcanic deposits. Gentle slopes in the upper catchment are separated by a relatively steep 'scarp' from the mid and lower valley which has generally easy slopes. Outcrops of harder ignimbrite form steep scarps which parallel the river in the mid reaches of the catchment (Figure 2.4).

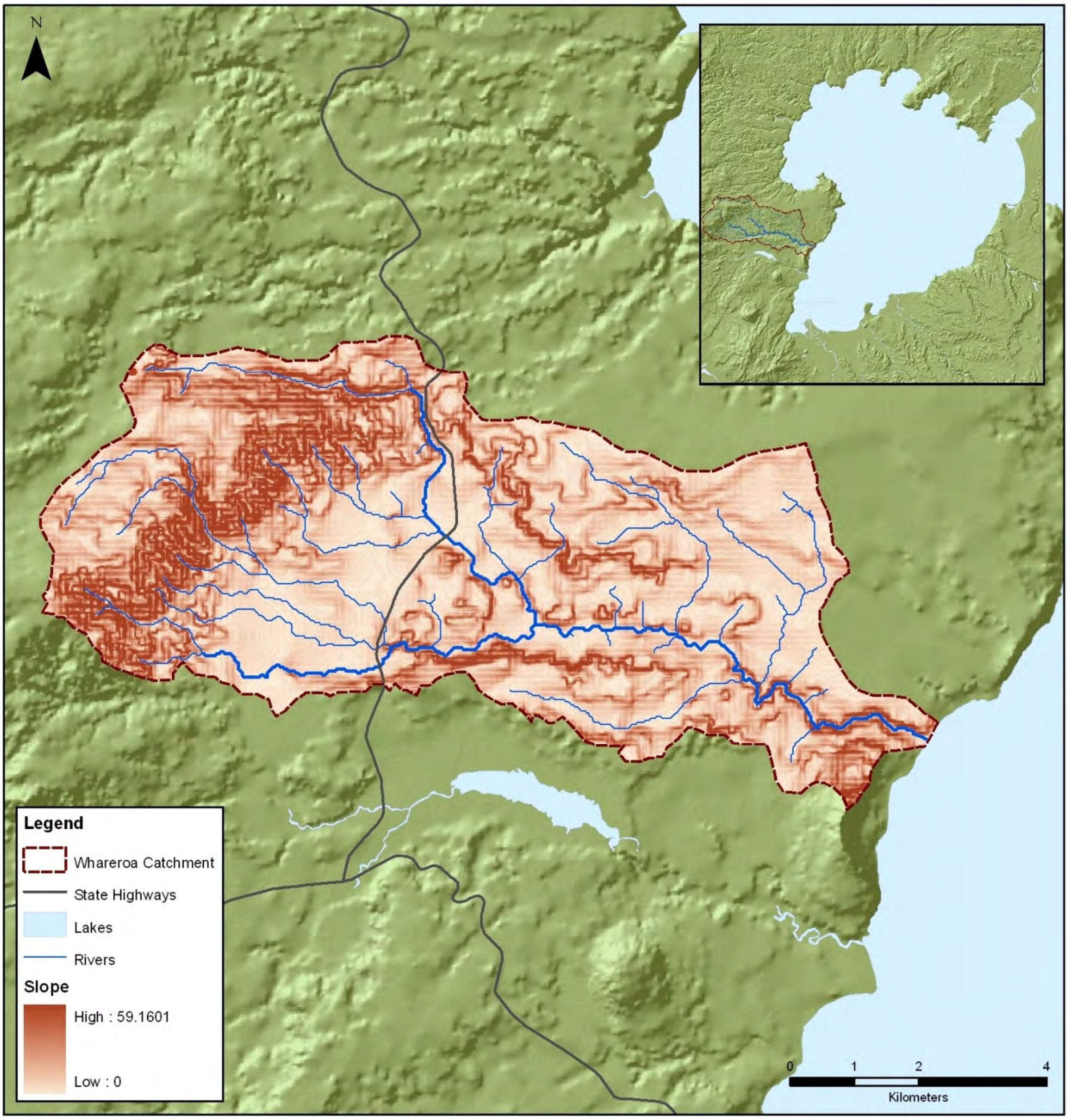


Figure 2.4: Slope within the Whareroa catchment.

Erosion is common in the upper catchment because of the soft unconsolidated nature of the volcanic deposits, steep slopes, and higher rainfall. This provides material which can be transported downslope and into the river system. The steeper terrain of the upper catchment allows the river to transport most of this sediment downstream. The Whareroa Stream consequently can on occasion carry a relatively high sediment load. In the lower catchment the channel slope decreases, reducing the flow velocity (Figure 2.4). As a result, the energy of the river decreases reducing its ability to transport sediment. Consequently, a considerable volume of material has been deposited on the flood plain. Changes to the river channel can be caused by both natural and anthropogenic processes. Floods, eruptions, land use change, and tectonic uplift in the upper catchment can all increase the sediment supply to the river. Higher lake levels and tectonic subsidence can affect where this material is deposited within the lower Whareroa catchment.

The Whareroa catchment has a relatively flat rainfall gradient. The mean annual rainfall in the headwaters, the area likely to produce the greatest runoff, reaches 1500mm. Rainfall then decreases with altitude to be only approximately 1220mm at Lake Taupo. Those areas which experience the highest annual rainfalls are also likely to experience the greatest rainfall intensities. Runoff from the upper catchment therefore has a critical affect on the flood magnitude and risk towards the river mouth (Figure 2.5).

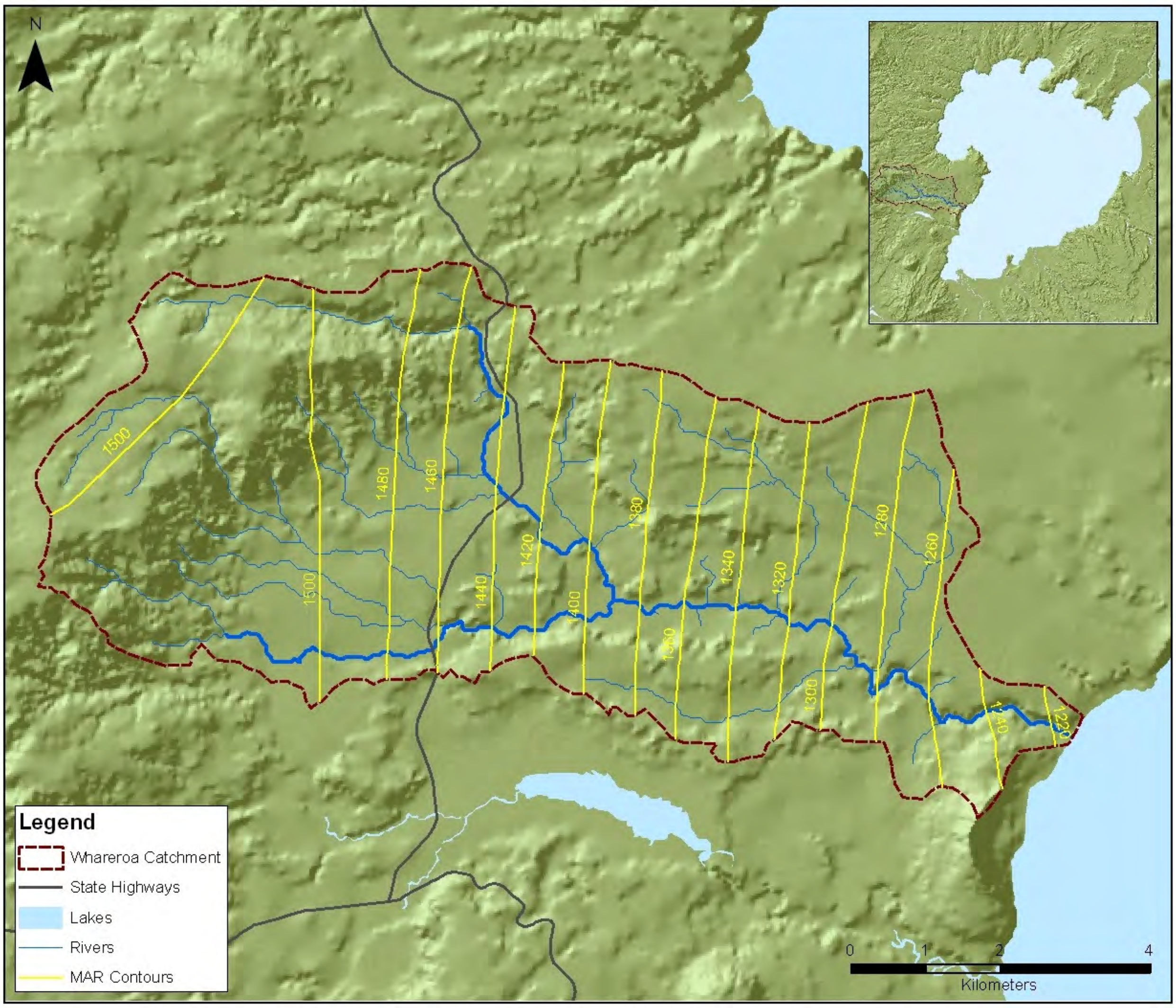


Figure 2.5: Mean annual rainfall over the Whareroa catchment.

Much of the Whareroa catchment is under some type of forest or scrub (66.5%). This includes indigenous forest, which is the largest single land use in this catchment (63.3%). Pasture covers another 33% of the catchment (Figure 2.6). Land use within the catchment is summarised in Table 2.1.

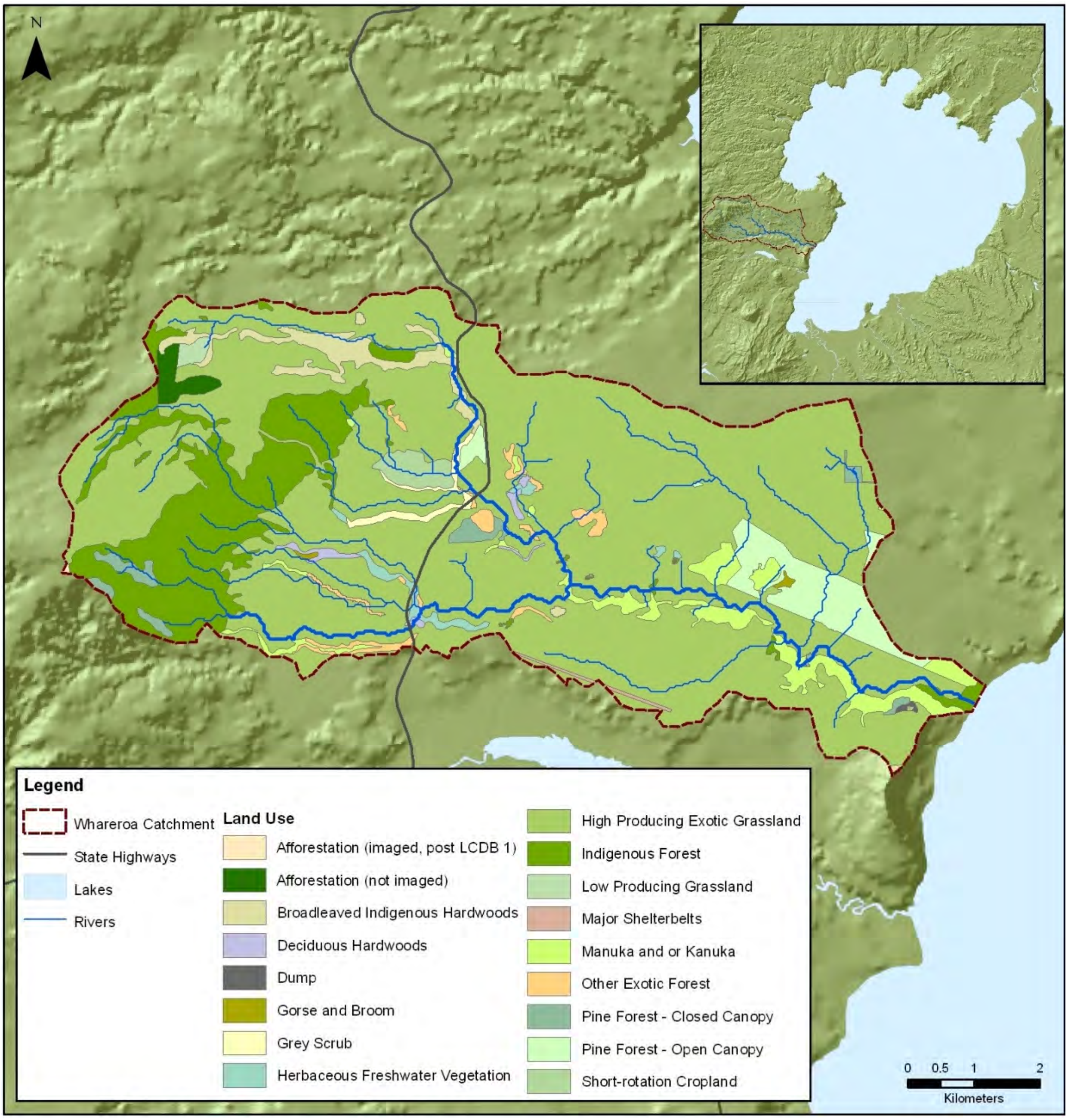


Figure 2.6: **Vegetation cover within the Whareroa catchment.**

Table 2.1: Land use in the Whareroa catchment.

Land use	Percentage
Afforestation (imaged – post LCDB1)	0.1
Afforestation (not imaged)	0.4
Broadleaved Indigenous Hardwoods	0.6
Deciduous Hardwoods	0.0
Dump	0.0
Gorse and Broom	0.0
Grey Scrub	0.1
Herbaceous Freshwater Vegetation	0.1
High Producing Exotic Grassland	33.3
Indigenous Forest	63.3
Low Producing Grassland	0.0
Major Shelterbelts	0.0
Manuka and/or Kanuka	0.7
Other Exotic Forest	0.1
Pine Forest – Closed Canopy	0.5
Pine Forest – Open Canopy	0.9
Short-rotation Cropland	0.1
Total	**100.0**

2.2 Study area

The greatest flood hazard within the Whareroa catchment is towards the mouth of the river near Lake Taupo. The terrain is less steeply sloping and more likely to be developed for housing. The focus of this study is therefore on the lower river, downstream of where Whareroa Stream emerges from a relatively steep, straight, incised gorge and begins to meander downstream to Lake Taupo.

3 Flow regime of Whareroa Stream

3.1 Whareroa Stream

The flow monitoring station, Whareroa at Fish Trap, is located approximately 1km upstream of the river mouth (Figure 3.1). Flows were monitored for three years between 1977 and 1980, and then since 2002 (Figure 3.2). Consequently, the combined flow record is only about 12 years long. This record is therefore too short to be used for a robust frequency analysis, and to provide estimates of the expected magnitudes of floods with return periods longer than about 5-10 years. This short nature of the flow record from Whareroa Stream acts as a major constraint on the accuracy and confidence that can be placed in flood magnitude estimates, and consequently the results of any flood modelling. To allow for this uncertainty, a conservative approach was taken at all steps in the flood risk assessment.

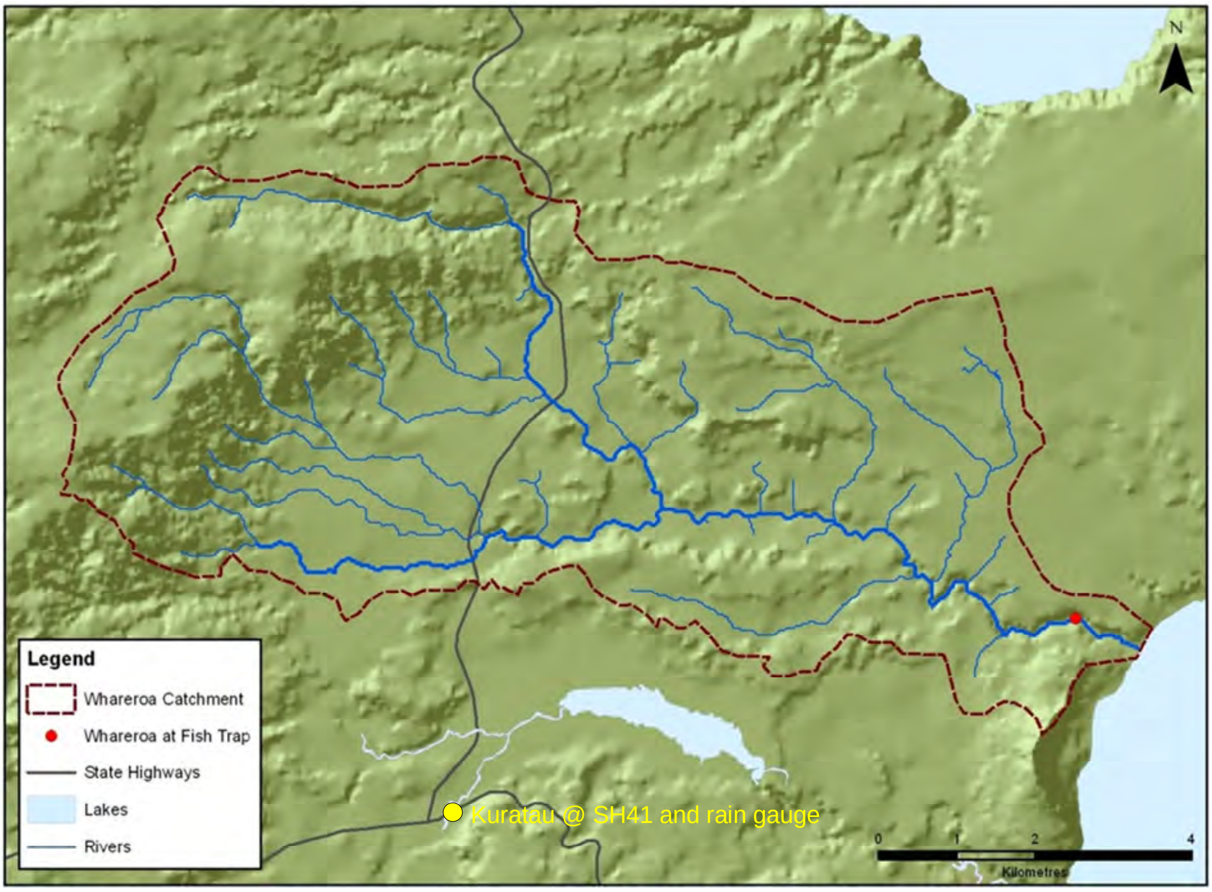


Figure 3.1: **Location of the flow station, Whareroa at Fish Trap.**

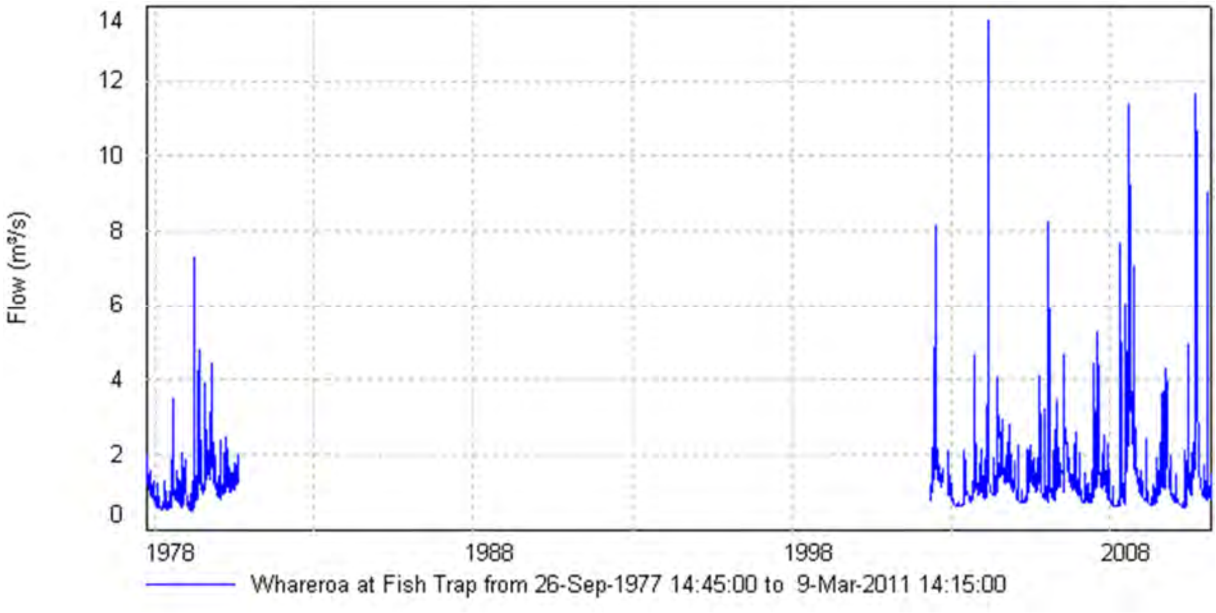


Figure 3.2: **Whareroa at Fish Trap flow record (1977-2011).**

3.2 Synthetic flow series

The short flow record from Whareroa Stream acts as a major constraint on the estimation of robust design flood magnitudes. Consequently, flows recorded in the adjacent Kuratau River at SH41 were used to create a long-term synthetic record for Whareroa Stream.

Overall the flow record for the Kuratau River at SH41 appears to be of high quality, containing a complete record of all the major flood events since the end of 1978 (Figure 3.3).

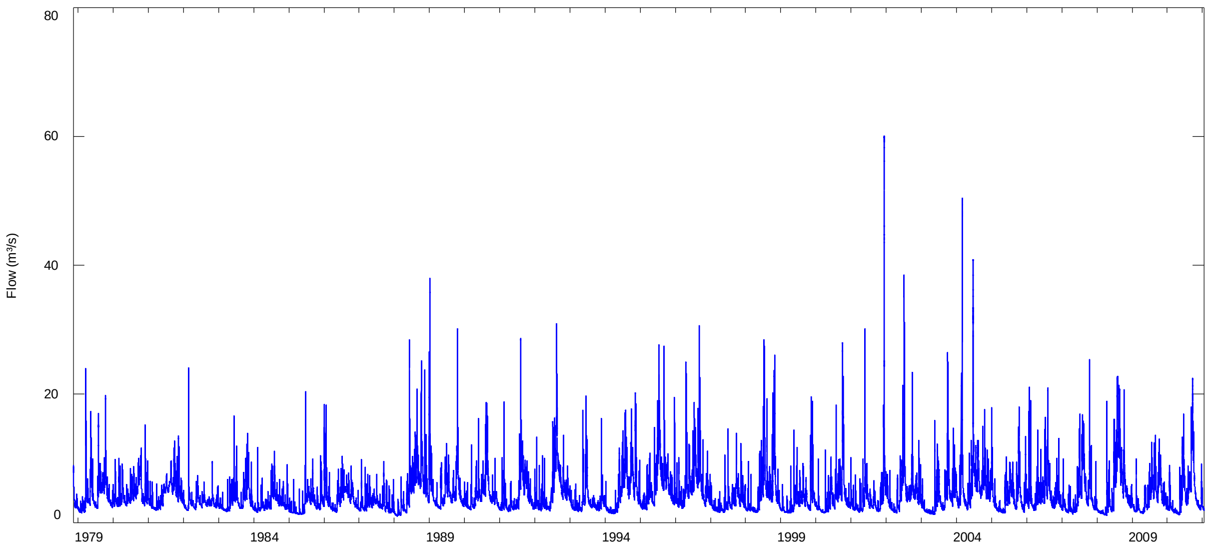


Figure 3.3: Flow record for the Kuratau River at SH41.

The flow record of the Kuratau River shows a relatively consistent annual pattern of flow variation. There are no significant trends or cycles apparent in the data. This flow record therefore provides a reliable set of data for analysis, and a realistic surrogate for the flows likely to be experienced within the adjacent Whareroa catchment.

These flows in the Kuratau River were therefore scaled by the ratio of the two catchment areas (A) to produce a 33-year synthetic flow record for the Whareroa Stream (Figure 3.4). Flows in the Kuratau River were also be scaled by the ratio of $A^{0.8}$ (Figure 3.5). McKerchar and Pearson (1989) have shown that in general the magnitude of floods in New Zealand vary as a function of $Area^{0.8}$ rather than simply Area.

Obviously the flows derived as a function of $A^{0.8}$ are slightly larger than those derived using a simple ratio of catchment area (i.e. A). The mean daily flow from these synthetic records were compared with the actual mean daily flow measured in the Whareroa Stream for the period of overlapping records to determine which is likely to more accurately reflect flows in the Whareroa catchment (Figures 3.6 & 3.7).

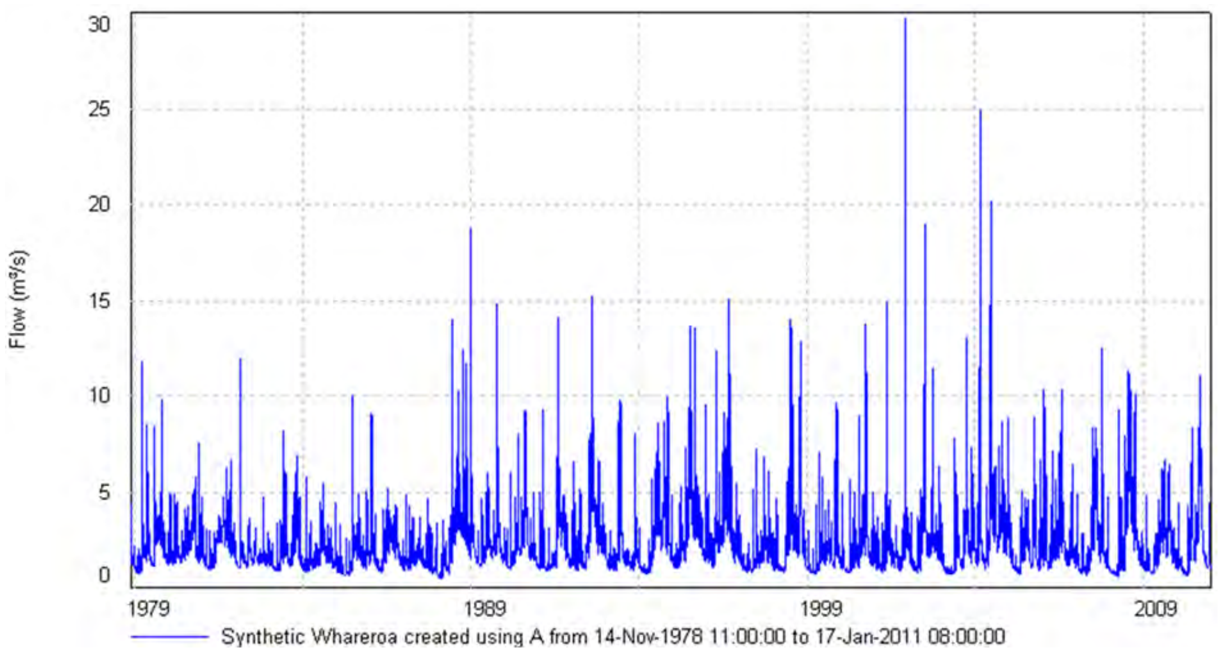


Figure 3.4: **Synthetic flow record for the Whareroa Stream; scaled from flows measured in the Kuratau River at SH41 using a ratio of the two catchment areas (A).**

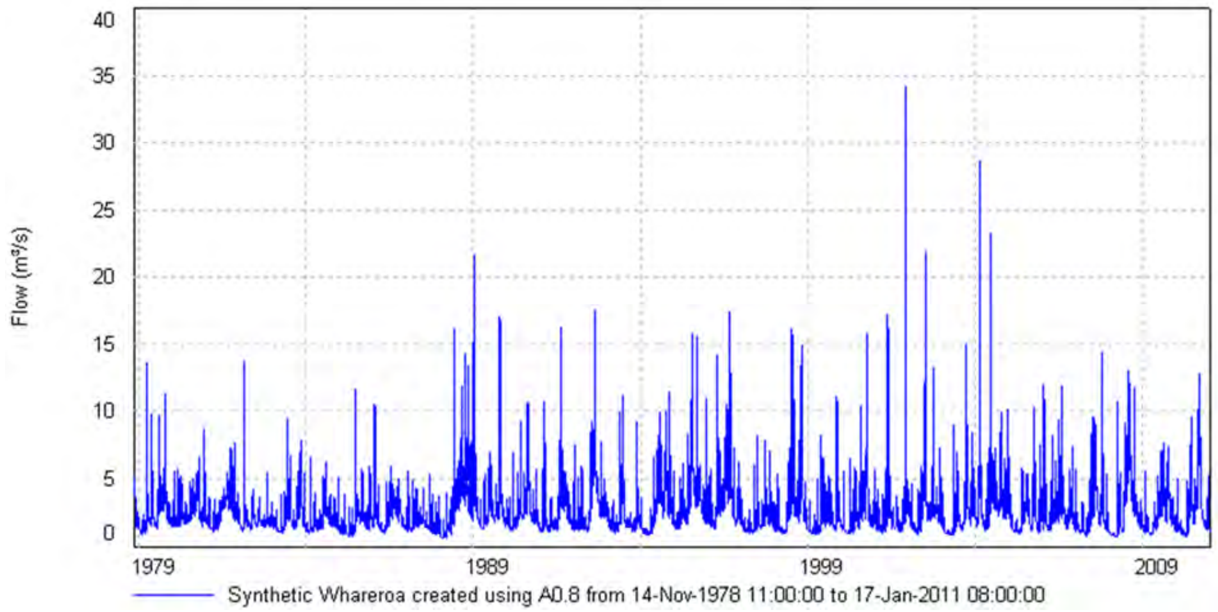


Figure 3.5: **Synthetic flow record for the Whareroa Stream; scaled from flows measured in the Kuratau River at SH41 using a ratio of the two catchment areas ($A^{0.8}$).**

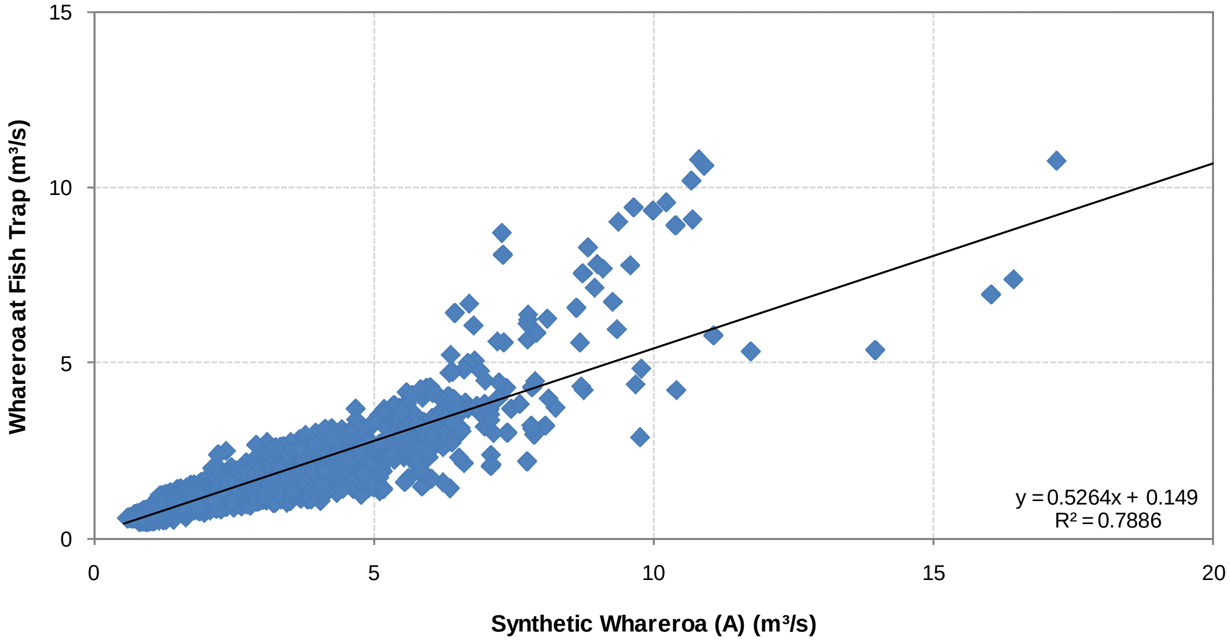


Figure 3.6: **Comparison of the mean daily flows from the Synthetic (A) and actual flows in the Whareroa Stream for the period of overlapping record.**

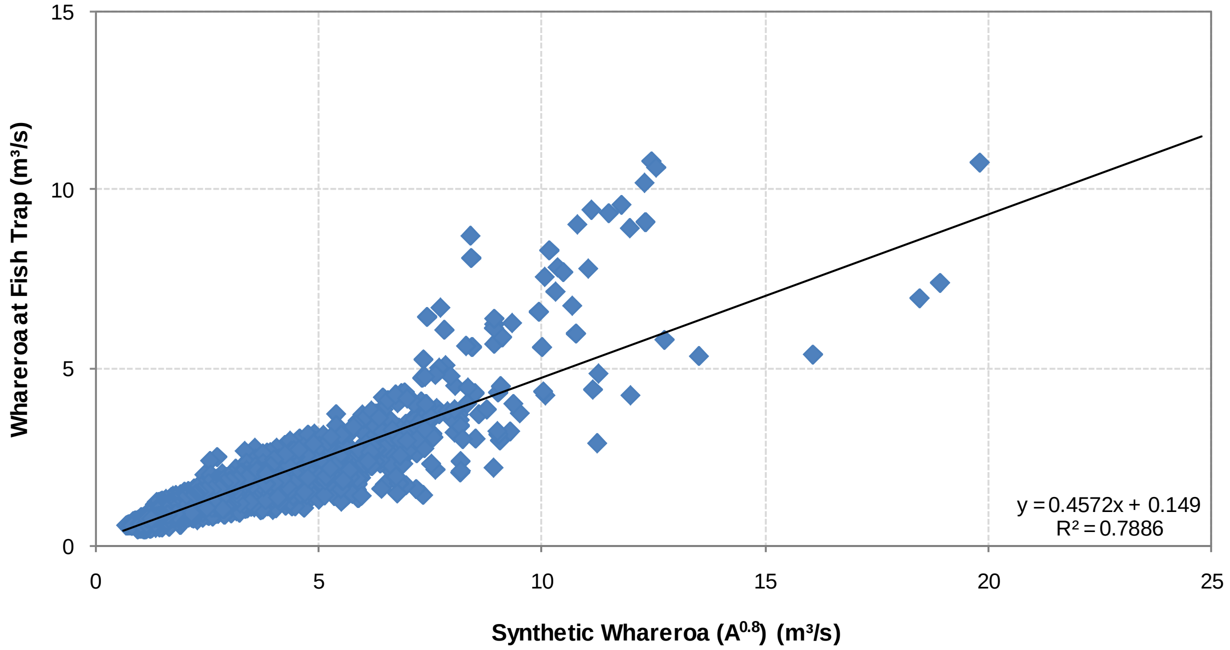


Figure 3.7: **Comparison of the mean daily flows from the Synthetic ($A^{0.8}$) and actual flows in the Whareroa Stream for the period of overlapping record.**

It would appear that the variation in the two synthetic flow records provides the same degree of accuracy in explaining variation in the actual recorded flows (i.e. 79%). Likewise, both regression models provide the same level of ‘accuracy’ when estimating the magnitude of larger events. In general, flows estimated using the synthetic records are about twice those actually recorded in the Whareroa Stream. Some of this difference is to be expected as the synthetic flows are estimated for the river mouth, while the flow monitoring station is approximately 1km upstream. The remaining difference is likely a reflection of the higher rainfalls experienced within the Kuratau catchment.

Table 3.1 compares the measured 'short term' hydrological parameters with those derived from the two longer synthetic flow series derived using data from the Kuratau River. All the various parameters are less in the measured flow series when compared to the synthetic records. This is consistent with the conclusion discussed above relating to the regression models used to derive the synthetic flow series. However, it is also noted that the recorded flow series is only 12 years long, while the synthetic records extend over 33 years.

Table 3.1: Summary statistics of the three flow records obtained for Whareroa Stream (1978-2011) (m^3/s).

	Minimum	Median	Maximum	Mean	Standard Deviation
Fish Trap	0.475	1.068	13.655	1.297	0.924
Synthetic (A)	0.534	1.663	29.697	2.112	1.491
Synthetic ($A^{0.8}$)	0.615	1.915	34.193	2.432	1.717

As expected the flood maxima obtained using the mean daily flows from the synthetic record derived as a function of $A^{0.8}$ are larger than those derived as a simple function of A (Figure 3.8). In general, neither of the synthetic records provides an extremely accurate measure of the mean daily annual flood maxima recorded in Whareroa Stream. Over the past 3 years the synthetic record derived using A appears to more closely approximate the measured flood maxima. Those derived using $A^{0.8}$ are slightly larger (i.e. more conservative). This is likely because of the relatively small magnitude of the annual flood maxima during these years. Therefore, using the long-term synthetic flow series derived using $A^{0.8}$ will result in higher estimates of the magnitudes of various design floods. Consequently, the flood hazard assessed using these flows will be slightly greater than may actually be the case i.e. the flood hazard assessments will be conservative.

Figure 3.9 shows the hydrograph for the largest flood actually recorded in the Whareroa Stream, which occurred in 2004. This figure also shows the same flood event derived from the Kuratau record using $A^{0.8}$. While the shapes of the hydrographs are very similar, that obtained from the synthetic record has a significantly higher flood peak and total storm runoff volume. The use of the synthetic hydrograph in any hydraulic modelling would therefore produce conservative results i.e. the modelled extent of inundation and flood velocities will likely be greater than would actually occur during an actual flood with a particular return period.

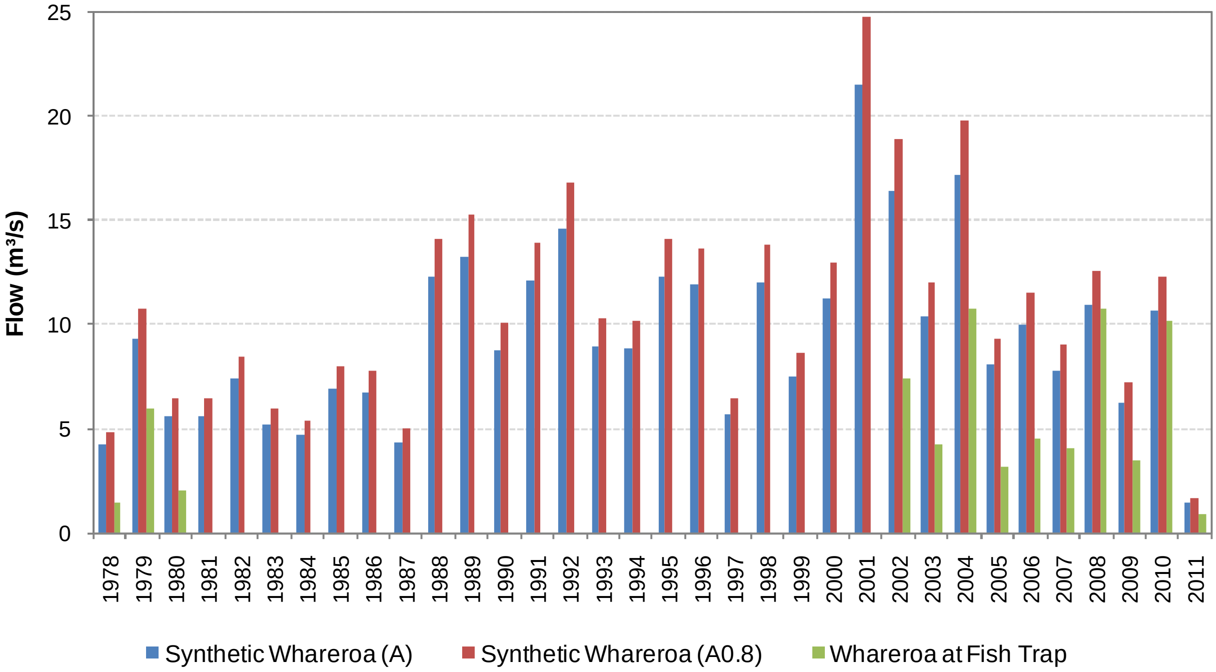


Figure 3.8: **Comparison of the annual flood maxima using mean daily flows from the Synthetic Whareroa ($A^{0.8}$), Synthetic Whareroa (A), and measured flow records (m³/s).**

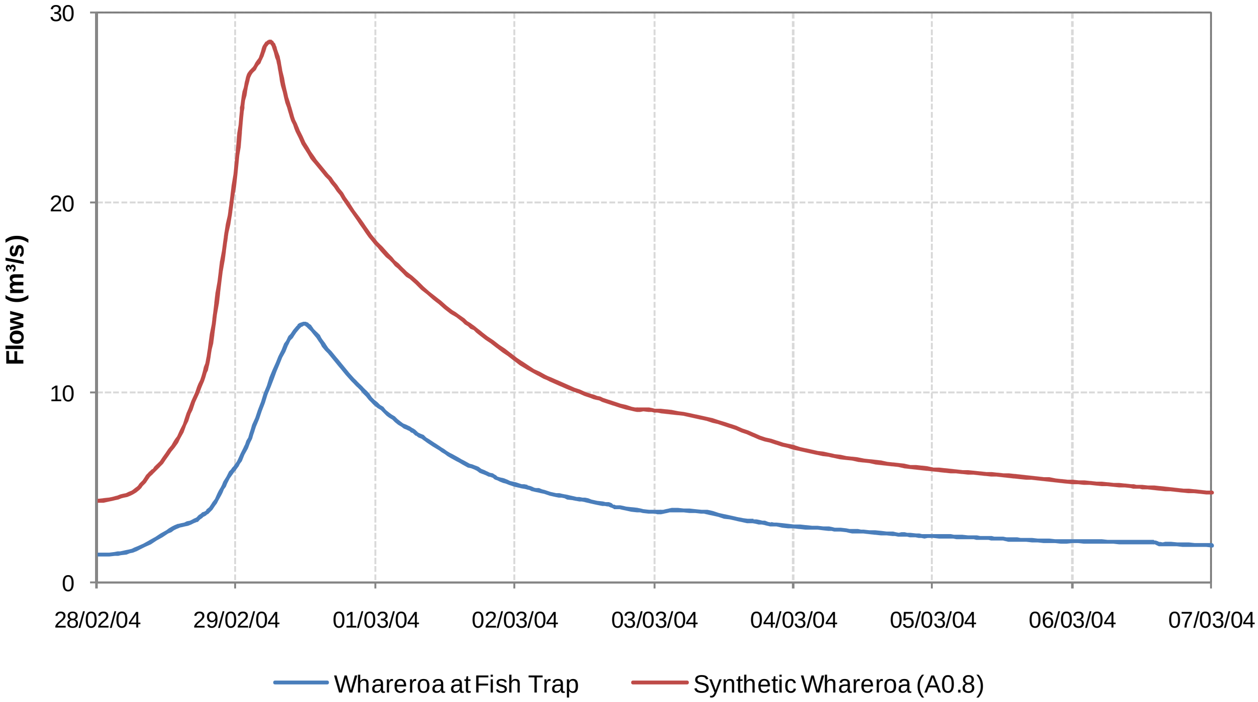


Figure 3.9: **Comparison of the measured hydrograph, and that obtained by scaling the flows in the Kuratau River by ($A^{0.8}$), for the 2004 flood event (m³/s).**

3.3 Stationarity

Stationarity is a key assumption in all frequency analyses, including those used in this study. Stationarity implies (and it is therefore assumed) that the annual maxima or minima used in any analysis exhibit no trends or cycles; and that the extremes are drawn randomly and independently from a single statistical distribution. Implicit in this assumption is that the same processes and relationships that existed in the past will continue to apply in the future. For example, the relationship between rainfall and runoff during particular events will be the same. However, should anything change this relationship e.g., climate or land use change, then stationarity may no longer apply. When this occurs, the reliability of the frequency analysis, and any derived design storm events, may be questioned.

Longer records have a greater likelihood of containing information relating to extreme events. Such records also tend to smooth any errors and other 'noise' in a data set. However, they also increase the chance of violating the basic rule of stationarity because longer records have the potential to be more affected by land use, climate, or other changes.

3.4 Flow characteristics of Whareroa Stream

The long-term synthetic flow series derived from the Kuratau River as a function of $A^{0.8}$ for Whareroa Stream allows some general conclusions to be made regarding the flow regime of the catchment (Figure 3.10 & Table 3.2).

The flow regime of Whareroa Stream is characterised by long periods of relatively low flow, interspersed with short duration, but high magnitude, flood events. The significance of these flood events on the summary statistics is that the mean flow is approximately 27% higher than the median. Table 3.3 lists the largest flood event in each year of the synthetic record.

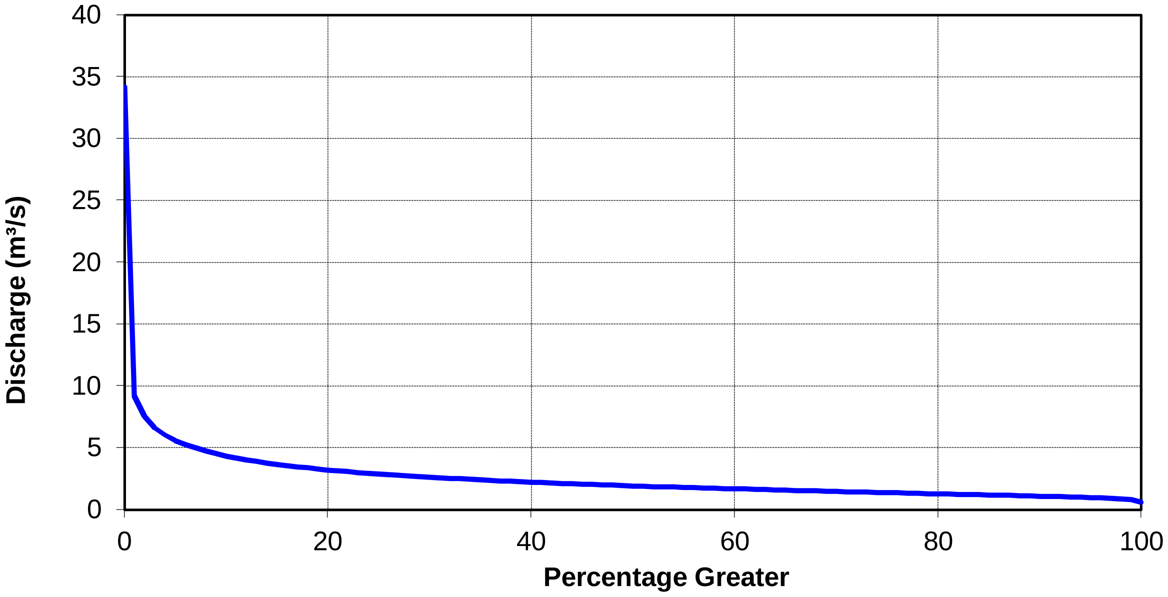


Figure 3.10: Flow duration for the synthetic flow record for Whareroa Stream (1978-2011) derived as a function of the ratio of $A^{0.8}$ (m^3/s).

Table 3.2: Summary statistics of the synthetic flow record for Whareroa Stream (1978-2011) derived as a function of the ratio of $A^{0.8}$ (m^3/s).

	Minimum	Median	Maximum	Mean	Lower quartile	Upper quartile	COV
Whareroa Stream	0.615	1.915	34.193	2.432	1.367	2.881	0.706

Table 3.3: Annual maximum flows recorded for the synthetic Whareroa record scaled using the ratio of $A^{0.8}$ (1979-2010).

Rank	Year	Flow (m^3/s)	Rank	Year	Flow (m^3/s)	Rank	Year	Flow (m^3/s)
1	2001	34.2	**12**	2003	15.1	**23**	1990	10.7
2	2004	28.7	**13**	2007	14.5	**24**	2005	10.5
3	2002	21.9	**14**	1982	13.7	**25**	2010	10.2
4	1989	21.6	**15**	1979	13.6	**26**	1983	9.5
5	1992	17.6	**16**	2008	13.0	**27**	1980	8.7
6	1996	17.4	**17**	2010	12.8	**28**	1997	8.3
7	1991	16.3	**18**	2006	12.0	**29**	2009	7.7
8	1998	16.2	**19**	1985	11.6	**30**	1981	7.7
9	1988	16.2	**20**	1994	11.5	**31**	1984	6.7
10	2000	15.9	**21**	1993	11.2	**32**	1987	5.6
11	1995	15.8	**22**	1999	11.2			

3.5 Characteristics of flood events

Figure 3.11 shows the flood hydrograph for the largest flow in the synthetic record i.e., 9 December 2001. This hydrograph highlights a number of features of flood events in the Whareroa catchment. In general, it takes rainfall events of from 6-12 hours duration to generate a significant flood.

Longer duration rainfall events produce more sustained flows, but usually with a lower peak discharge. High intensity rainfall events tend to produce sharp, short duration flood peaks. Also, once the catchment has been ‘wetted up’ i.e., all the storage is full, the river responds rapidly and sharply to any additional rainfall.

Despite the variability of specific storms, there is a high degree of similarity in flood response. Figure 3.12 compares the recorded 2004 flood hydrograph with the 2001 flood hydrograph from the synthetic record. The peak discharges are only approximately 5m^3/s different. The 2001 flood contained two smaller peaks on the rising limb, while the 2004 event had a much higher initial base flow. The shapes of the flood hydrograph for each of these events, however, are remarkably similar despite them being measured in two different catchments. This indicates that using the 2004 flood measured in the Whareroa Stream as a basis to scale a flood hydrograph for the 100-year event is suitable for hydraulic modelling.

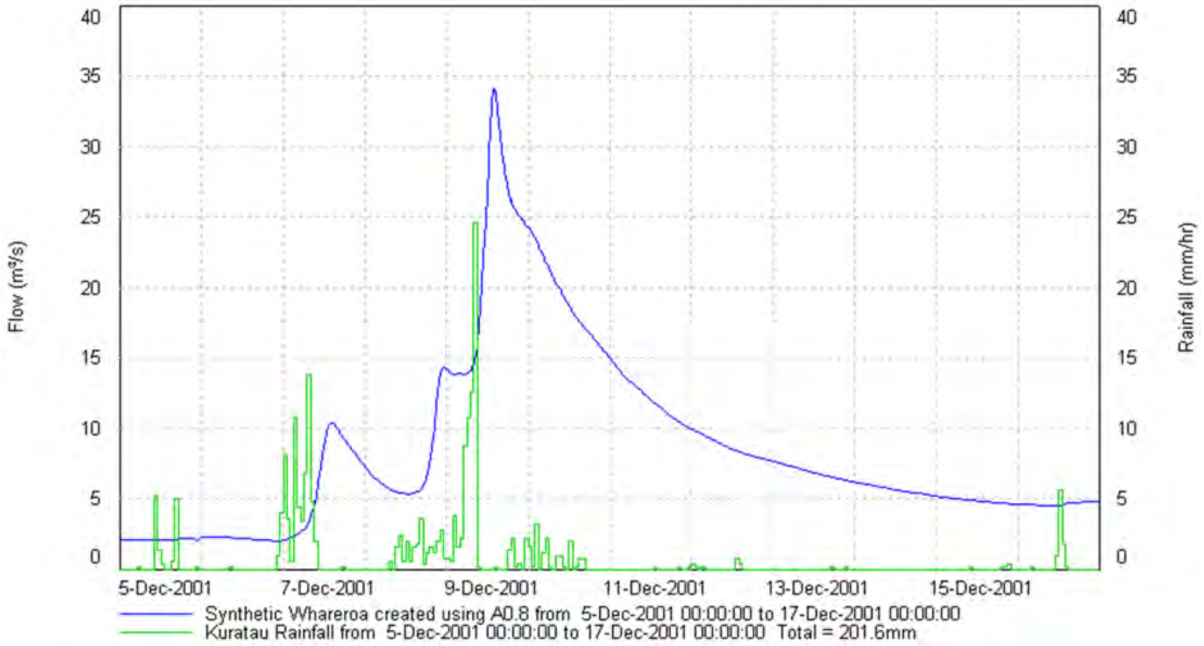


Figure 3.11: **Flood hydrograph of the largest flow on record for the Whareroa Stream ($A^{0.8}$).**

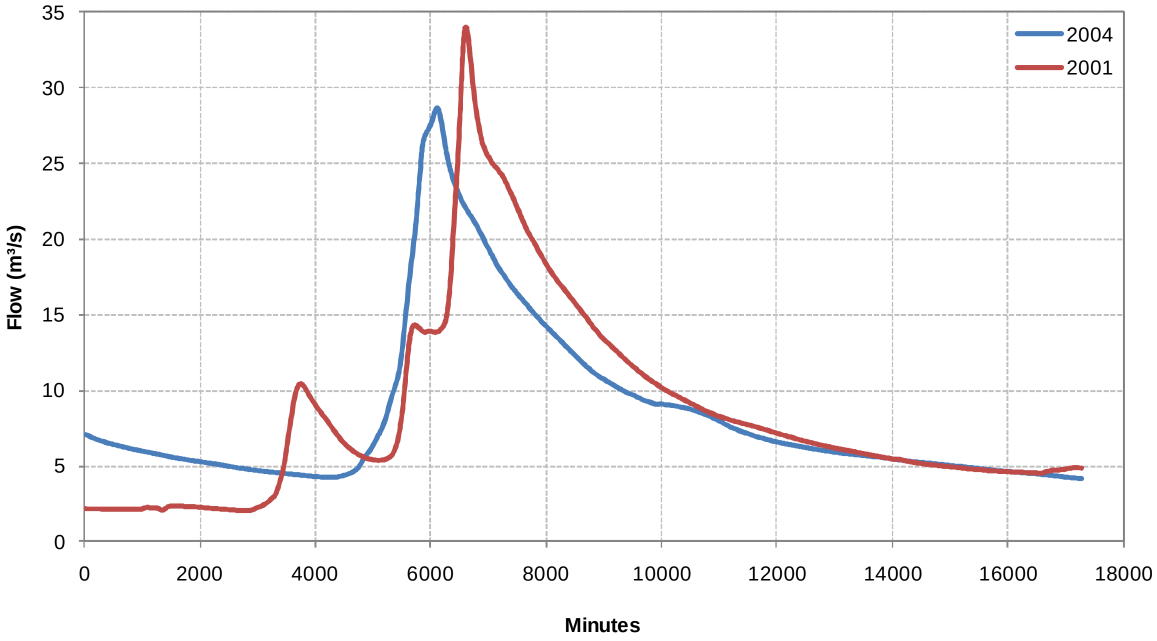


Figure 3.12: **Comparison of two large floods likely experienced in the Whareroa Stream. The hydrograph for the 2001 flood is derived from the same event in the Kuratau River while the 2004 flood was actually measured in the Whareroa Stream.**

Analysis of a series of flood hydrographs for the Whareroa Stream indicate a consistent pattern of response. Rainstorm durations leading to significant flood events are usually 6-12 hours in duration. The resulting floods typically have one major peak, and the body of the flood lasts for between 24 to 36 hours.

3.6 Flood frequency analysis

The relatively short length of the flow record from the Whareroa catchment acts as a major constraint on its ability to provide a robust analysis of the frequency and magnitude of flood events in the catchment. The longer synthetic flow record derived by scaling the flows in the Kuratau catchment as a function of $A^{0.8}$ was therefore used for the frequency analysis of flood events. For the reasons discussed previously, the use of this record is likely to result in conservative estimates of the flood magnitudes for specific design events.

A frequency analysis was undertaken using the entire length of synthetic record, and using the maximum flood event recorded each month rather than just the largest event in each year. This approach samples 12 times the number of events than just using the annual maxima. It is therefore more likely to reflect the actual distribution of flood events. It should be noted, however, that while this approach overcomes the 'loss' of multiple large floods in a single year, it still misses multiple large flood events if they occur in a single month. The flood frequency analysis provides estimates of the flood magnitudes for events with various return periods (Table 3.4). A Wakeby statistical distribution provides the best fit to the monthly maxima series (Figure 3.13).

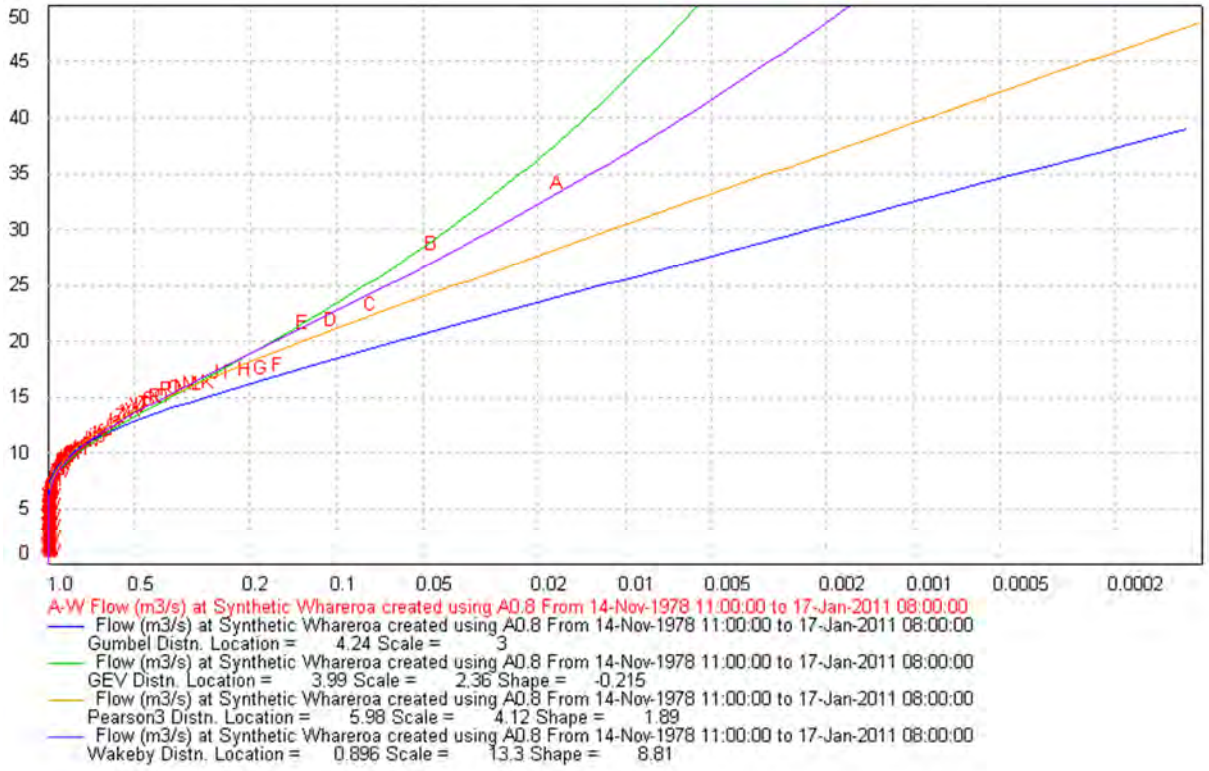


Figure 3.13: Flood frequency analysis of the synthetic flow record for Whareroa Stream scaled from the Kuratau using $A^{0.8}$.

Table 3.4: Flood estimates for the synthetic record of the Whareroa Stream scaled from the Kuratau using $A^{0.8}$ (assuming a Wakeby distribution).

Return Period	Whareroa Stream 1977-2011 (m^3/s)
2.33 (annual)	14.5
5	18.8
10	22.7
20	26.6
50	32.2
100	36.8
200	41.6
500	48.5

3.7 Potential effects of land use change

Recent work has investigated the link between land use and runoff in pumice catchments (Hamilton, 2001; Environment Waikato, 2006). This work was summarised in *McConchie et al.* (2008) and used to predict the effects of land use change on both flood peak discharges and runoff volumes in the Lake Taupo catchment. The major conclusions of this work are presented in Table 3.5.

Table 3.5: Estimated increases in flood peak discharge and volumes with a change in land use from forest to pasture (Environment Waikato, 2006).

Average recurrence interval	Increase in flood peak discharge (m^3/s)			Change in flood runoff volume (m^3)	
	Regional frequency analysis method (m^3/s)	*Unit hydrograph method (m^3/s)*	*Average increase per km^2 of forest converted*	*SCS method (m^3X10^6)*	*Average increase per km^2 of forest converted*
2	23.9	55.4	0.18	4.2	0.019
10	77.7	102.4	0.40	7.5	0.033
20	109.8	131.4	0.54	9.4	0.042
50	165.9	184.1	0.78	12.8	0.057
100	222.5	239.3	1.03	16.2	0.072

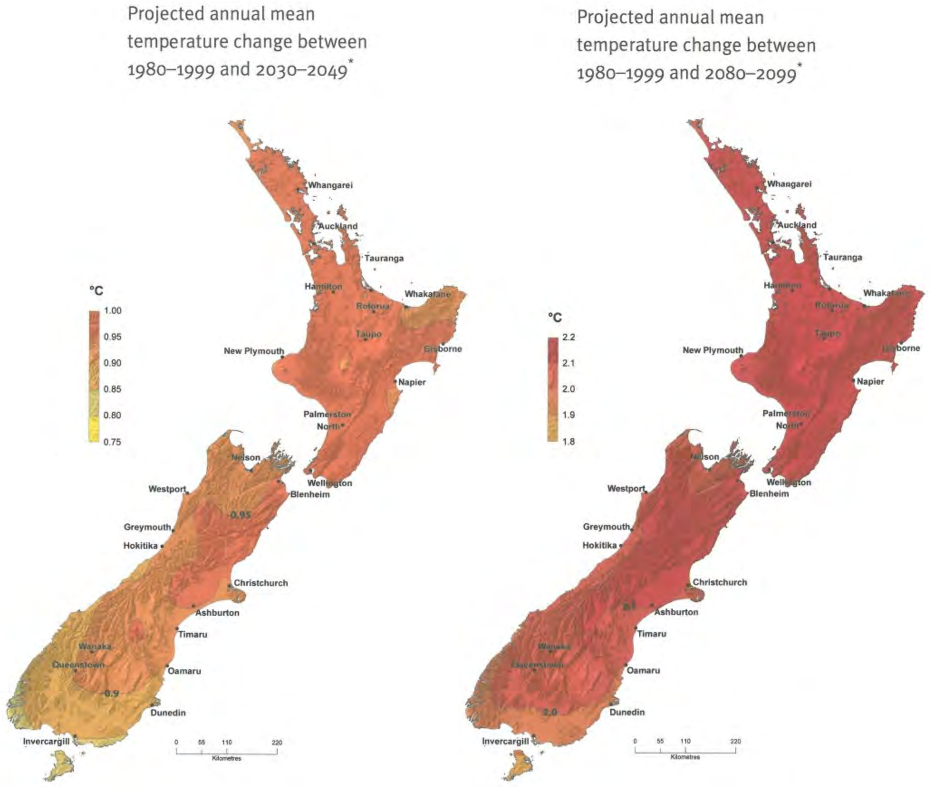
Given the current land use distribution and land management within the Whareroa catchment, the worst case scenario from a flooding perspective would be the conversion of all forest to pasture. It must be recognised that such a land use change is extremely unlikely, especially given the restrictions on milling indigenous forest. There are only 9.5km^2 under some kind of exotic forestry management within the Whareroa catchment (LCDB2 – 2004).

Given how little exotic forest there is within the catchment, any conversion to pasture would have little effect on the risk of flooding. If anything, a conversion from pasture to forestry appears a more likely scenario. Such a conversion would cause a reduction in the flood peak rather than any increase.

3.8 Potential effects of climate change

If predicted global warming eventuates, it could cause more than just a rise in the world's temperature. Warmer temperatures mean that more water vapour will enter the atmosphere. Higher temperatures will also increase the ability of the air to hold moisture. Therefore, apart from higher temperatures, the greatest effect of climate change is likely to be on water resources. Furthermore, sensitivity analysis has indicated that changes in rainfall are always amplified in runoff, and this effect is greater in drier catchments. A detailed discussion of the potential effects of climate change within the Lake Taupo catchment is provided in McConchie *et al.* (2008).

A methodology has been developed for determining the projected increase in rainfall as a result of climate change in New Zealand (Ministry for the Environment, 2008). The mean annual temperature for the Lake Taupo catchment is predicted to increase by between 0.2 and 2.4°C by the 2040s and 0.6 and 5.6°C by the 2090s (Figures 3.14). These changes are data are summarised in Table 3.6.



Projected annual mean temperature change between 1980–1999 and 2030–2049*

Projected annual mean temperature change between 1980–1999 and 2080–2099*

Figure 3.14: Projections for increases in mean annual temperature by 2040 and 2090 relative to 1990; average of 12 climate models for A1B emission scenario (Figure 2.3, Ministry for the Environment, 2010a).

Table 3.6: **Projected increases in mean annual temperature by 2040 and 2090 for the Lake Taupo catchment (Ministry for the Environment, 2010).**

Scenario	2040 (°C)	2090(°C)
Lower limit	0.2	0.6
Average	0.9	2.1
Upper limit	2.4	5.6

Note: These data are from Tables 2 and 3 in Ministry for the Environment (2010). The original tables cover the period from 1990 (1980-1999) to 2040 (2030-2049) and 2090 (2080-2099) based on downscaled temperature changes for 12 global climate models, re-scaled to match the IPCC global warming range for six illustrative emission scenarios.

These predicted increases in temperature are expected to cause a significant change in both the rainfall pattern and rainfall intensity during specific storm events (Figure 3.15).

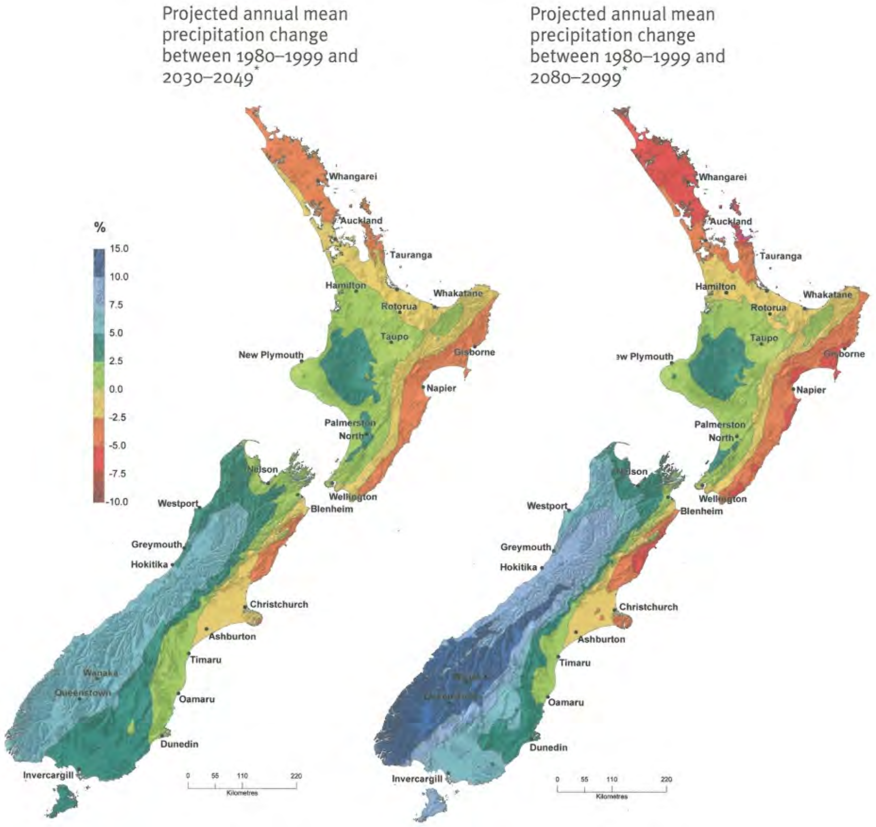


Figure 3.15: **Projections for increases in rainfall by 2040 and 2090 relative to 1990; average of 12 climate models for A1B emission scenario (Figure 2.3, Ministry for the Environment, 2010a).**

The MfE methodology recommends percentage adjustments per degree of warming that should be applied to the high intensity rainfall totals to account for the effect of global warming. For example, a 12-hour duration 100-year return period rainfall will increase by 8 percent per degree of projected warming (highlighted in Table 3.7).

Earlier flood analysis in this report has shown that rain-storm durations of 12 hours and longer pose the greatest flood risk in the Whareroa catchment. Since the percentage increase in rainfall (per degree warming) decreases with increasing storm duration, and to take a conservative approach to flood risk, a critical storm duration of 12 hours was used in this analysis.

Assuming temperature increases of between 0.2°C and 2.4°C (2040s) and 0.6°C and 5.6°C (2090s) for the respective scenarios, the 100-year return period rainfall will increase by a maximum of 19.2% by 2040 and 44.8% by the 2090s (Table 3.8). This is based on the upper limits of the various global warming scenarios. The percentage increase will vary depending on the actual temperature increase, storm magnitude, and storm duration.

Table 3.7: Percentage increase in rainfall per degree of temperature for different rainfall durations.

	ARI (years)						
Duration	**2**	**5**	**10**	**20**	**30**	**50**	**100**
< 10 mins	8.0	8.0	8.0	8.0	8.0	8.0	8.0
10 mins	8.0	8.0	8.0	8.0	8.0	8.0	8.0
30 mins	7.2	7.4	7.6	7.8	8.0	8.0	8.0
1 hr	6.7	7.1	7.4	7.7	8.0	8.0	8.0
2 hr	6.2	6.7	7.2	7.6	8.0	8.0	8.0
3 hr	5.9	6.5	7.0	7.5	8.0	8.0	8.0
6 hr	5.3	6.1	6.8	7.4	8.0	8.0	8.0
12 hr	4.8	5.8	6.5	7.3	8.0	8.0	**8.0**
24 hr	4.3	5.4	6.3	7.2	8.0	8.0	8.0
48 hr	3.8	5.0	6.1	7.1	7.8	8.0	8.0
72 hr	3.5	4.8	5.9	7.0	7.7	8.0	8.0

Source: Ministry for the Environment, 2010.

Table 3.8: Estimated percentage increase in 12-hour rainfall totals for the Whareroa Stream as a result of global warming.

Return period	**2040**			**2090**		
	Lower limit (0.2°)	**Average (0.9°)**	**Upper limit (2.4°)**	**Lower limit (0.6°)**	**Average (2.1°)**	**Upper limit (5.6°)**
2.3	1.0	4.3	11.5	2.9	10.1	26.9
5	1.2	5.2	13.9	3.5	12.2	32.5
10	1.3	5.9	15.6	3.9	13.7	36.4
20	1.5	6.6	17.5	4.4	15.3	40.9
50	1.6	7.2	19.2	4.8	16.8	44.8
100	1.6	7.2	**19.2**	4.8	16.8	**44.8**

Note: Guidelines for the effect of climate change on rainfall do not extend beyond 100 years.

At the present time, the direct effect of global warming on stream runoff has not been quantified. Therefore, since this study is particularly concerned with extreme events, when catchment storage is approaching saturation, it has been assumed that an increase in rainfall will produce an equal and corresponding increase in runoff. This is likely to over-estimate the actual increase in runoff, creating a conservative approach when assessing flood risk. Therefore, the percentage increases in rainfall listed in Table 3.8 have been translated directly to percentage increases in flow.

Table 3.9 lists the increases in peak discharge as a result of predictions of global warming. The maximum predicted increases in temperature were used to estimate the increases in flood peak discharges by 2040. The average temperature increases were used for 2090 (Table 3.8). It should be noted, however, that the predicted flood peaks by 2040, using the highest temperature increases, are similar to those by 2090 using the 'average' values. This is therefore considered to be a conservative approach. It allows predicted increases in flood peaks to be managed efficiently now. There is sufficient lead time by 2090 that, should the maximum predicted increase appear likely, further mitigation of the flood risk is possible.

Table 3.9: Increased flood discharge for the Whareroa Stream as a result of global warming.

Return Period	Flood peak discharge estimated from the synthetic record	Flood peak discharge 2040 – highest temperature prediction (m^3/s)	Flood peak discharge 2090 – average temperature prediction (m^3/s)
2.33 (annual)	14.5	16.2	16.0
5	18.8	21.4	21.1
10	22.7	26.2	25.8
20	26.6	31.3	30.7
50	32.2	38.4	37.6
100	36.8	43.9	43.0

Note: Estimates are based on the highest temperature scenario for 2040 but the average temperature increase for 2090. Guidelines for the effect of climate change on rainfall do not extend beyond 100 years.

4 Other factors that affect flooding

4.1 Sediment transport

Under normal flow conditions the sediment load of the Whareroa Stream consists of sands and silts in suspension. Because this material is in suspension it is generally transported through the lower reaches to the river mouth. The finest material is deposited in Lake Taupo. This sediment therefore has little effect on the flow capacity and the potential for flooding. However, as already mentioned, flood events can mobilise significant quantities of bed load which is eroded from the upper catchment and channel during these high energy events. While this material can be transported through the steeper reaches, it is often deposited on the lower flood plain.

The deposition or erosion of material within the channel, and resulting changes in channel geometry, can affect the capacity of the channel to contain flood flows, and therefore the potential for overbank (flood) flows. While these affects can either exacerbate or limit the flood extent, duration, and inundation depth they are difficult to build into a flood hazard model. This is because these effects are essentially random occurrences in both time and place. When modelling the passage of large flood events down the Whareroa Stream the current configuration of the channel was assumed constant. Given the small flood storage volume of the channel relative to the volume of large floods any change in the flood risk caused by changes to the channel geometry would be minor.

4.2 Lake level

The extent and depth of inundation caused by flooding of the Whareroa Stream is partly controlled by the water level in Lake Taupo. Higher lake levels can exacerbate flooding. Lower lake levels can potentially reduce the extent, depth and duration of flooding. A full discussion of all the factors that affect the level of Lake Taupo is contained in McConchie *et al.,* (2008). In summary, however, the static water level for any specific return period is equal to the sum of the estimates of the lake level together with the appropriate seiche, and climate change components (Table 4.1). To this must be added the site-specific effect of tectonic deformation over the particular return period chosen as discussed below.

Table 4.1: Expected static water level for different return period events excluding deformation.

Return Period	Lake Level (m)	Climate Change 2080s (m)	Seiche Effect (m)	STATIC WATER LEVEL
2.33	357.17	0.07	0.08	357.32
5	357.29	0.10	0.09	357.48
10	357.35	0.12	0.10	357.57
20	357.41	0.14	0.11	357.66
50	357.47	0.16	0.11	357.74
100	357.50	0.18	0.11	357.79
200	357.53	0.19	0.11	357.83
500	357.57	0.21	0.11	357.89

4.3 Tectonic deformation

The risk of flooding and inundation on the Whareroa flood plain is not a simple function of the peak flood discharge and the level of Lake Taupo. This is because the Taupo basin is not stable. Some areas are rising, while others are subsiding. The movement of the land means that for a fixed volume of water, areas that are subsiding are exposed to greater risk in the longer term (Figure 4.1). This relative movement of the land has the potential to have a significant effect on the flood risk and potential depth of inundation.

A full review of tectonic deformation around Lake Taupo is provided in McConchie *et al.* (2008). That discussion showed near-continuous deformation around Lake Taupo. This deformation is likely to be a combination of tectonic stresses, subsidence caused by the extraction of geothermal steam to the north-east of the lake, and sediment compaction at the mouths of the various streams and rivers. The northern and southern shorelines tend to be subsiding relative to the central Horomatangi Reef which is rising. This deformation is likely to continue, but the rates and direction are variable and site specific. In addition to this 'continual' deformation, earthquakes may cause instantaneous vertical movement of the land.

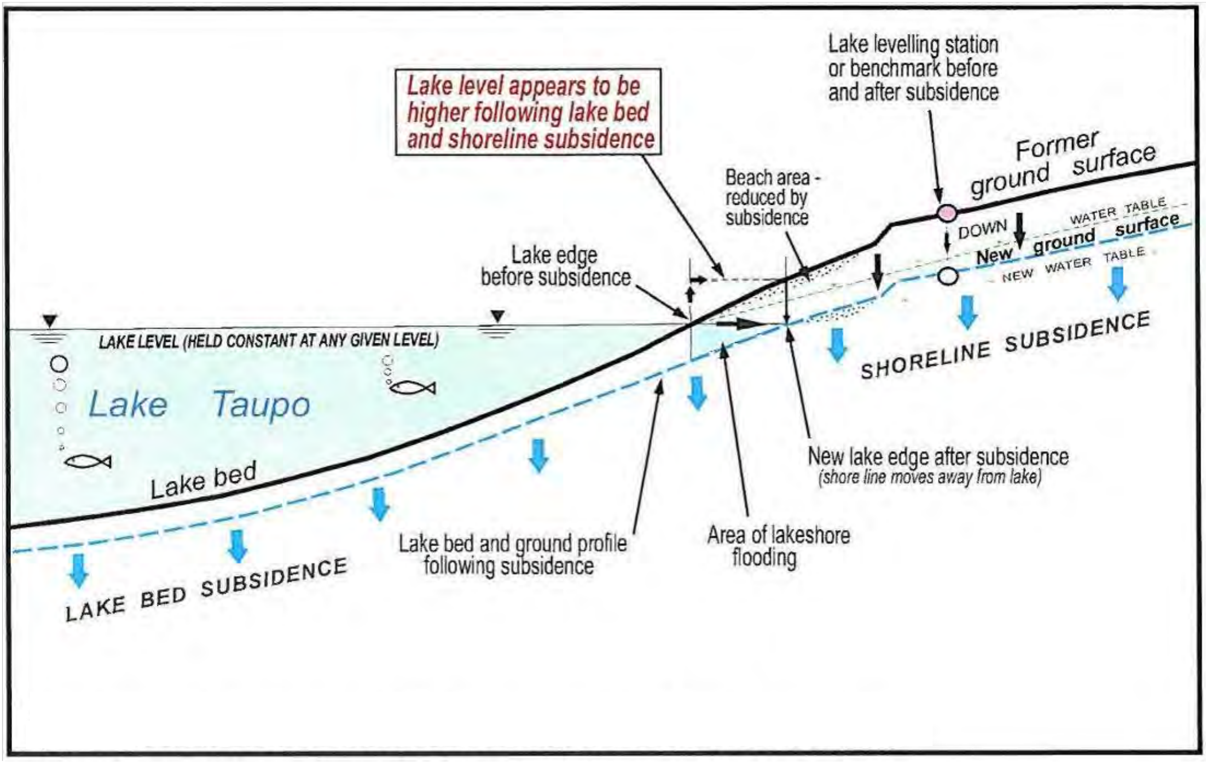


Figure 4.1: **Effect of ground level subsidence on relative lake levels (Hancox, 2002).**

Because of its magnitude, and potential impact on water levels, this tectonic deformation needs to be built into projections of future lake and river levels; and consequently the flood hazard model. In areas that are subsiding, the total amount of ground surface lowering over various time periods need to be considered. This provides a measure of the potential lowering of the ground surface, and as a consequence, the effective increase in water level in this vicinity.

Table 4.2 lists the deformation rates for particular locations around Lake Taupo. The total amount of movement over particular time periods is also shown. These data were used to create a deformation model of the Lake Taupo area (Figure 4.2). This model allows the effect of deformation on static water levels to be predicted for any position around the entire lake shore, and over any time period. For the purpose of establishing a flood risk level, it is suggested that the 100-year values are most appropriate.

Table 4.2: Tectonic deformation (mm) over various time periods.

Time Period	Kinloch	Whakaipo	Kaiapo	Rangatira Point	Acacia Bay	Rainbow Point	Horomatangi Reef	Rotongaio	Bulli Point	Motuoapa	Waihi	Scenic Bay	Waihaha	Kawakawa
mm/yr	-6.8	-4.0	-1.2	2.1	0.6	0.0	2.2	1.1	0.1	-2.3	-2.6	0.6	-1.9	-3.5
2.33	-9	-9	-3	5	1	0	5	3	0	-5	-6	1	-4	-8
5	-34	-20	-6	11	3	0	11	6	1	-12	-13	3	-10	-18
10	-68	-40	-12	21	6	0	22	11	1	-23	-26	6	-19	-35
20	-136	-80	-24	42	12	0	44	22	2	-46	-52	12	-38	-70
50	-340	-200	-60	105	30	0	110	55	5	-115	-130	30	-95	-175
100	-680	-400	-120	210	60	0	220	110	10	-230	-260	60	-190	-350
200	-1360	-800	-240	420	120	0	440	220	20	-460	-520	120	-380	-700
500	-3400	-2000	-600	1050	300	0	1100	550	50	-1150	-1300	300	-950	-1750

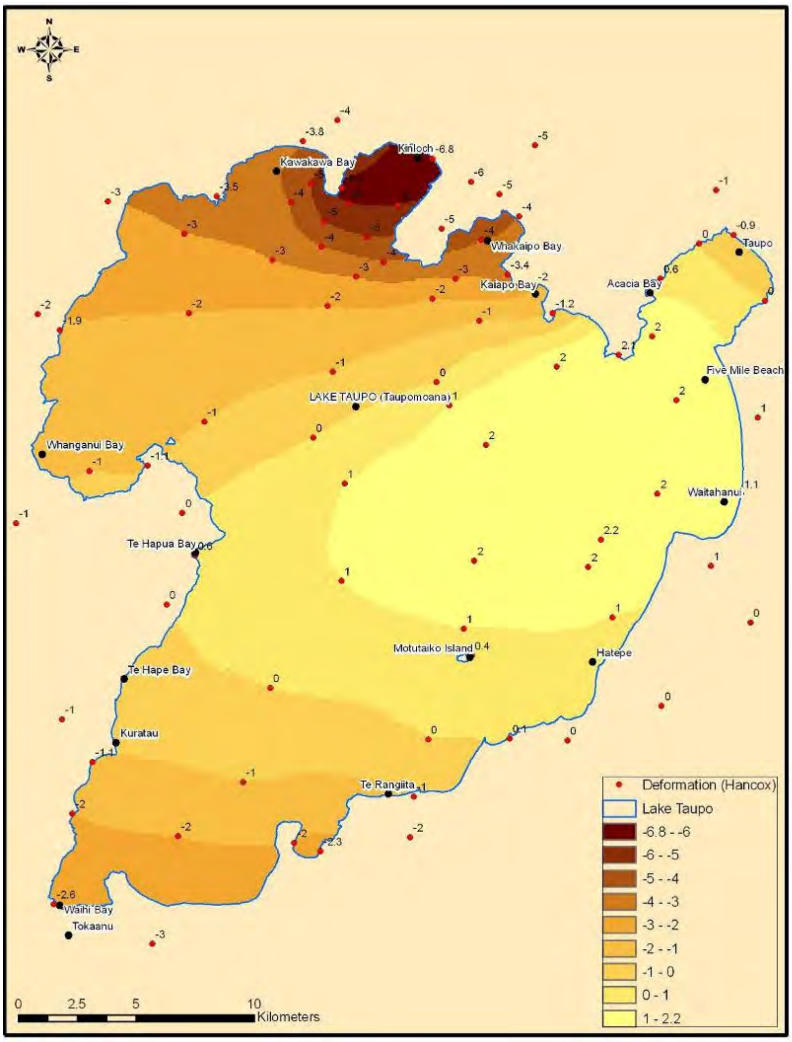


Figure 4.2: Average rates (mm/yr) of tectonic deformation between 1979 and 2002 (After Hancox, 2002).

Based on the tectonic deformation model, the area in the vicinity of the Whareroa flood plain is estimated to be subsiding at approximately 1mm/yr. Because of its magnitude, and potential impact on water levels, this tectonic deformation needs to be built into projections of future lake and river levels, and consequently the flood hazard model. Over a 100-year period the Whareroa flood plain is likely to subside approximately 110mm. The effect of this on the flood risk is that lake levels will be relatively higher, and this, in combination with reduced channel slopes, may increase the extent, duration, and depth of flooding caused by large storm events.

4.4 Waves

Although waves do not affect the river level and flooding directly, they can increase the effects of high lake levels, and consequently worsen inundation. A full discussion of Lake Taupo's different wave environments is contained in McConchie *et al.* (2008). The Whareroa Stream discharges into the Kuratau wave environment (Figure 4.3).

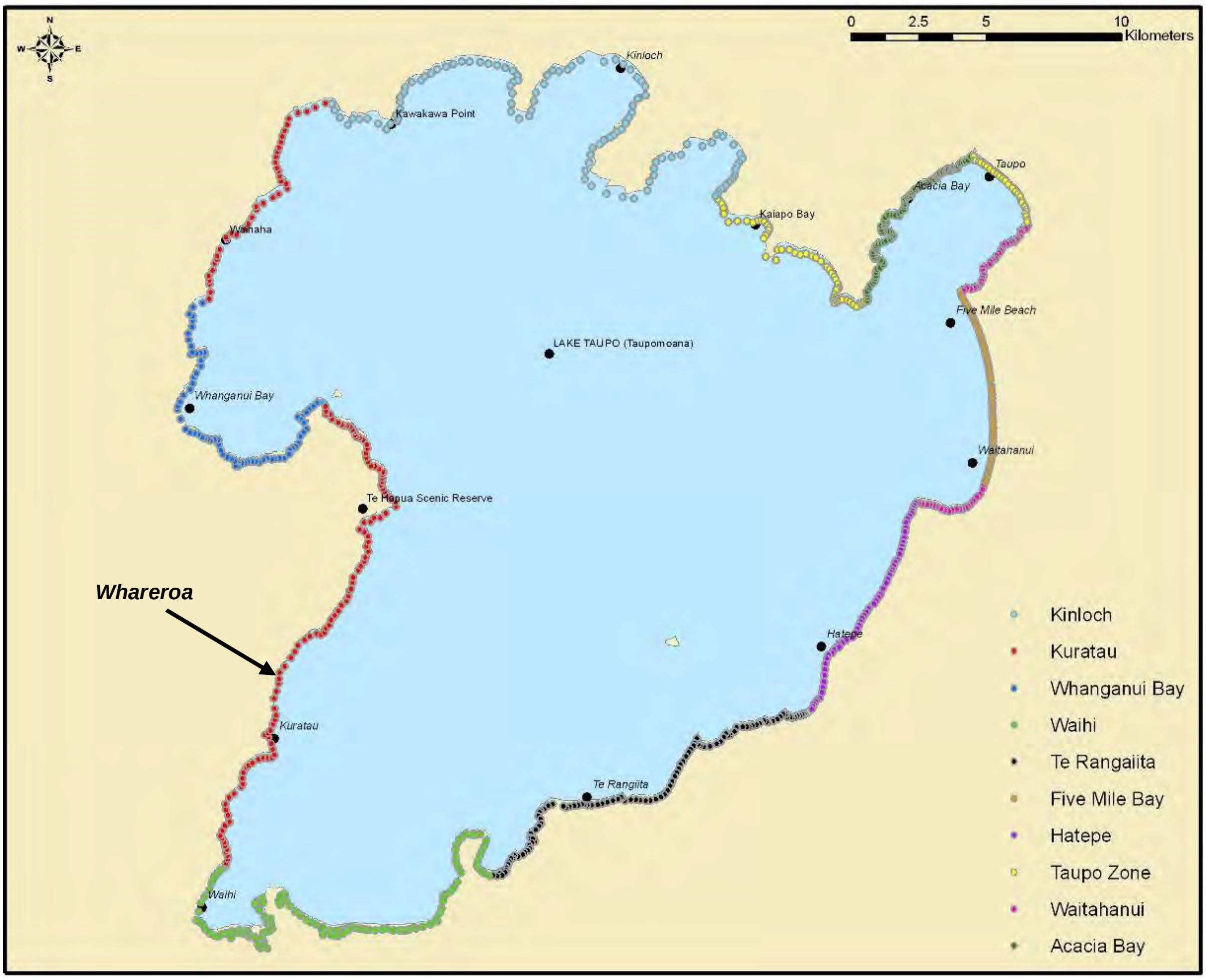


Figure 4.3: Wave run-up environments around the shore of Lake Taupo.

The frequency distribution for the 2% exceedance wave run-up for the Kuratau wave environment is shown in Figure 4.4. The Kuratau wave environment is one of the lower wind energy locations around the lake, and therefore has a lower wave run-up compared to other areas around Lake Taupo.

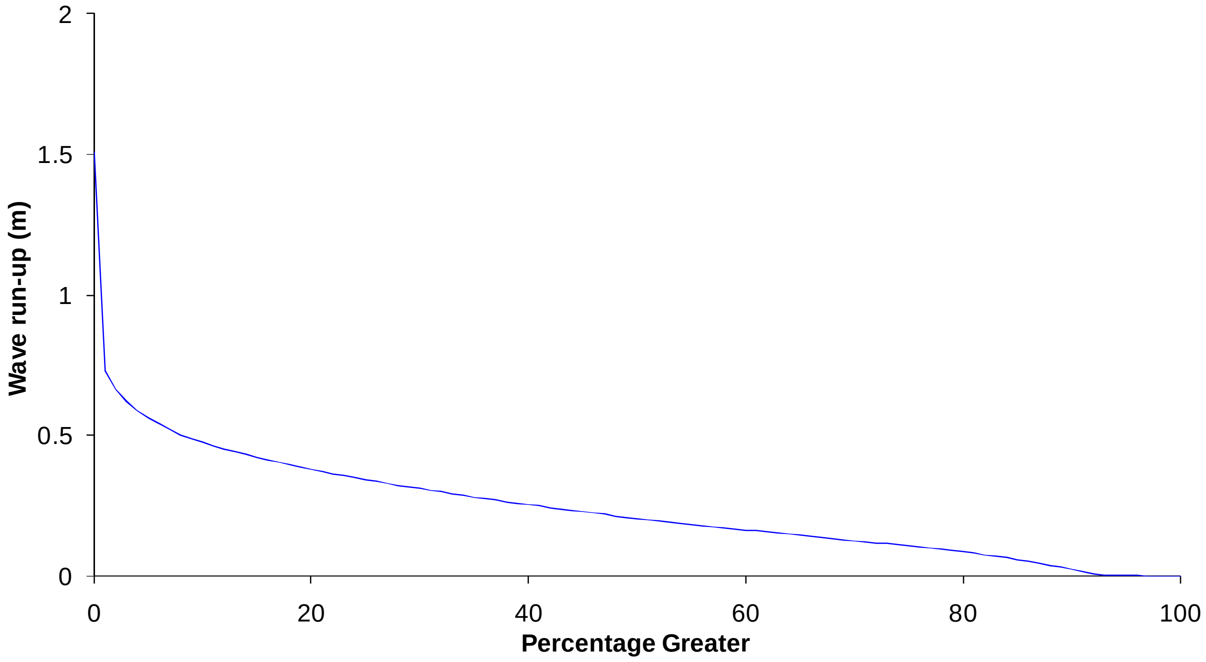


Figure 4.4: Frequency distribution of wave run-up in the Kuratau wave environment.

A frequency analysis of the wave run-up data for the Kuratau wave environment shows that a Gumbel statistical distribution fits the data well. This distribution provides good estimates of the magnitude of wave run-up events for particular return periods (Table 4.3).

Table 4.3: Estimated 2% exceedance wave run-up height (m) for Kuratau.

Best-fit Distribution	Gumbel
Return Period	
2.33	0.96
5	1.08
10	1.17
20	1.26
50	1.38
100	1.47
200	1.50

Figure 4.5 shows how the magnitude of the wave run-up changes with increasing return period. The most rapid increase in wave run-up occurs out to a return period of 20 years. After this, the increase is significantly more gradual.

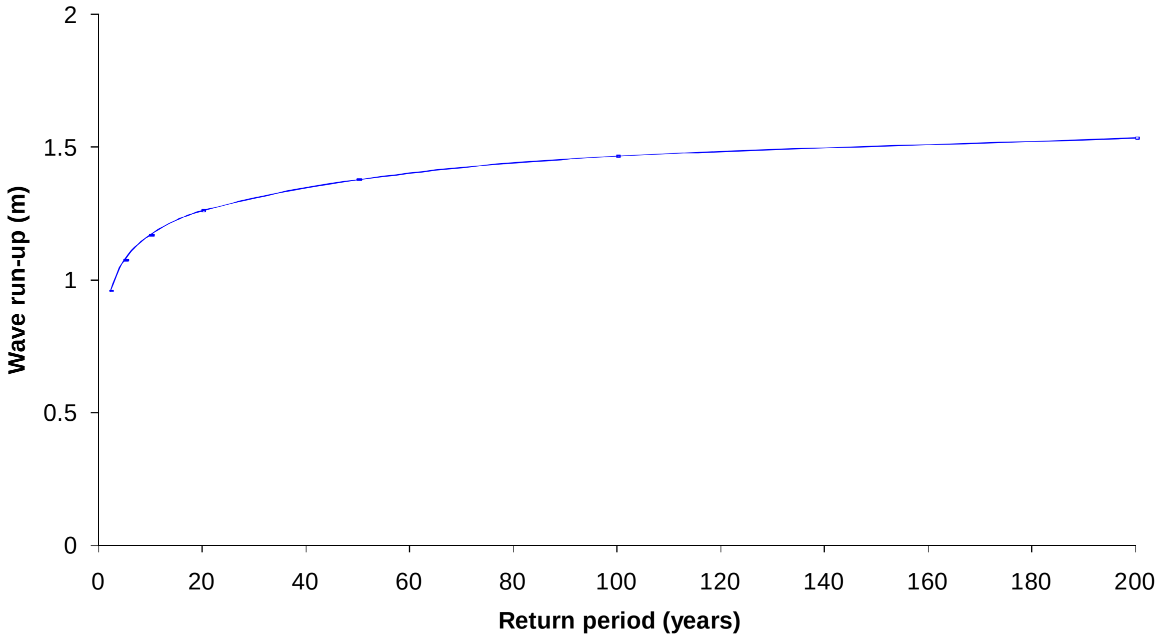


Figure 4.5 **Wave run-up for the different environments at different return periods.**

4.5 Summary of lake effects

The various factors that affect lake level were analysed in McConchie *et al.* (2008). It was recommended that the static water level used for defining the flood level should include: the 100-year lake level (357.50m); the potential effect of climate change on the 100-year lake level (0.18m); the 100-year seiche (0.11m); and 100 years of accumulated tectonic deformation (0.110m at Whareroa). The static water level defined in this manner delineates areas where inundation to some degree is considered to be inevitable over a 100-year period, or with a likelihood of 1% each year (i.e. 1%AEP).

Two hazard zones were subsequently recommended. The first is the maximum static water level, relative to the land, that is likely to be experienced over the next hundred years. The second is a buffer zone, higher than the first, where the effect of waves might be significant if not mitigated at the shore.

It is obvious that some areas in the vicinity of the Whareroa Village along the shoreline of Lake Taupo are likely to be affected by flooding over the next 100 years as a result of a combination of high lake levels and ongoing subsidence. Since this area is subject to relatively small waves, the majority of the risk is the result of higher effective static water levels. Waves add little to the overall risk. Despite this, the flood risk zones still extend some distance inland. From a hazard management perspective, higher effective static water levels are more problematic than the potential risk of periodic wave encroachment which can be relatively easily mitigated.

5 Flood risk

The flood risk in the vicinity of the Whareroa Stream is a combination of both lake-induced flooding, and overbank flows from the river. These two situations may not occur at the same time. The total area potentially affected by flooding, however, needs to be considered in any planning and management framework. The area likely to be affected by high lake levels over the next 100-years is shown in Figure 5.1. Water levels may actually be 110mm higher than shown if subsidence of the area continues at the present rate.

The majority of the current Whareroa Village is located well above a maximum potential lake level of 357.8m (MSL Moturiki) shown in Figure 5.1. Near the river mouth, the same areas will be affected under either high lake levels or high river levels. This is partly because both of the flood risks are controlled largely by ground elevation.

Figure 5.1: **Area affected by a lake level of 357.8m (MSL Moturiki) (NZTM grid coordinates shown).**

To assess the likely extent, depth, and velocity of a 100-year flood event in Whareroa Stream, adjusted for the predicted effects of climate change by the 2090s, a MIKE FLOOD two-dimensional coupled hydraulic model was developed for the area.

6 MIKE FLOOD model

MIKE FLOOD is a software package developed by DHI (formally the Danish Hydraulic Institute) which allows the user to dynamically link one-dimensional (MIKE11) and two-dimensional (MIKE21) hydrodynamic models. This approach has many advantages over a simple one-dimensional model. For example, overbank flow can be modelled more realistically in two dimensions. The results therefore more accurately reflect the flood plain response to river channel overtopping. At the same time, one-dimensional upstream and downstream boundary conditions can be specified much more simply than in a single two-dimensional model. Also, a deep, narrow channel (such as the Whareroa Stream contains in places) can be difficult to represent in a two-dimensional grid. To do so requires an extremely high resolution (high number of grid cells) model. To run such a model then requires prohibitively long computer processing time.

MIKE FLOOD therefore allows the benefits of both two-dimensional modelling of flood plain flow with a reasonable resolution, and simpler implementation of one-dimensional boundary conditions and main channel flow simulation.

6.1 Methodology

Using LiDAR topographic information a one-dimensional MIKE11 model was established. The model covers an approximately 2.5km long reach of the river from the mouth at Lake Taupo upstream to a narrow confined portion of the channel (Figure 6.1).

When LiDAR signals are processed, various algorithms are used to remove the effects of vegetation so as to provide a more accurate representation of the actual ground surface. Over heavily vegetated areas this can be difficult and may lead to errors. Therefore, levels in heavily vegetated areas should be analysed with caution.

LiDAR also does not provide information beneath water bodies such as lakes, rivers and ponds. In the hydraulic model, the volume of a river cross-section below the water surface was ignored. However, given that the Whareroa Stream is very steep (>2% grade) any baseflow is likely to occupy only a very small proportion of the total channel volume during a large flood. This assumption is also reasonable when compared to those necessary when deriving the hydrological inputs for the hydraulic model.

No surveyed cross-sections were available for use in the hydraulic model. Therefore, cross-sections were extracted from a high resolution 0.5m DTM, and then checked carefully against the un-interpolated LiDAR data. These cross-sections were then implemented in the one-dimensional portion of the hydraulic model.

Figure 6.1: **MIKE21 approximate model extent.**

Also using LiDAR topographic information, a two-dimensional MIKE21 model was established of the flood plain. The model covers an area of approximately 26ha along the river, and includes the majority of the Whareroa Village that could potentially be impacted by the river. The MIKE11 and MIKE21 components were dynamically coupled together using MIKE FLOOD. Model parameters were estimated using expert professional advice, and knowledge from previously calibrated hydraulic model of other rivers draining to Lake Taupo.

The MIKE FLOOD model was then used to estimate the characteristics and extent of a 100-year average recurrence interval (ARI) event; incorporating the potential effects of climate change predicted by 2090. The February-March 2004 flood hydrograph measured in the Whareroa Stream at Fish Trap was also run through the model. Although no flood extent or water level data are available for calibration the results are useful for comparison. These results will also be valuable should calibration data become available at some stage in the future.

6.2 Sensitivity analysis

A sensitivity analysis was carried out on the input data and several hydrodynamic modelling parameters using the 100-year ARI event, plus the potential effects of climate change. This was to assess the effects and consequences of any errors, and therefore the confidence that can be placed in the model outputs. Inputs were varied by amounts corresponding to the realistic ranges which the various inputs might be expected to have when modelling a catchment such as the Whareroa.

The sensitivity analysis confirmed that over the ranges tested, Manning's n is the most sensitive parameter; however, no parameter had a significant effect on predicted flood levels. This is not surprising given the steeply sloping, and relatively confined, nature of the Whareroa Stream. The nature of the stream would suggest that channel geometry is the most important hydraulic control.

The sensitivity analysis also showed that the effect of increasing the lake water level by 0.3m was only noticeable over the first 30m of the river upstream its mouth. Beyond this distance lake level has negligible impact on the water levels resulting from modelling the 100-year ARI with climate change flood hydrograph.

Considering the accuracy of the input data, together with the lack of calibration data, the sensitivity analysis showed that the model produces sensible and realistic results. The model behaves in a realistic manner to small changes to the various inputs. The results of the hydraulic model can therefore be relied on to provide a good indication of the potential flood hazard in the Whareroa catchment.

6.3 Effect of lake level on Whareroa Stream flooding

Figure 6.2 shows a sketch of the longitudinal water surface profile along a river which flows into a lake. This is commonly referred to as the 'backwater profile' (Henderson, 1966). Beyond a certain distance upstream, the backwater profile for a given river discharge (flow) is governed by the size, shape, slope and frictional characteristics of the river channel. Toward the lake at the downstream end of the reach, the backwater profile has a concave upwards shape which transitions asymptotically to the horizontal lake level surface. The downstream lake level in fact acts as a hydraulic control on the backwater profile so that river levels, for a given discharge, are influenced also by the lake level for a certain distance upstream of the lake depending on the river channel slope.

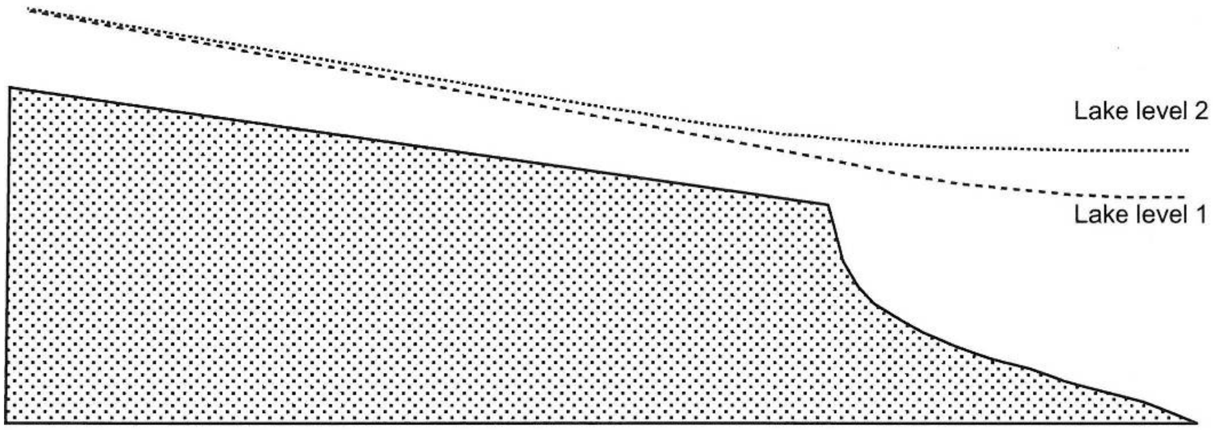


Figure 6.2: Backwater profiles for river flow discharging into a lake (constant discharge).

The effective lake level that controls the backwater profile extending upstream in the river is the static water level of the lake. The static water level is the water level that would be measured by a stilling well connected to the lake by a submerged pipe. The stilling well dampens any surface waves on the lake. As illustrated in Figure 6.2, the portion of the backwater profile influenced by the magnitude of the lake level for a given river discharge extends only a limited distance upstream. Generally, in hydraulically steep rivers, like most New Zealand rivers including the Whareroa, the extent of any backwater influence from the lake is relatively short. This is shown by the merging of the two backwater profiles in Figure 6.2 for the same river discharge but different lake levels. This means that upstream of this limit flood levels, and consequently the extent of flood inundation, will only be determined by the size, shape, slope and frictional characteristics of the channel in addition to the magnitude of the flood peak.

Figure 6.3 shows the predicted backwater profile along the Whareroa Stream for the 100-year ARI with climate change event; which has an estimated peak discharge of 43m^3/s. The backwater profile is based on the 100-year ARI lake level, estimated to be RL 357.5m. The shape of the backwater profile is slightly different from that shown in Figure 6.2 in that it is faintly concave downwards towards the mouth of the river, before the profile flattens off as it reaches Lake Taupo (i.e. chainage 2640). This is quite significant as it indicates that the influence of the size, shape, slope and frictional characteristics of the river channel on the backwater profile is much more dominant than the influence of the lake level towards the mouth of the river.

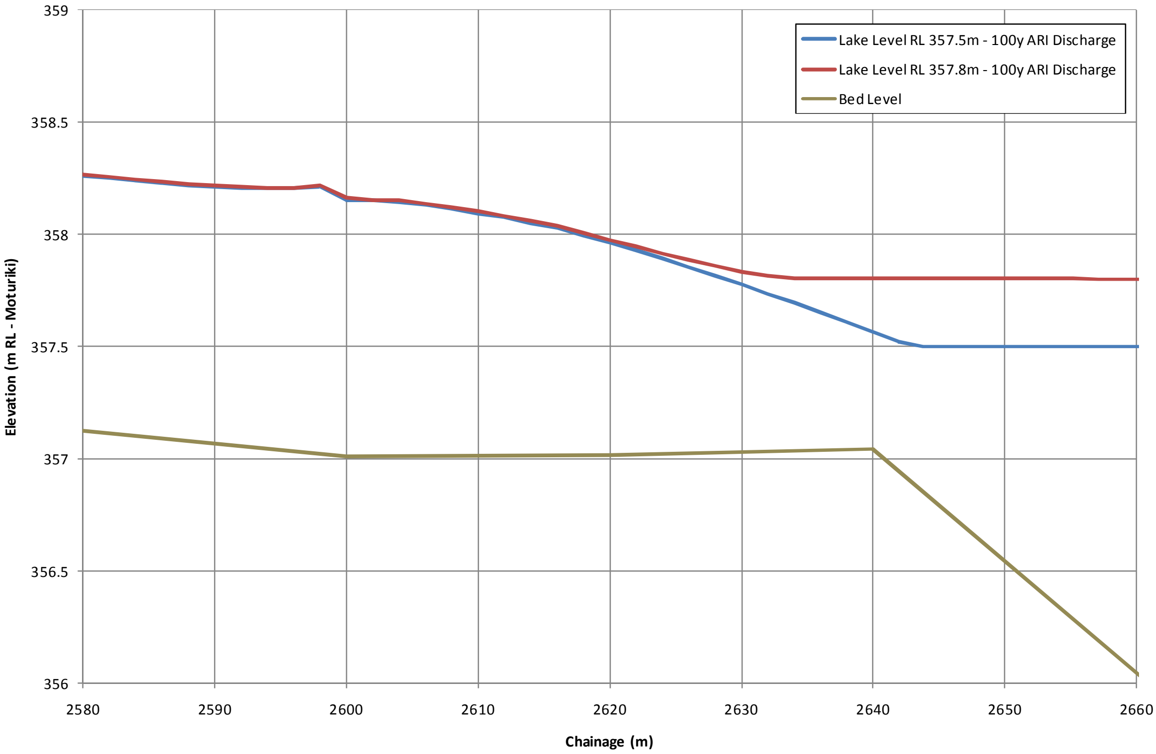


Figure 6.3: **Backwater profiles simulated for the 100-year ARI plus climate change event showing the effect of increasing the lake level by 0.1m.**

Sensitivity tests were carried out using the hydraulic model and the simulated flood hydrograph for the 100-year ARI plus climate change event. The downstream lake level was arbitrarily shifted vertically upwards by 0.3m. The results confirm that the backwater profile only changes noticeably with varying lake levels over the last 30 metres of Whareroa Stream. For example, 20 metres upstream of the mouth a 100mm difference in lake level causes a shift in the backwater profile of less than 15mm. This effect is likely to be well within the range of the other uncertainty within the hydraulic model.

The shift in the backwater profile decreases with increasing discharge as the energy of the flow becomes more dominant. The precise lake level used as the downstream boundary condition therefore has only a small effect on the extent, depth, and velocity of inundation during major flood events.

6.4 Description of scenarios modelled

The largest flood recorded within Whareroa Stream, the 28 February - 1 March 2004 event, was simulated within the hydraulic model to investigate the predicted response to an event which has actually been experienced. The hydrograph recorded at the Fish Trap gauging station was used as the model's inflow boundary condition. The water level record from Lake Taupo over the same period was used as the downstream boundary condition for the model.

One major flood hazard scenario was also simulated using the MIKE FLOOD model. The scenario simulated the flood response to a 100-year ARI event including the effects of climate change. Because of uncertainties regarding hydrologic flow record, this scenario is considered a useful benchmark for flood hazard classification, and long-term flood risk management.

For the downstream boundary condition of the hydraulic model, the predicted 100-year ARI lake level was used. This is likely to result in conservative (i.e. higher) estimates of flood depths in some areas. It should, however, provide good estimates of the flood depths near the mouth of the river where the lake level has some effect on flood depths. The same lake level boundary condition was used when modelling the 100-year ARI event including the effects of climate change. The reasons for this are discussed in McConchie *et al.* (2008).

Table 6.1 summarises the boundary conditions used in the flood estimation scenarios simulated using the MIKE FLOOD model.

Table 6.1: Description of flood estimation scenarios which were modelled.

Scenario	**Boundary Conditions**	
	Whareroa Stream peak flow (m^3/s)	**Lake Taupo level (m)**
Feb/March 2004 flood	13.7	Actual lake level record
100-year ARI flood event adjusted for climate change to 2090 and scaled to mouth of Whareroa Stream	43.0	357.5

6.5 Flood inundation maps

Figure 6.4 shows the maximum inundation extent predicted when simulating the 100-year ARI event, increased to allow for the predicted effects of climate change. During such an event the river overtops its meandering channel and water flows over the lower banks. Since the meandering channel is within a gorge, the gorge constrains the outer limit of the flood water. The overbank flow results in the flow shortcutting some of the meander bends. Around 200m upstream of the mouth of the river, the channel banks become lower and consequently the flood water overtops the channel and spreads out as it flows towards Lake Taupo.

Figure 6.5 shows the peak inundation extent predicted when simulating the 28 February to 1 March 2004 flood event. This flood shows a similar pattern of flooding to that predicted using the previous extreme scenario, but with less overtopping of the banks and fewer meanders being shortcut. Also, less of the area near the river mouth is inundated. This map will be very useful if calibration information from the 28 February to 1 March 2004 flood becomes available. It is also useful in confirming the results obtained by modelling the extreme flood scenario.

The accuracy of the model should be considered when analysing areas at risk of flood. The horizontal resolution of the data used in the model is 2m. When considering the horizontal flood extent a ±2m margin of error should be allowed. The vertical accuracy of the flood levels should also be taken into account. LiDAR data typically contains a vertical error of ±0.15m. This vertical error may be exacerbated in areas where correction for vegetation has been made (LiDAR cannot penetrate vegetation and water surfaces).

6.6 Maximum velocity maps

Figure 6.6 shows the maximum flood velocity during the 100-year ARI event; adjusted for climate change. Faster flow velocities occur in the river channel, and in particular, where the channel is narrow. Faster velocities also occur within the overland flow paths formed by old abandoned river channels.

The highest velocities are in the main river channel as expected. Some higher velocities, of around 1.3m/s, are also simulated over a reach 200m upstream of the lake where flood waters break out of the channel.

Velocities over the majority of the channel are predicted to be less than 5m/s. The Whareroa Stream is very steep, and one of the limitations that must be accepted is the inability to account for scouring of the river bed and around sharp bends. This process is essentially random and chaotic which makes it almost impossible to predict. However, any uncertainty caused by these processes is not significant at the catchment scale of this flood risk assessment.

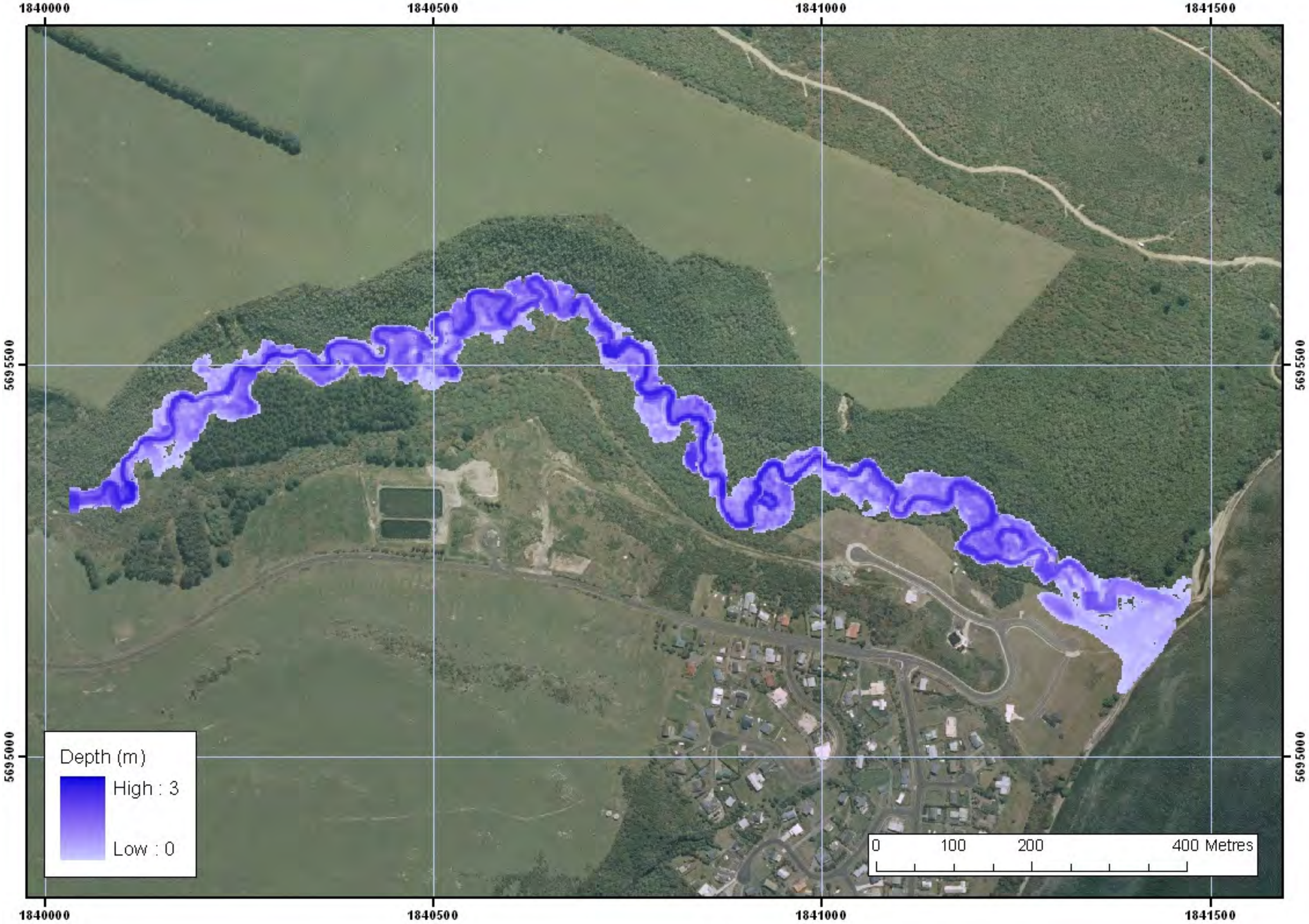


Figure 6.4: **Depth of inundation predicted by flooding of the Whareroa Stream assuming the ‘worst case’ scenario modelled; i.e. 100-year event, increased to allow for climate change, and a lake level of 357.5m (NZTM grid coordinates shown).**

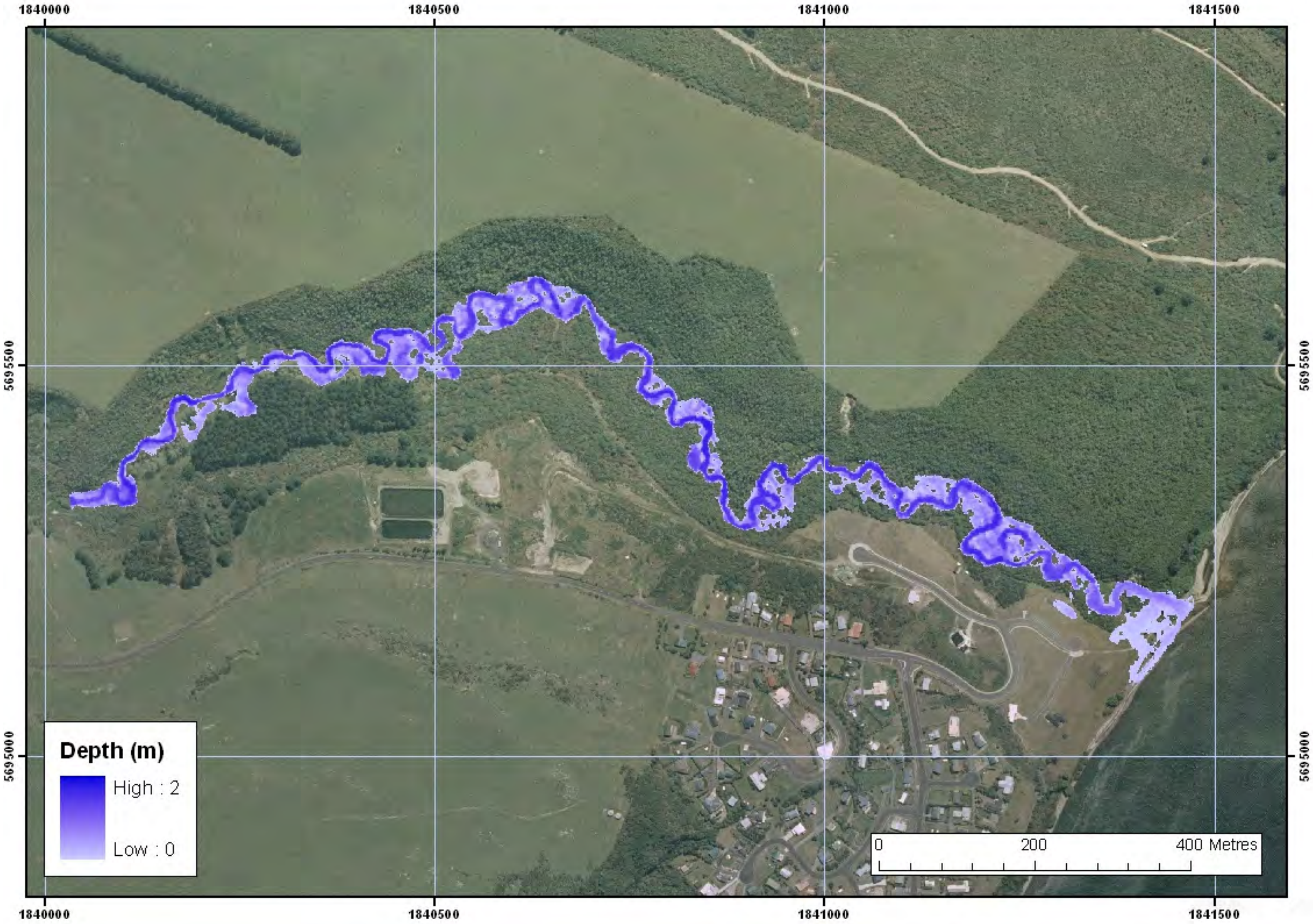


Figure 6.5: **Depth of inundation predicted by flooding of the Whareroa Stream for the recorded 28 February – 1 March 2004 flood event (NZTM grid coordinates shown).**

Figure 6.6: **Velocity of flood waters assuming the 'worst case' scenario modelled i.e. 100-year event increased to allow for climate change, and a lake level of 357.5m (NZTM grid coordinates shown).**

7 River flood hazard classification

7.1 Introduction

Just because an area is subject to flooding does not fully quantify the actual risk to life and to property. The actual risk relates not just to 'getting wet' but to the depth of water, its velocity, and the duration of inundation. Considerable work has been done to define a flood hazard index that relates to, and combines, these various characteristics of the flood event (Environment Waikato, 2008a). This index was adopted for use within the region following public consultation and refinement (Environment Waikato, 2008b).

7.2 Significance to people and property

A river flood hazard classification describes the potential impact of the flood event on people and property. The classification refined by Environment Waikato was developed using the following considerations:

- *Flood waters have the potential to cause a person to become unstable and unable to manoeuvre.* International research suggests that there is a danger of being knocked over when the product of the flood depth and flood speed exceeds 0.5m, with a significantly greater risk to life when the same product exceeds 1.0m.

- *Flood waters have the potential to impede a person's ability to rescue themselves or others.* When the flood depth exceeds 1.0m (i.e. waist depth), a person's ability to navigate through flood waters (both on foot and using a vehicle) is restricted, therefore impeding the rescue of themselves and others.

- *Flood waters have the potential to damage buildings, both superficially and structurally.* International research suggests that structural damage is likely when the flood speed exceeds 2m/s. It is also likely that structurally weak points such as doors and windows will be damaged when the flood speed exceeds 1m/s.

These considerations have been translated into a river flood hazard classification. Four distinct levels of river flood hazard have been defined on their likely impact on people and property (Environment Waikato, 2008b). These levels are outlined in Table 7.1.

The three levels of river flood hazard (low, medium and high) have then been quantified through the creation of a matrix that assigns a river flood hazard level based on the predicted depth and speed of the flood waters (Figure 7.1).

The following two scenarios also result in a 'high' flood hazard classification:

- Land that is surrounded by flooding that is classified as a 'high' flood hazard.

- Instances where floodwaters are directed by flood defences, including formal spillways.

The fourth level of flood hazard (i.e. defended) is intended to represent instances where a property is located within the natural flood plain but benefits from flood defences (e.g. floodwalls and stop banks) (Environment Waikato, 2008b).

Table 7.1: **Description of river flood hazard categories (Environment Waikato, 2008b).**

Category	Impact on people	Damage to property
Low	The combined depth and speed of floodwaters are unlikely to impede the manoeuvrability or stability of the average person.	Damage to property is likely to be non-structural and mainly due to inundation and deposition of sediment.
Medium	The combined depth and speed of floodwaters are likely to start to impede the manoeuvrability or stability of the average person.	Damage to property is unlikely to be structural provided that weak points such as windows and doors are retained above flood level.
High	The combined depth and speed of floodwaters are likely to significantly impede the manoeuvrability or stability of the average person.	Damage to property is likely to be widespread and structural, including instances where buildings have been raised above the 'flood level'.
Defended	This flood hazard category identifies land that is within an identified river flood hazard area but has been subsequently included in a flood protection scheme that is managed and maintained by Environment Waikato.	

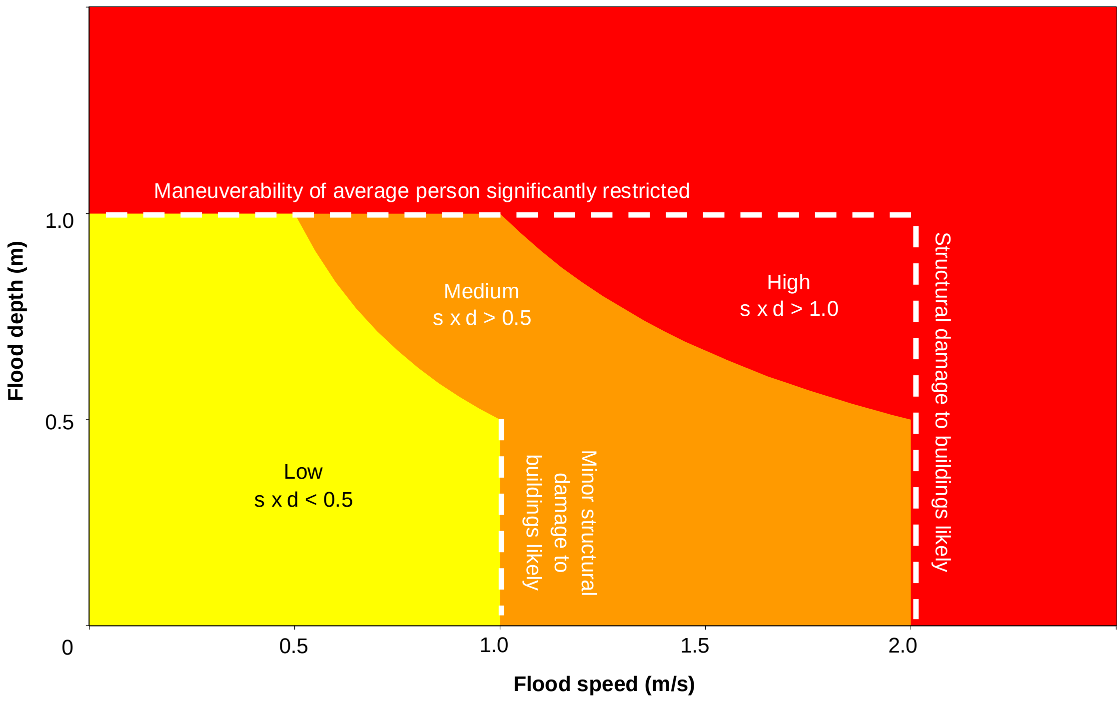


Figure 7.1: **River flood hazard classification matrix (Environment Waikato, 2008b).**

7.3 Flood hazard assessment

The analysis of the sensitivity of the hydraulic model discussed previously showed that the extent and depth of flooding of the Whareroa Stream are relatively insensitive to the level of Lake Taupo. Therefore, the flood hazard posed by the Whareroa Stream was assessed assuming a 100-year ARI event, adjusted for the effects climate change, and assuming a lake level of 357.5m.

The depth of inundation during such a scenario is shown in Figure 7.2, and the maximum flow velocity in Figure 7.3.

Multiplying these two risks (i.e., that from the depth of water and that from the flow velocity) together provides the combined measure of the flood hazard (Figure 7.4). In this flood study, flood hazard is calculated from the simple product of the maximum velocity and maximum depth during the event. However, since the peak velocity may not always coincide with peak water depth this approach will result in a conservative assessment of the combined flood hazard.

Within the flood zone evaluated using this classification system, the hazard may be low, medium, or high. It is important to recognise that, although the flood hazard classification may be low, this does not mean that the area will not flood. It simply means that the depth of inundation and flow velocities during a flood, when combined, present only a low risk to life and property.

It is apparent that a significant proportion of the flood plain adjacent to Whareroa Stream is not prone to flooding because of the incised nature of the river. Over most of the area that would potentially flood, the risk to life and property is low. The areas that are prone to flooding lie near the mouth of the river, and around the lake shore. These areas are also prone to flooding from high lake levels.

Flood waters that break out of the main channel flow across river bends and occupy low lying areas. A large volume of water can be accommodated by inundation to a relatively shallow depth. Likewise, once any flood water leaves the channel, the depth of flow is generally shallow and so friction slows the velocity dramatically.

The areas subject to the greatest risk are within the main channel. Therefore, during the 100-year event, the hazard outside of the obvious channels and flow paths is generally low. A small portion of the ‘urban area’ near the mouth of the river is subject to a risk of flooding. However, while the cost of flooding and inconvenience may still be high, the actual risks to life and property are not great.

There is one area approximately 120m upstream of Lake Taupo that appears from the aerial photographs to be a localised depression (Figure 7.4). When flooding occurs, flood water fills this depression to a depth of over 1m. This produces a small area of high flood hazard outside of the main river channel. Surrounding this area flood water flows across the flood plain towards the river and produces hazards ranging from low to medium.

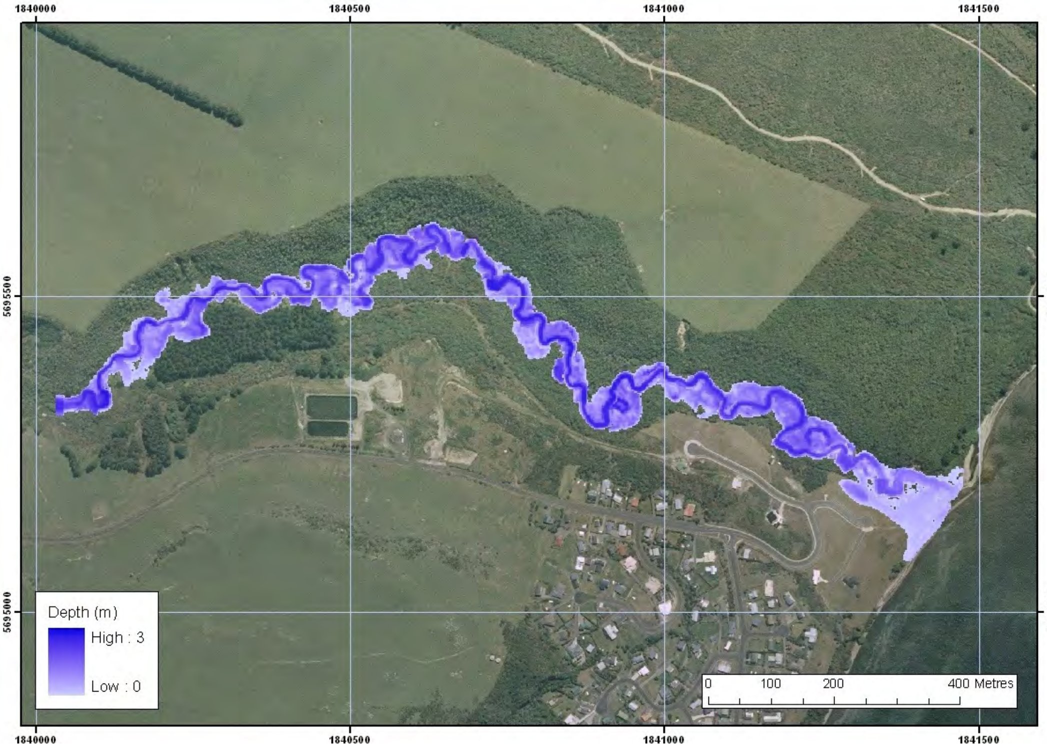


Figure 7.2 **Maximum water depth during a 100-year ARI flood event in Whareroa Stream, adjusted for the effects of climate change. Lake level was assumed to be at 357.5m.**

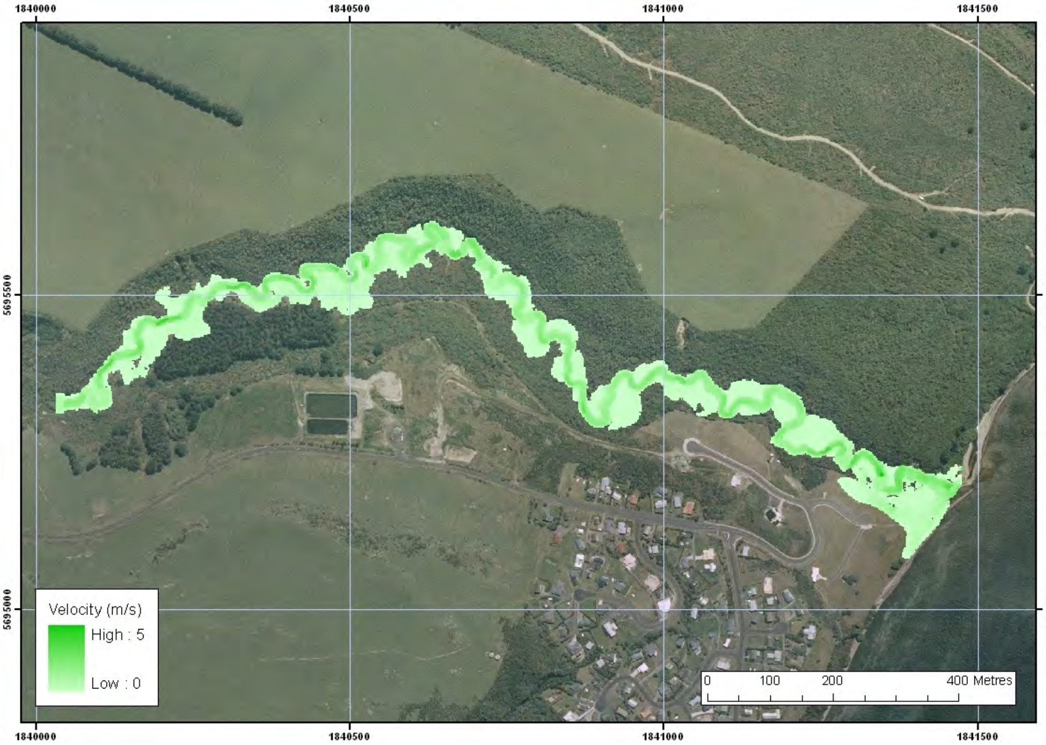


Figure 7.3: **Maximum flow velocity during a 100-year ARI flood event in Whareroa Stream, adjusted for the effects of climate change. Lake level was assumed to be at 357.5m.**

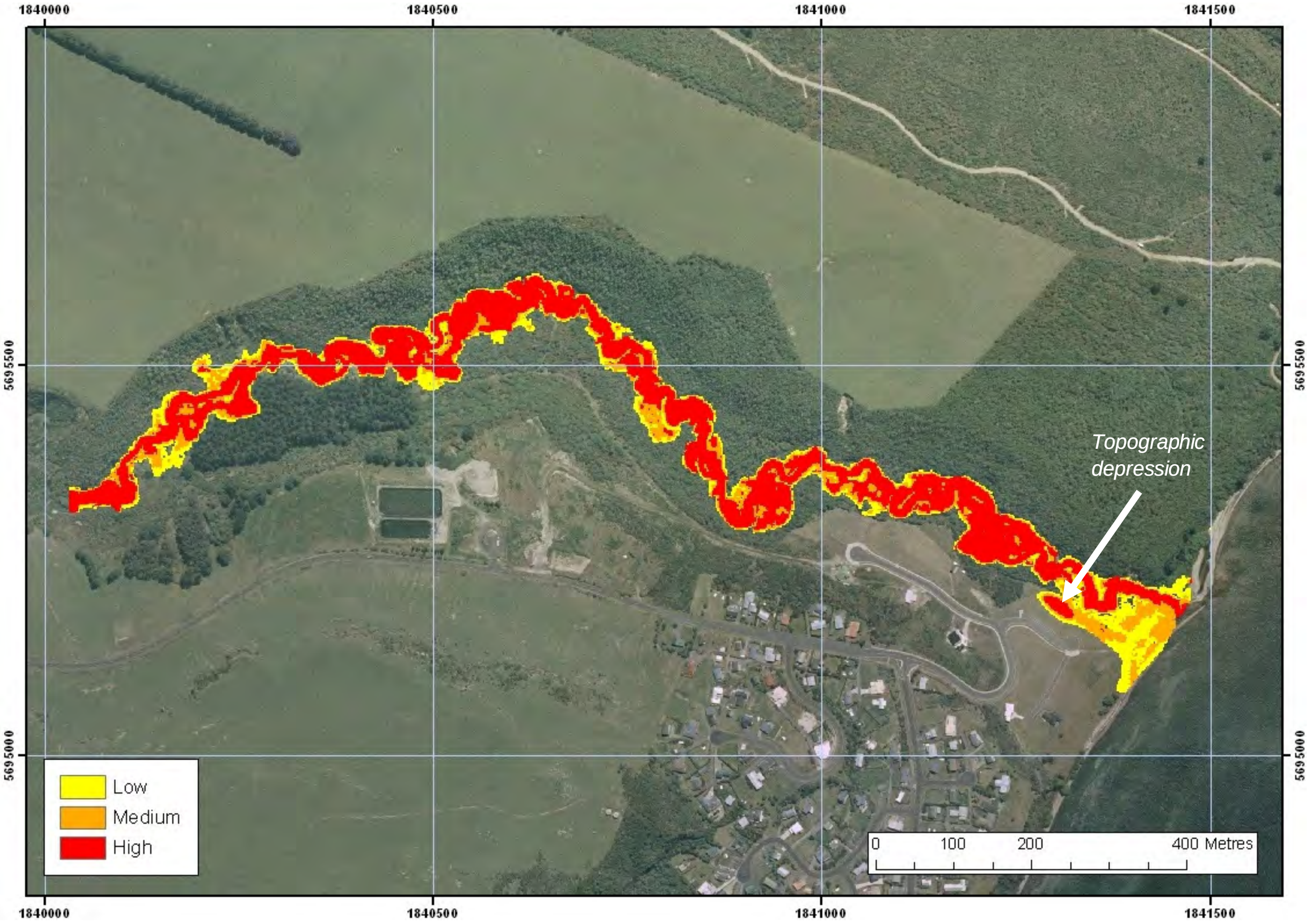


Figure 7.4: **Flood hazard during a 100-year ARI flood event in Whareroa Stream, adjusted for the effects of climate change. Lake level was assumed to be at 357.5m.**

The MIKE FLOOD hydraulic model was been created to simulate the velocity, extent, and depth of flood water during extreme events as accurately as possible, and to allow the potential impact of flood flows to be quantified. Now that the model has been established, it can be re-tuned quickly to explore any scenario; including climate change, channel works, flood protection options etc.

7.4 Summary

A MIKE FLOOD hydraulic model was established for the Whareroa Stream covering a 2.5km long reach upstream of Lake Taupo. The topography of the channel and flood plain is based on LiDAR data. No information was available with which to calibrate the model. The best estimates where made when selecting model parameters based on expert advice and calibrated models for other tributaries draining into Lake Taupo. A comprehensive set of sensitivity analyses was undertaken to confirm the appropriateness and reliability of the model. The model is most sensitive to channel roughness and geometry. The model was then used to estimate various flood parameters during a 100-year ARI event, adjusted for the effects of climate change.

8 Conclusion

Flooding in the Whareroa Stream is a persistent and ongoing process. The main river channel is constantly evolving over the lower reaches of the river, as can be seen by the old bends visible from the aerial photographs and flood inundation maps.

The risk of flooding, and the potential extent and depth of inundation of land near the Whareroa Stream, however is not a simple problem. A number of factors combine to control the water level and extent of inundation during any particular flood event. These factors include: the rainstorm event, climate regime, land use, antecedent moisture conditions, lake level, channel condition, and the amount and character of any sediment entrained. The same water level can be reached by the coincidence of a number of different factors. Likewise, the same rainstorm event will not always generate the same magnitude flood. In addition, the potential effect of a particular flood on the landscape varies with topography, runoff, lake level, flood mitigation measures, and the level of capital investment and development. The magnitude and extent of any flooding is therefore both a temporal and spatial problem. Fundamentally, however, flooding has become a human problem.

8.1 The river flood hazard

Analysis of a series of flood hydrographs for the Whareroa Stream indicate a consistent pattern of response. Rainstorm durations leading to significant flood events are usually 6-12 hours in duration. The resulting floods typically have one major peak, and the body of the flood lasts for about 24-36 hours.

A 100-year ARI event, increased to allow for the predicted effects of climate change, (i.e., 43m^3/s) was modelled. The flood would likely cause the river to breach its main channel and shortcut across bends along the 2.5km reach modelled. The fastest and deepest flood waters will be within the existing active channel, and some of the older abandoned river channels and secondary flow paths. The majority of the area away from the active flow paths would be subject to relatively low velocities and shallow inundation.

When both the depth and velocity of flood water are considered together, the majority of the area that would be inundated will be subject to a relatively low flood hazard. The risks to life and property in the urbanised area are generally low. The highest flood hazard is within the currently active river channel, and within the secondary flow paths across the Whareroa flood plain.

8.2 The combined flood hazard

The total flood hazard in the vicinity of the Whareroa Stream is the result of the combined effect of the risk from high lake levels and waves; and the risk from overbank flows from the stream. The frequency of, and risk from, high lake levels and waves was discussed in detail in McConchie *et al.* (2008).

The detailed modelling discussed in this report has identified those areas at risk from flooding of the Whareroa Stream. It also shows how the catchment, and therefore flooding, may be affected by land use and climate change. Although the total area that may be affected by flooding may increase slightly in response to global warming and higher lake levels, the outer boundary of the flood extent changes little. The ‘extra’ water that results from these more extreme scenarios is generally accommodated by flooding within the current flood limits.

8.3 Area affected

The combined flood hazard resulting from both high lake and river levels depends on the topography of the land as well as the water levels. Therefore, the water levels were overlaid on a LiDAR-derived terrain model to determine the location of flooding, and depth of inundation. Maps of the combined flood hazard defined in the above manner are included in the data appendix to this report. These maps will help form a basis for developing robust, long term, hazard management policies.

8.4 Uncertainty

Any estimate of the magnitude of the design flood will only ever be an estimate. There is no way of determining the exact magnitude of any potential event; even after the event. This issue of uncertainty of the design flood estimate is problematic. The uncertainty is actually a function of a wide range of variables, including: the accuracy of water level measurement; flow gaugings; the rating curve, especially for high magnitude flows; the length of record; the appropriateness of the statistical distribution; how well the chosen distribution models the annual maxima series; and the appropriateness of the flow record in representing the future rainfall-runoff relationship. Therefore while recognising the uncertainty is relatively easy, quantifying it is not.

With respect to flood studies this uncertainty can be accommodated by adopting conservative, but still realistic and reasonable, estimates for the magnitudes of the various design flood events.

Despite the uncertainty inherent in estimating the magnitudes of more extreme design flood events, a sensitivity analysis of the various Taupō flood studies indicates that the extents and depths of inundation are not extremely sensitive to the exact flood magnitude used in the model. Any uncertainty in the design flood estimates is likely to have less effect on the result than other uncertainties in the hydraulic modelling.

With respect to Whareroa Stream, the magnitude of the design flood hydrographs had to be ‘modelled’ rather than extrapolated from an appropriate annual maxima series as the annual flood maxima series covers only about 16 years.

The scaling of the annual flood maxima from adjacent catchments provides a useful ‘first approximation’ of the magnitudes of design floods. The regional flood estimation procedure (Pearson & McKerchar, 1989) could be used to provide additional support for the likely magnitude of the design floods.

The design flood estimates for Whareroa Stream are likely to be very conservative i.e. higher flows are modelled than may likely be experienced.

Given the preliminary and ‘screening’ nature of these flood studies, and the fact that the Whareroa flood models could not be calibrated, it is considered that conservative flood estimates, and consequently flood extents, velocities and depth, are reasonable. For example, it will be easier to ‘retract’ or ‘reduce’ flood hazard areas as more information becomes available than to try to ‘expand’ them once development has taken place.

The regional flood frequency indices are currently being revised and updated to include all information collected since the original report (i.e. since 1985). Once these new indices are available it would be appropriate to undertake a revision of the design flood estimates for Whareroa Stream. This would add to the robustness and consistency of design flood estimates derived from the short annual flood maxima series available from Whareroa Stream.

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10 Glossary

Hazard – something that threatens a person's well-being.

Inundate – to cover usually dry land with flood waters.

LiDAR – (Light Detection and Ranging) is an optical remote sensing technology that measures properties of scattered light to find the range and/or other information i.e., elevation of a distant target. The usual method of determining distance to an object or surface is to use laser pulses.

masl – metres above sea level (amsl – height above mean sea level).

Return period (2.33-year) – a return period is also known as a recurrence interval. It is an estimate of the likelihood of an event of a certain size. It is a statistical measurement denoting the average recurrence interval over an extended period of time. The 2.33-year return period flood is often used as a measure of the mean annual flood.

Risk – The possibility of suffering harm or hurt.

Seiche – a wave that oscillates in lakes, bays, or gulfs from a few minutes to a few hours as a result of seismic or atmospheric disturbances, or variations in level.

Tectonic deformation – changes in the landscape caused by tectonic (internal to the earth) stresses.

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