OPUS

Taupo District Flood Hazard Study

KURATAU RIVER

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

July 2011

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1 Overview

1.1 Purpose

Under the Resource Management Act (1991), Regional Councils and other 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, 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 flood risk 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 posed by the Kuratau River. Of particular concern is the flood risk to the Kuratau settlement which is adjacent to the 1-1.5km channel immediately upstream of Lake Taupo. The flood risk was analysed with the aid of two-dimensional computational hydraulic modelling.

2 Kuratau catchment

2.1 Description of the Kuratau catchment

The Kuratau River flows generally eastwards, draining the slopes of the Pureora Forest Park and Pukepoto Forest before turning northeast to reach Lake Kuratau. From there it flows east a further 5km before flowing into the southwest of Lake Taupo, close to the settlement of Kuratau. The catchment contains two main tributaries; the Mangaongoki Stream and the Kuratau River (Figure 2.1).

Figure 2.1: **Location of the Kuratau catchment.**

Lake Kuratau was formed following construction of a dam across a gorge in the river to supply water to the Kuratau Hydro Station which was commissioned in 1962. The Kuratau power station, owned by King Country Energy, has a head of 64m and a mean annual output of 29GWh. Being essentially a flooded river valley, the volume of Lake Kuratau is relatively small, even though the lake covers approximately 100ha. For example, when inflows are about 4m³/s, the lake would be 'drained' if the station operated at capacity for between 36 and 48 hours. The consented operating range is only 2.61m although this is not fully utilised in the day to day operation of the station. The lake therefore provides little attenuation of the passage of flood peaks passing down the river. For example, if there is 300mm of storage prior to a flood event, the lake only has the capacity to retain a short duration thunderstorm with a flood peak of about 20m³/s. Any event either larger or longer than this will pass through the lake and over the spillway to the lower valley.

The northern part of the Kuratau catchment within the Pureora Forest State Park is underlain by mudstone, fine and coarse siltstone, and sandstone. The eastern, lower elevation area has a greater concentration of breccias older than the Taupo breccias (Figure 2.2). The majority of the catchment (33%) is eroded into Taupo and Kaharoa breccia, and volcanic alluvium. These rocks are composed of broken fragments of minerals and rock cemented together or reshaped by water and deposited in valley basins. Lavas, ignimbrite and other hard volcanic rocks underlie 26% of the catchment, while 20% of the catchment is comprised of ashes older than Taupo pumice. All these rocks are the result of volcanic activity from the Taupo Volcanic Zone which runs from Mt Ruapehu in the south to White Island in the Bay of Plenty.

The soils on the slopes to the north are predominately humose orthic podzols (27%) and podzolic orthic pumice soils (26%). Podzol soils often occur in areas of high rainfall and have low fertility, low base saturation, and are strongly acidic. The pumice soils, however, have a low clay content and are mostly gravelly soils or pumice sand. They have low soil strengths, high macroporosity, deep rooting depth, and low strength when disturbed. The impeded pumice soils (12%) occur when there is a subsoil layer that restricts the downward movement of water and roots. The other dominant soil type in the Kuratau catchment is the typic orthic allophanic soils (12%). These soils are dominated by allophane minerals and are predominantly found in North Island volcanic ash, and from the weathering of other volcanic rocks. The soil is porous, with a low density structure and weak strength (Figure 2.3).

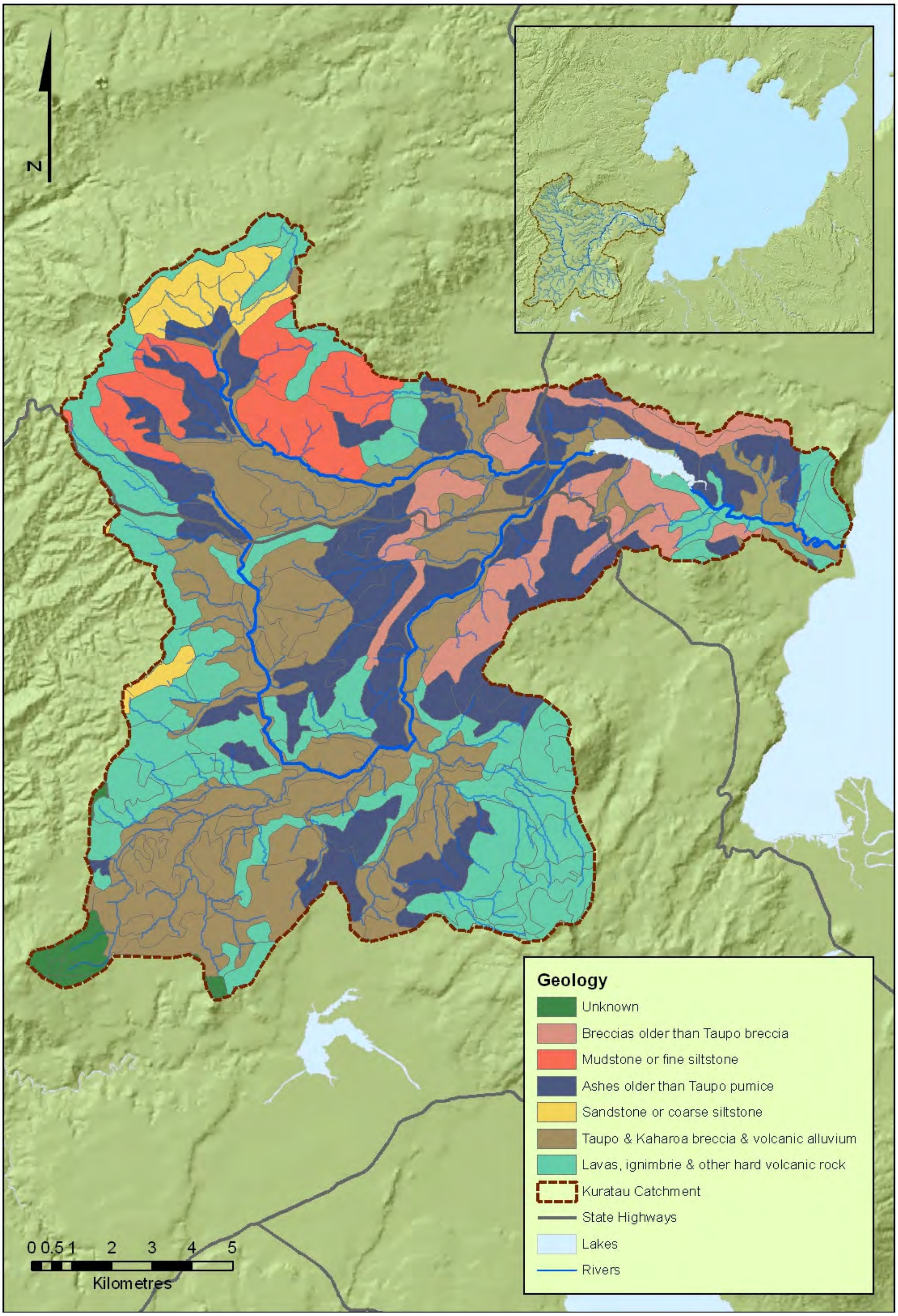

Figure 2.2: **Catchment geology of the Kuratau River.**

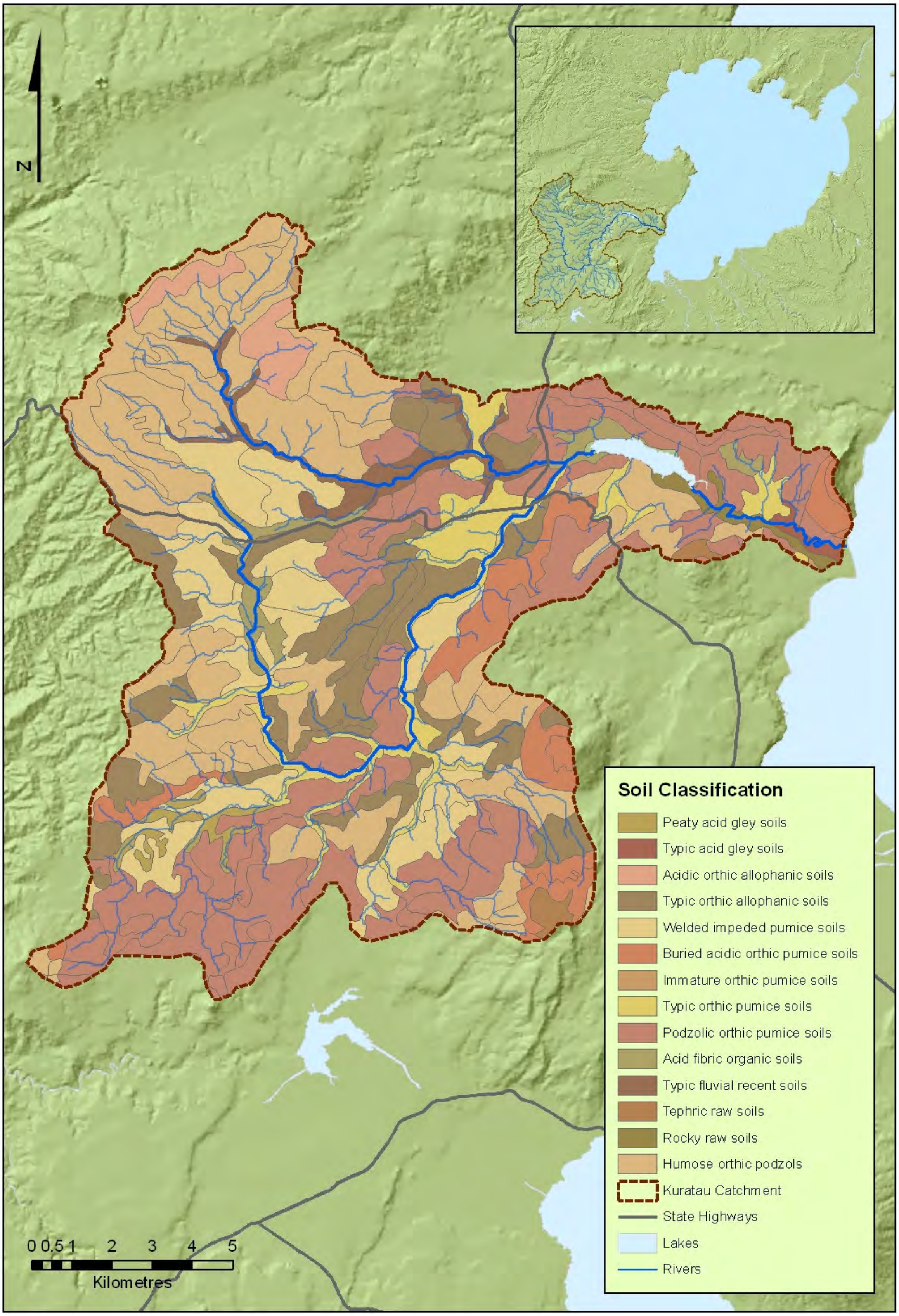

Figure 2.3: **Soils of the Kuratau catchment.**

Erosion is common in the upper catchment because of the soft unconsolidated nature of the volcanic deposits, steep slopes, and high rainfall. This provides a large volume of material which can be transported downslope and into the river system. The steep terrain of the upper catchment allows the river to transport most of this sediment downstream (Figure 2.4). The Kuratau River consequently carries a relatively high sediment load. In the lower catchment the channel slope decreases, reducing the flow velocity. As a result, the energy of the river decreases reducing its ability to transport sediment. Consequently, a considerable volume of material is deposited within Lake Kuratau, and on the lower flood plain. Sediment deposited in Lake Taupo forms a delta. Changes to the river channel, and aggradation of the delta, can be caused by both natural and anthropogenic processes. Floods, eruptions and tectonic uplift can also increase the sediment supply to the river (Figure 2.5).

The Kuratau catchment has a very steep rainfall gradient. The mean annual rainfall in the headwaters, the area likely to produce the greatest runoff, reaches 2240mm near the Pukepoto Forest (973masl) to the west, and about 1500mm in the Pureora State Forest Park (1036masl). Rainfall then decreases rapidly with altitude to be only approximately 1260mm at Lake Taupo. Those areas which experience the highest annual rainfalls are also likely to experience the greatest rainfall intensities. Runoff from these areas therefore has a critical affect on the flood magnitude and risk in the lower catchment.

Much of the Kuratau catchment is under some type of forest or scrub cover (58%). This includes mixed native scrub which covers 20% of the catchment. Pasture covers an additional 30% of the catchment (Figure 2.6). Land use within the catchment is summarised in Table 2.1 and Figure 2.7.

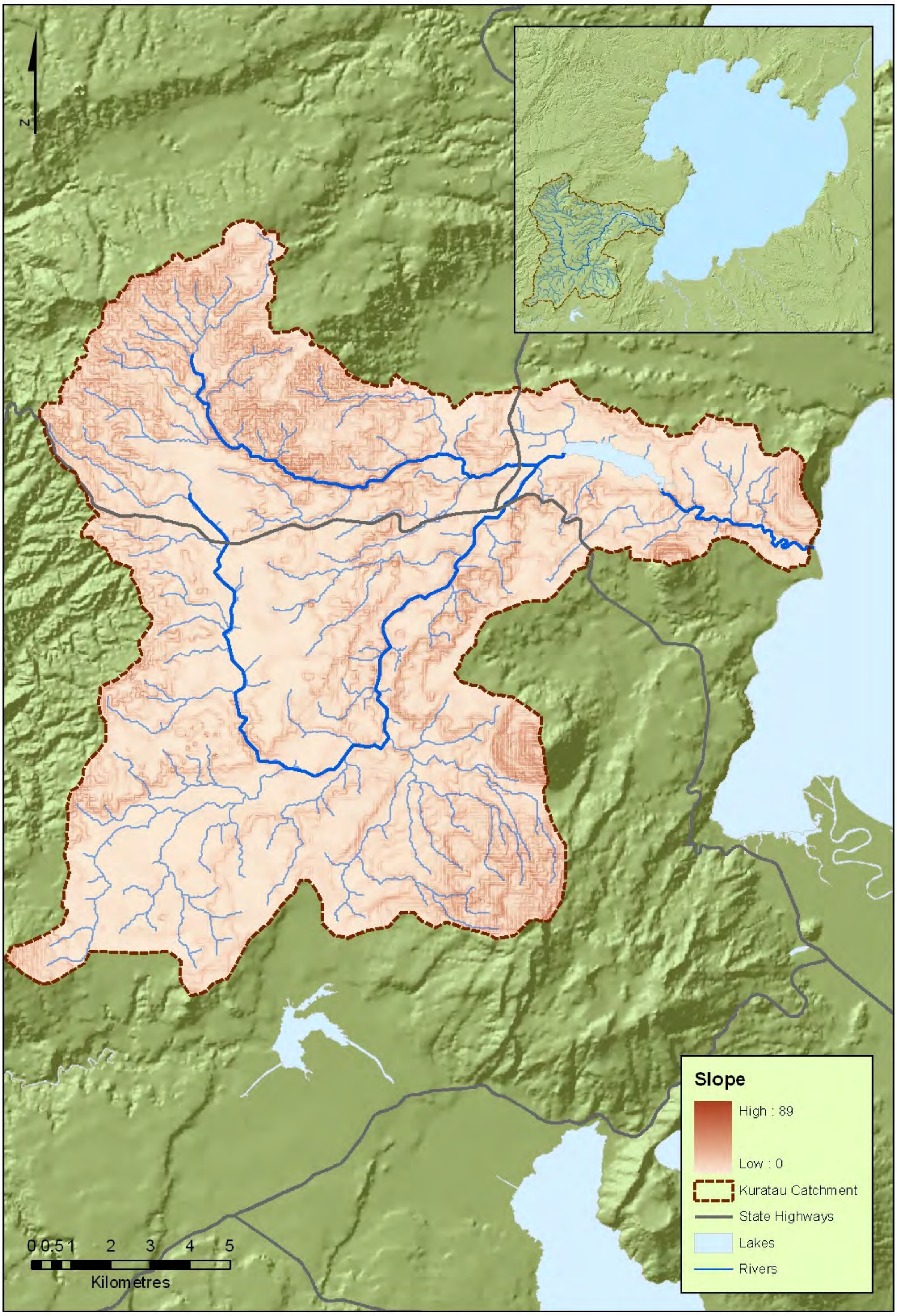

Figure 2.4: Slope within the Kuratau catchment.

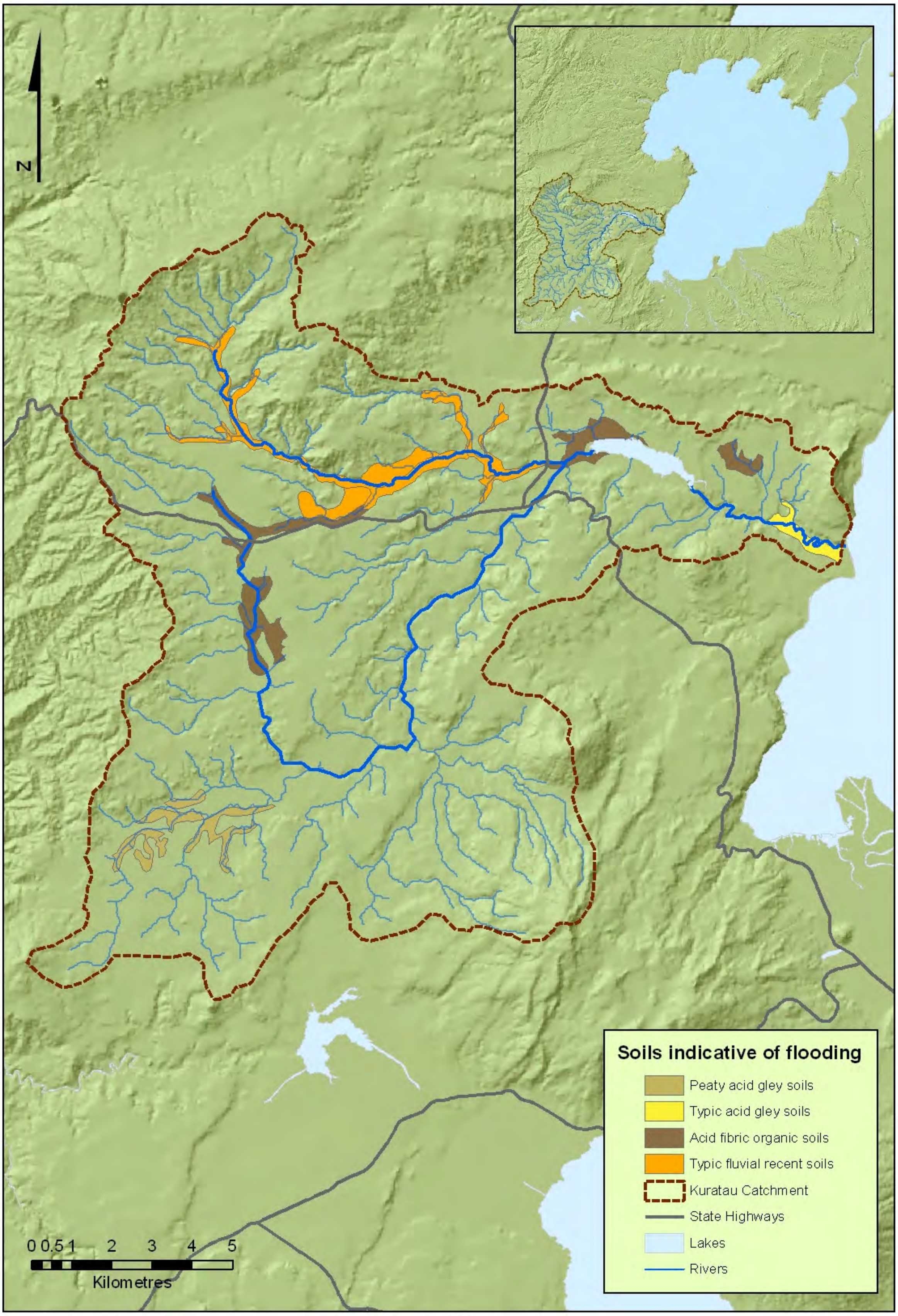

Figure 2.5: Flood deposits within the Kuratau catchment.

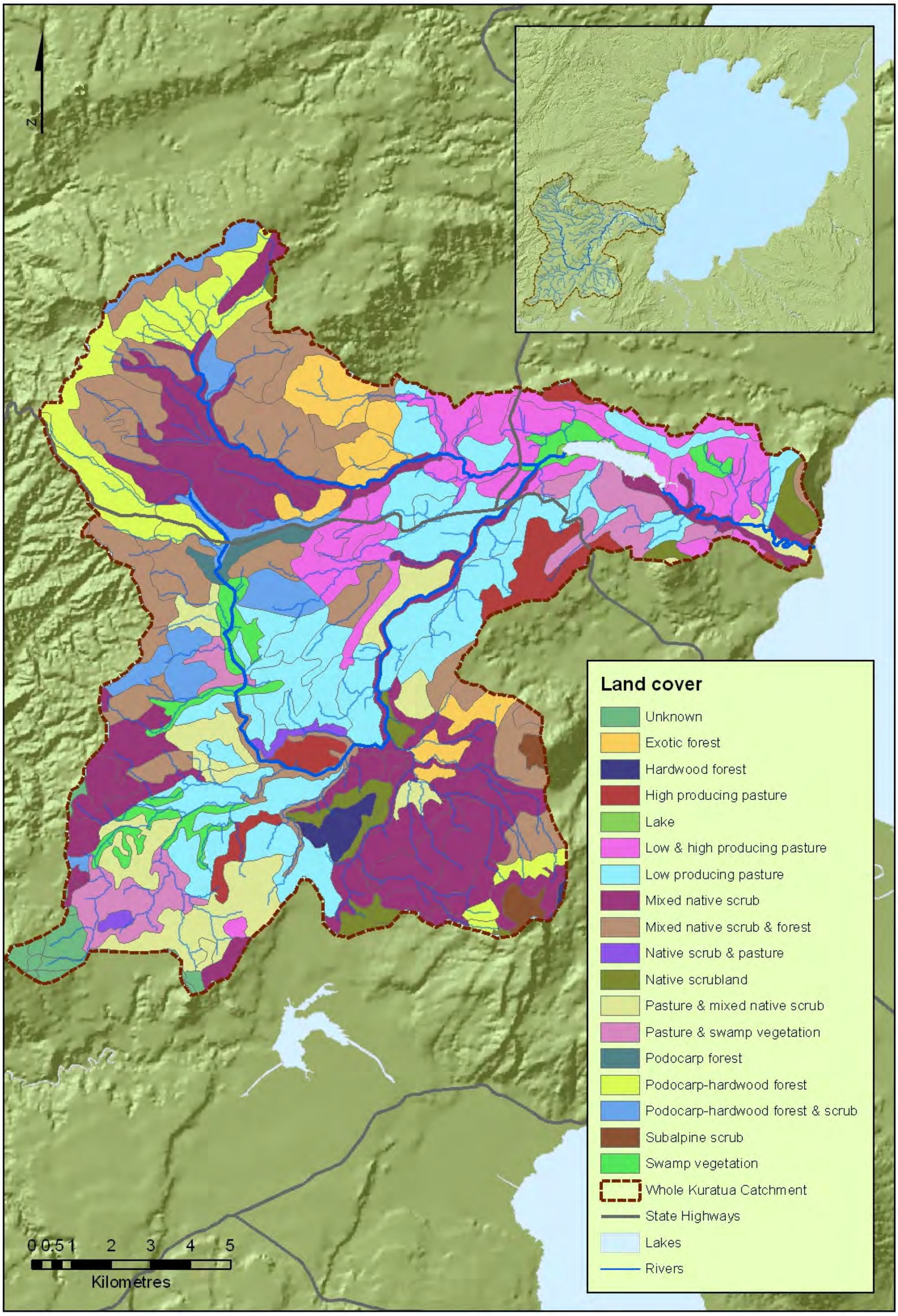

Figure 2.6: **Vegetation cover within the Kuratau catchment.**

Table 2.1: Land use in the Kuratau River catchment.

Land use	Percentage
Unknown	1.25
Exotic forest	4.07
High producing pasture	2.99
Low and high producing pasture	9.23
Low producing pasture	17.61
Mixed native scrub	19.83
Mixed native scrub and forest	15.57
Native scrubland	2.18
Pasture and mixed native scrub	6.82
Pasture and swamp vegetation	4.42
Podocarp-hardwood forest	6.03
Podocarp-hardwood forest and scrub	3.84
Swamp vegetation	3.04
Total	**99.88%**

Note: Only those land use classes occupying at least 1% of the catchment are included in the above table.

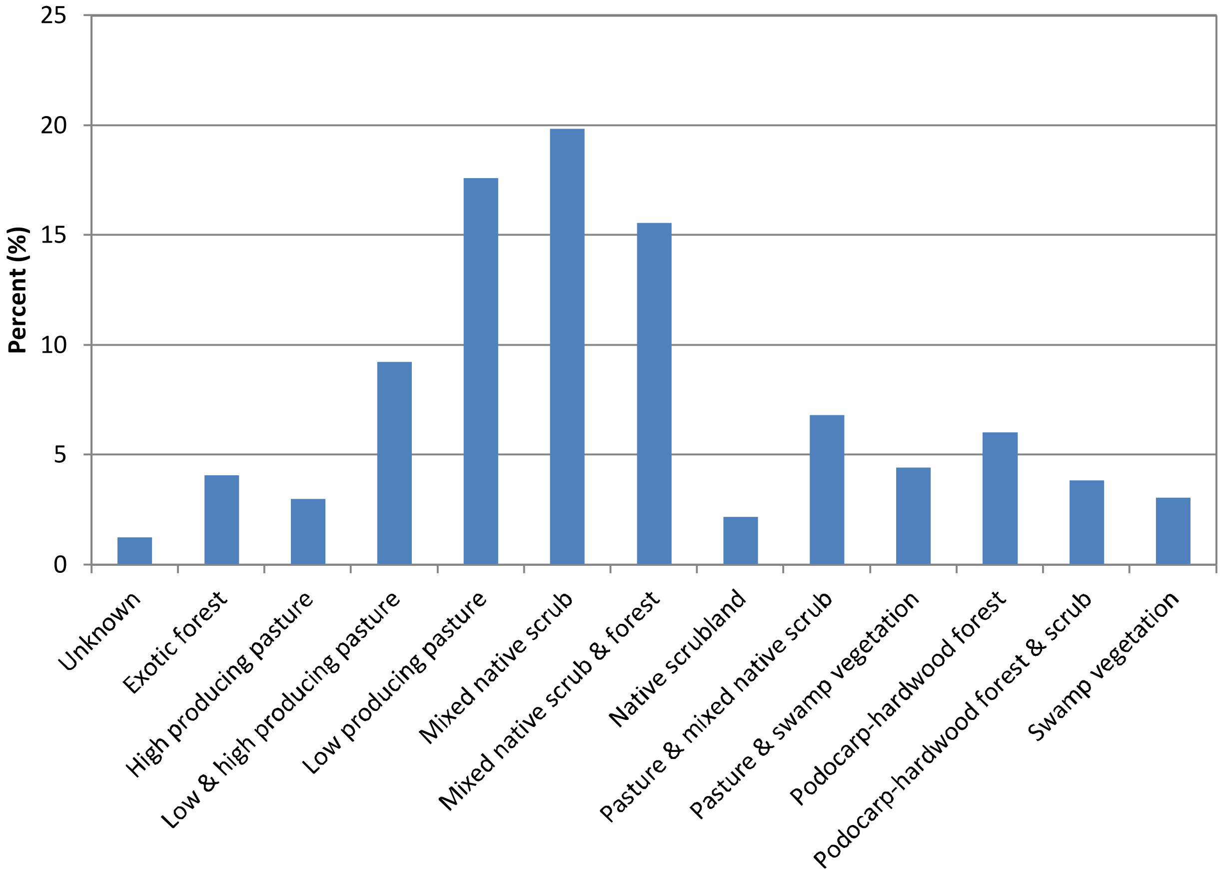

Figure 2.7: Distribution of land uses occupying at least 1% of the catchment.

2.2 Study area

The greatest flood hazard within the Kuratau catchment exists on the flood plain of the lower valley. The river flows from Lake Kuratau and down a relatively steep and narrow channel. The river then transitions to a wider channel between relatively low banks composed of alluvium over the last 1km before flowing into Lake Taupo. This low-lying area near Lake Taupo has the greatest capital investment, and density of people and infrastructure, within the catchment. Therefore the focus of this flood study is the area marked on Figure 2.8, i.e., the lower 4km of the Kuratau River.

Figure 2.8: Kuratau River study area.

3 Flow regime of the Kuratau River

3.1 Kuratau River @ SH41 & synthetic flow record for the Kuratau River at the mouth

Flows of the Kuratau River have been continuously recorded since November 1978 at a gauge located at the SH41 Bridge (Figure 3.1). There have been a number of other recorder sites within the catchment, but the one at SH41 has the longest record. The other sites all have short-term records. There are a number of significant tributaries downstream of this recorder site. This site, which records the flow from a catchment of approximately 119km^2, therefore needs to be scaled to account for catchment inflows below the SH41 recorder.

Previous work (McKerchar and Pearson, 1989) has shown that flood magnitudes in New Zealand vary as a function of catchment area to the power of 0.8, rather than simply by catchment area. While the exact reasons for this have not be discussed, it is likely to relate to the average rainfall and storm intensity which both decrease with increasing catchment size.

The flows measured in the Kuratau River at the SH41 Bridge therefore need to be scaled by a function of Area$^{0.8}$ to provide an estimate of flows that could potentially affect the lower valley, flood plain, and at the river mouth. Given that the total catchment area of the Kuratau is 198km^2, while that above the SH41 Bridge is 119km^2, the resulting scale factor is 1.50. The synthetic flow record for the entire Kuratau catchment draining into Lake Taupo is shown in Figure 3.2. This synthetic record should be used for the analysis of the flood risk to the lower Kuratau valley.

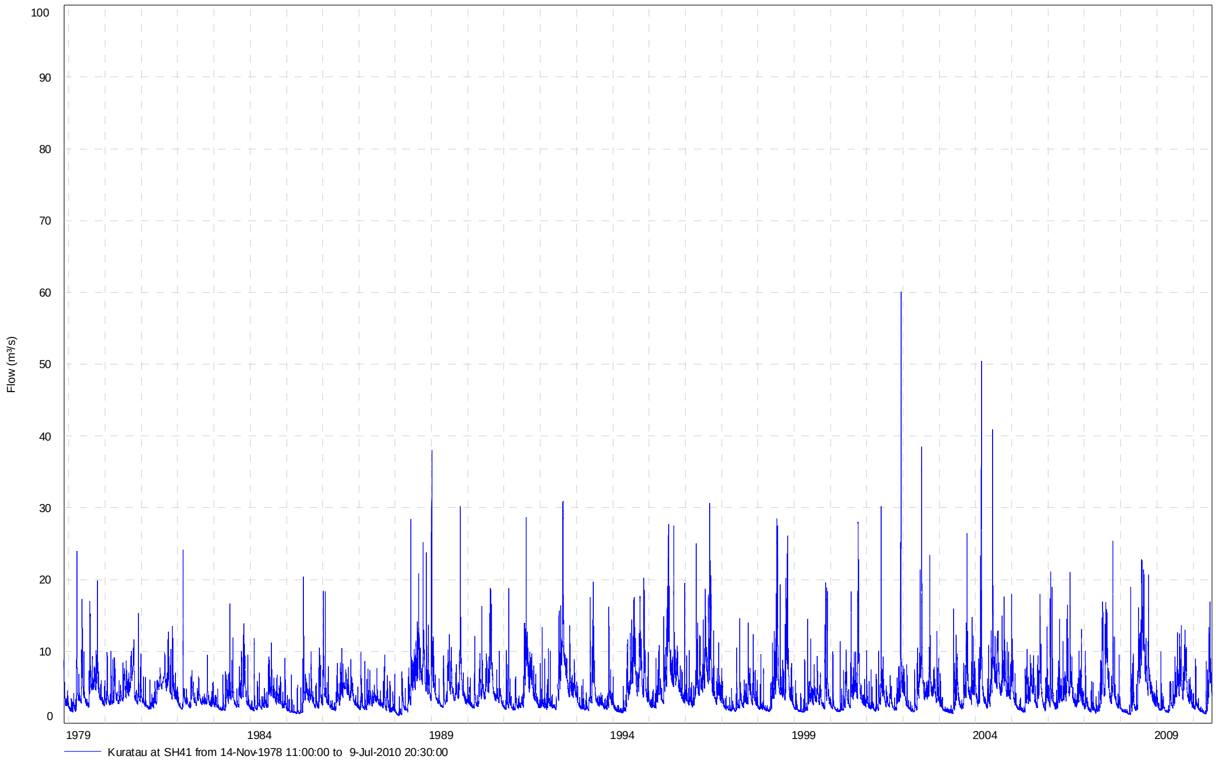

Figure 3.1: Flow record for the Kuratau River @ SH41.

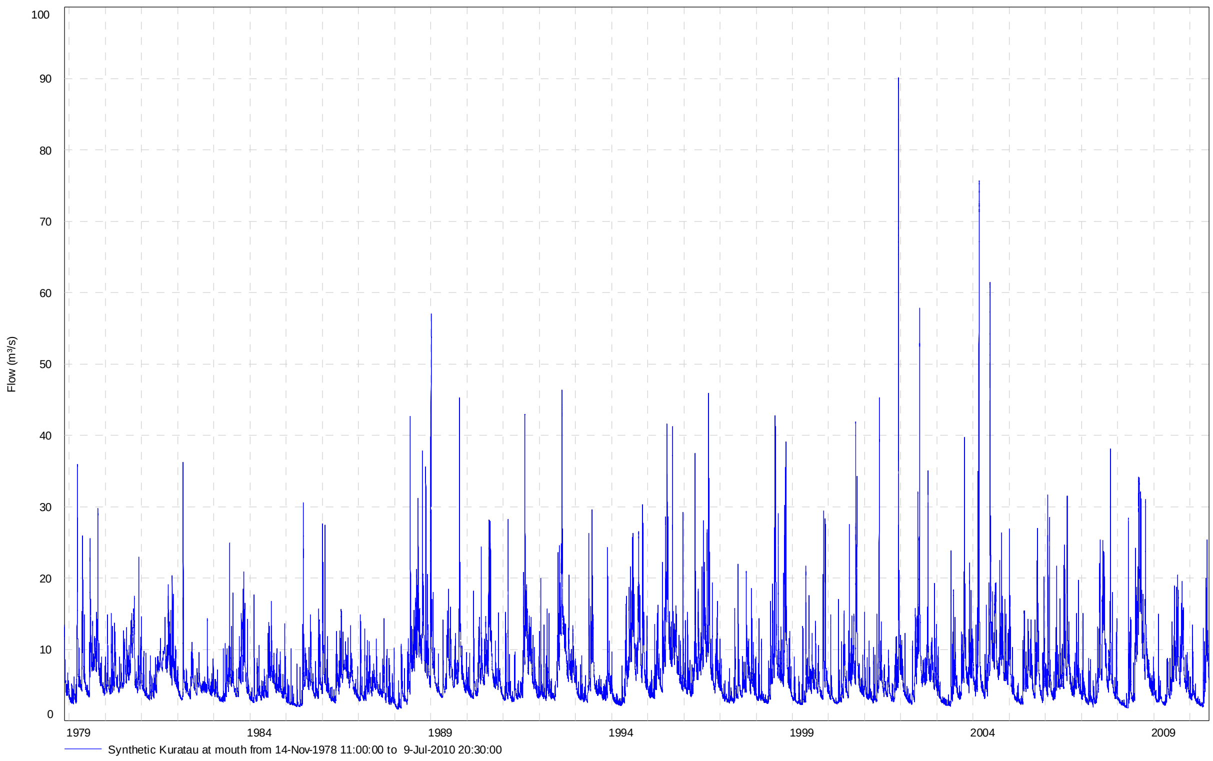

Figure 3.2: Synthetic flow record for the Kuratau River @ mouth.

3.2 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 the analysis exhibit no trends or cycles; and that these 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. Longer records have the potential to be more affected by land use, climate, or other changes.

The flow record shown in Figure 3.2 shows no evidence of either cyclic behaviour (other than annual) or trends over time. Stationarity of the rainfall-runoff relationship and the resulting flow record has therefore been assumed.

3.3 Flow characteristics

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. Given the limited effect of Lake Kuratau on the flow regime, the same conclusions are likely to hold for the synthetic record of flows at the river mouth.

The flow record 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 basis for any flood analyses.

The summary of flow statistics (Table 3.1 and Figure 3.3) show that the Kuratau River 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 3.2 lists the largest flood event in each complete year of record.

Table 3.1: Summary of flow statistics for the Synthetic Kuratau River @ mouth (m^3/s) November 1978-July 2010.

Site	Minimum	Mean	Median	Maximum	Standard deviation	Coefficient of variation
Synthetic Kuratau River @ mouth	1.62	6.38	5.04	90.2	4.49	0.703

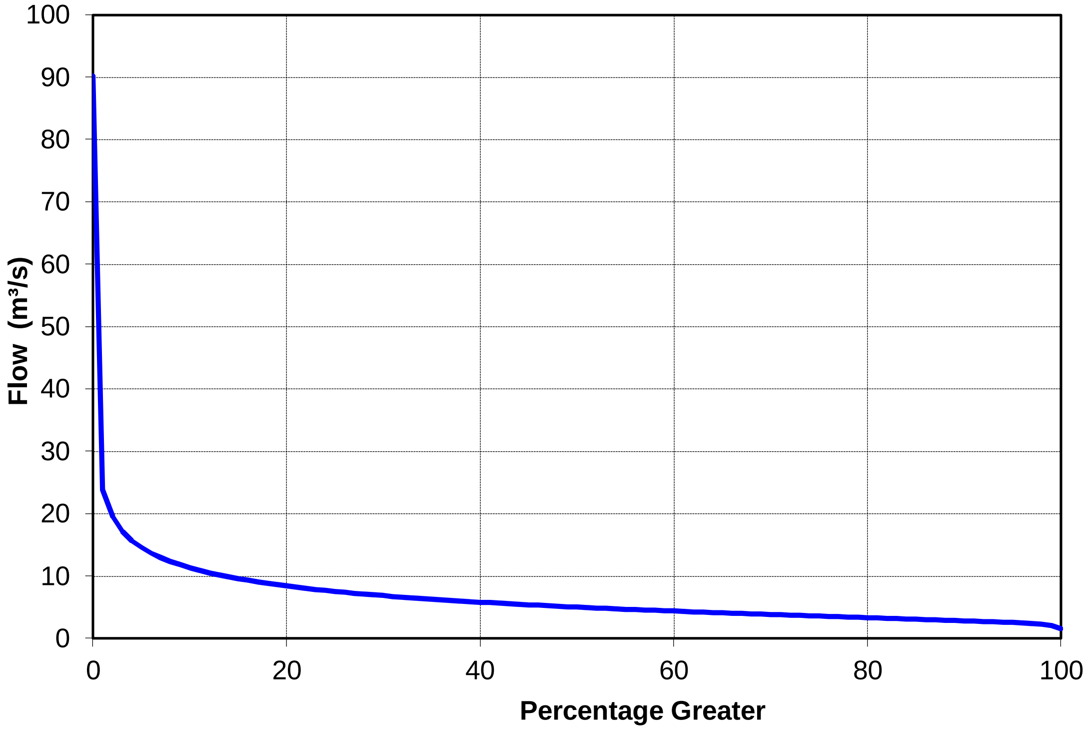

Figure 3.3: Flow duration for the Synthetic Kuratau River @ mouth.

Table 3.2: Annual maximum flows recorded for synthetic Kuratau at mouth 1979-2009.

Rank	Year	Flow (m^3/s)	Rank	Year	Flow (m^3/s)	Rank	Year	Flow (m^3/s)
1	2001	90.2	**12**	2003	39.7	**24**	2005	27.0
2	2004	75.7	**13**	2007	38.1	**25**	2010*	25.4
3	2002	57.8	**14**	1982	36.2	**26**	1983	24.9
4	1989	57.1	**15**	1979	36.0	**27**	1980	22.9
5	1992	46.4	**16**	2008	34.2	**28**	1997	22.0
6	1996	45.9	**17**	2006	31.7	**29**	2009	20.4
7	1991	43.0	**18**	1985	30.6	**30**	1981	20.4
8	1998	42.8	**19**	1994	30.3	**31**	1984	17.7
9	1988	42.7	**20**	1993	29.6	**32**	1987	14.9
10	2000	41.9	**21**	1999	29.4			
11	1995	41.6	**23**	1990	28.2			

**Note: 2010 only includes data up until July.*

Figure 3.4 shows the hydrograph for the largest flood on record i.e., 9 December 2001. This hydrograph highlights a number of features of flood events in the Kuratau catchment. In general, it takes rainfall events of approximately 24 hours duration to generate a significant flood.

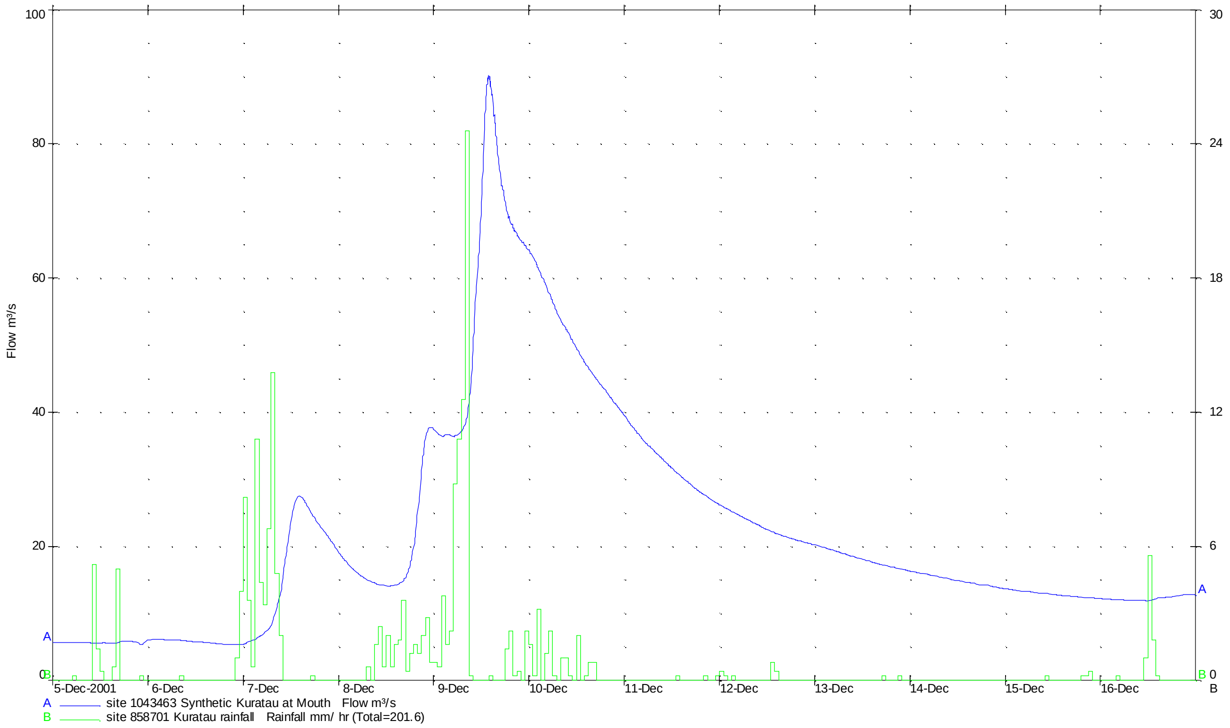

Figure 3.4: Flood hydrograph of the largest flow on record (Rainfall is in mm/hour).

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

Despite the variability of specific storm events, there is a high degree of similarity in flood response. Figure 3.5 compares the four largest flood events on record. In particular, it shows the relatively consistent response of all these large events. With regard to the two largest floods, 2001 followed by 2004, it should be noted that the peak discharges are only approximately 15m³/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 hydrographs for these events are, however, remarkably similar. This indicates that using these events as a basis to scale a flood hydrograph for a 100-year event is appropriate for hydraulic modelling.

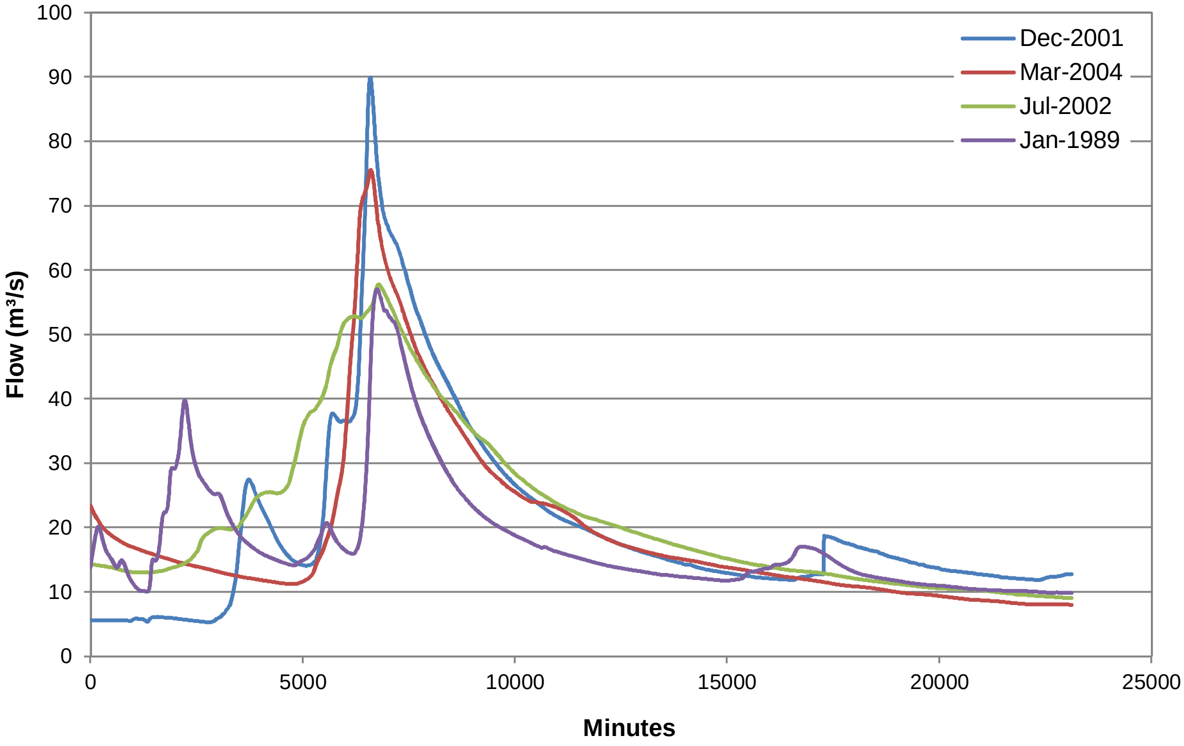

Figure 3.5: **Comparison of the four largest floods on record.**

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

It is important to note that by using the scaled, synthetic, flow record of flood hydrograph for the Kuratau River at its mouth for the hydraulic modelling, it is assumed that all of the water from the entire catchment is input at the upstream limit of the model. Given that there are no major tributaries between the start of the modelled reach and the river mouth, the effect of this is likely to be negligible, although conservative i.e., higher flows within the model than would be expected until the river mouth.

The effects of Lake Kuratau, are also not being taken into account for the hydraulic modelling. Given the limited capacity to store flood waters within the lake, this is reasonable. Also, it is possible that the shape of the hydrograph derived from flow data based on the response at the Kuratau at SH41 monitoring site could be slightly different to that which would occur at the river mouth. That is, the actual time of rise would be longer, the hydrograph would be attenuated, and the effects of the flood would therefore be potentially less than modelled. Consequently, the results of the hydraulic modelling are likely to be conservative i.e., show a greater level of flood risk than actually exists.

3.4 Flood frequency analysis

A frequency analysis was undertaken using the entire length of the synthetic flow record, and using the maximum flood event in each month rather than just the largest flood each year. This approach samples 12 times the number of flood events than when using just the annual flood maxima. It is therefore likely to more accurately reflect the actual distribution of flood events. It should be noted 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. A Wakeby statistical distribution provides the best fit to the data series (Figure 3.6). The results of this analysis are contained in Table 3.3.

Table 3.3: Flood estimates for the synthetic record of the Kuratau River at the mouth (assuming a Wakeby distribution).

Return Period	Kuratau River at mouth 1978-2010 (m^3/s)
2.33 (annual)	38.3
5	49.7
10	60.0
20	70.6
50	85.6
100	97.8
200	110.9
500	129.6

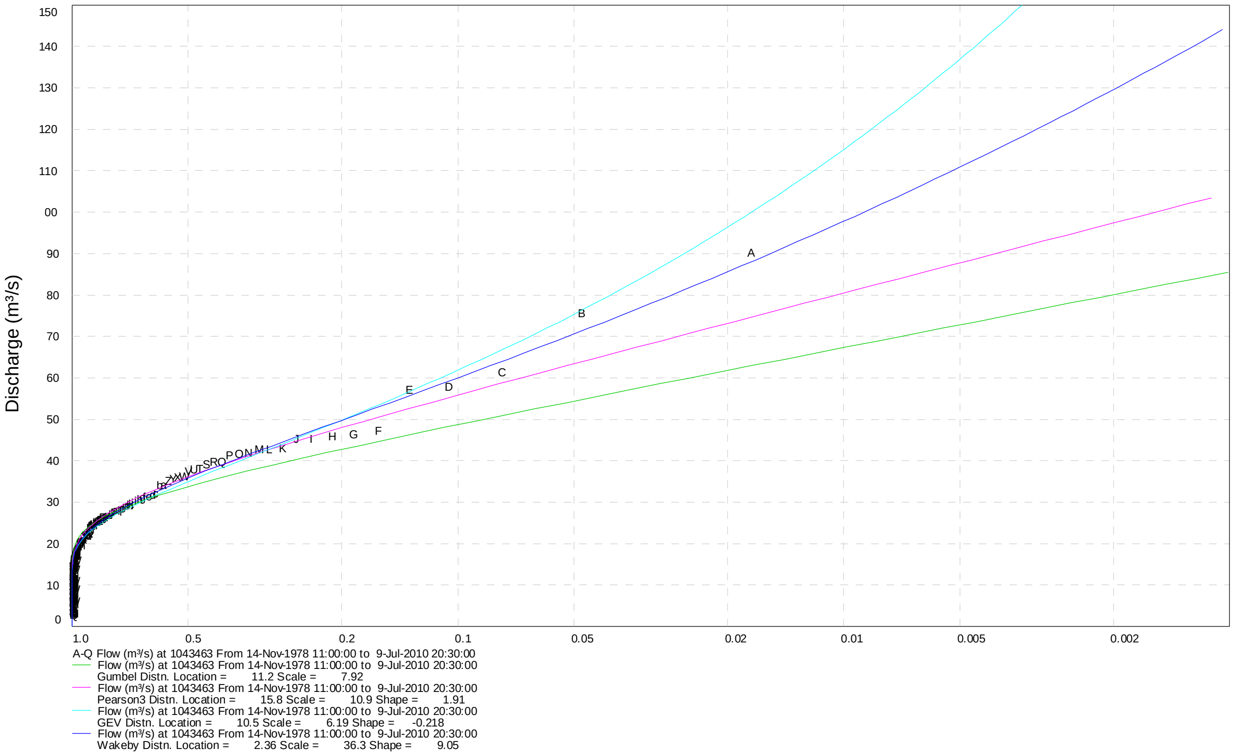

Figure 3.6: Flood frequency analysis of the Kuratau River at mouth.

It should be noted that while the Wakeby distribution provides a reasonable model of the flood maxima, both the more common Gumbel and PE3 distributions do not. The use of the Gumbel and PE3 distributions would produce significantly lower estimates of the flood magnitudes for various return periods. They would also indicate that the two largest flow events on record were extremely rare events i.e., average recurrence intervals (ARIs) of between 200 and 500 years. The use of the Wakeby distribution, and its estimates of the magnitude of the 100-year ARI event, is therefore again likely to be conservative.

3.5 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 3.4.

Given the current land use distribution and land management within the Kuratau catchment, the most extreme land use change would be the conversion of all the forestry lands to pasture. It must be recognised that such a land use change is extremely unlikely given the various constraints on land use within the catchment. There are at present only 8km^2 under some kind of exotic forestry management within the Kuratau catchment (LCDB2 – 2004). Given how little exotic forest there is within the catchment, any conversion to pasture would have very little effect. If anything, a conversion from pasture to forestry would be more likely. This is likely to cause a reduction in the flood peak rather than an increased flood risk.

Table 3.4: **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

3.6 Potential effects of climate change

If predicted global warming eventuates it will 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 (Figure 3.7). These data are summarised in Table 3.5.

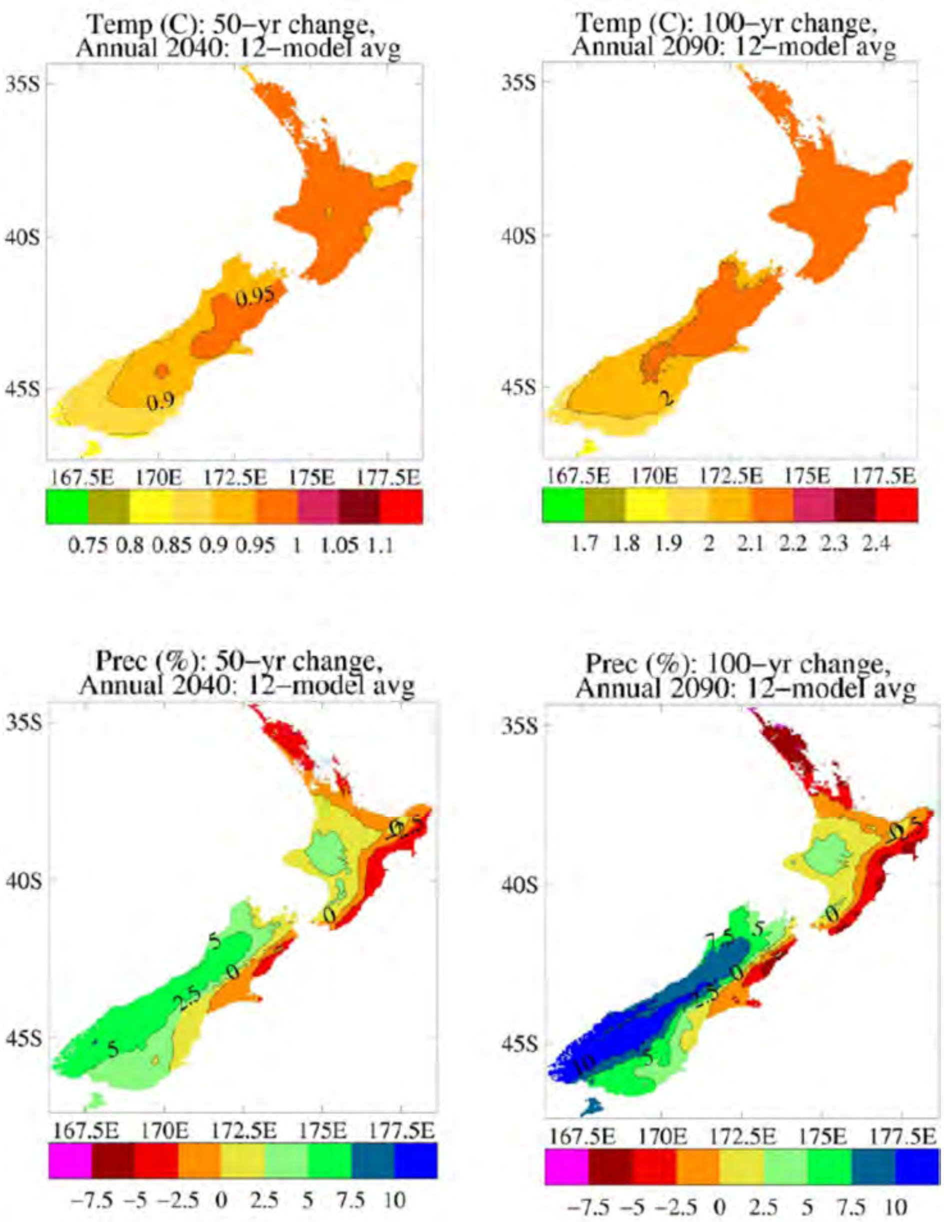

Figure 3.7: **Projections for increases in mean annual temperature and rainfall by 2040 and 2090 relative to 1990; average of 12 climate models for A1B emission scenario (Figure 2.3, Ministry for the Environment, 2008).**

Table 3.5: **Projected increases in mean annual temperature by 2040 and 2090 for the Lake Taupo catchment. (Ministry for the Environment, 2008).**

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 2.2 and 2.3 in Ministry for the Environment (2008). 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.

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 24-hour duration 100-year return period rainfall will increase by 8 percent per degree of projected warming (highlighted in Table 3.6).

Earlier flood analysis in this report has shown that rain-storm durations of 24 hours and longer pose the greatest flood risk in the Kuratau 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 24 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 3.7). 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 3.6: 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: Table 5.2, Ministry for the Environment, 2008.

Table 3.7 Estimated percentage increase in 24-hour rainfall totals for the Kuratau River 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	0.9	3.9	10.3	2.6	9.0	24.1
5	1.1	4.9	13.0	3.2	11.3	30.2
10	1.3	5.7	15.1	3.8	13.2	35.3
20	1.4	6.5	17.3	4.3	15.1	40.3
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 3.7 have been translated directly to percentage increases in flow.

Table 3.8 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 3.7). 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, given the current level of uncertainty. There is sufficient lead time by 2090 that, should the maximum predicted increase appear likely, further mitigation of the flood risk will be possible.

Table 3.8: Increased design flood discharge for the Kuratau River as a result of global warming, using predicted temperature change.

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)	38.3	42.2	41.7
5	49.7	56.2	55.3
10	60.0	69.1	67.9
20	70.6	82.8	81.3
50	85.6	102.0	100.0
100	97.8	116.6	114.2

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 Kuratau River consists of sands and silts in suspension. Because this material is in suspension it is generally transported through the lower reaches of the river 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, flood events can mobilise significant quantities of bed load which is eroded from the catchment below Lake Kuratau. While this material can be transported through the upper reaches, it is often deposited on the lower floodplain. Large floods, such as the 2004 event, erode material from the narrow confined reaches, deepening the channel, and increasing the 'freeboard' before the river banks are overtopped. Where the river is wider and less steep, aggradation may occur.

The deposition or erosion of material within the channel, and changes in channel geometry, can both 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 reduce the flood extent, duration, and inundation depth they are difficult to build into flood hazard model. This is because they are essentially random occurrences in both time and place.

The nature of the material eroded and transported down the Kuratau River, and the steep high-energy nature of flow during flood events, means that sediment deposition is minimal except at the delta in Lake Taupo. Any changes in channel form caused by erosion or deposition are therefore likely to have no quantifiable effect on the flood hazard of the lower valley.

4.2 Lake level

The extent and depth of inundation caused by flooding of the Kuratau River 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 (which acts as the downstream boundary condition) 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 (m)
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 Kuratau flood plain is not a simple function of the peak flood discharge of the river 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 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 in the vicinity of the Kuratau River delta. 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.

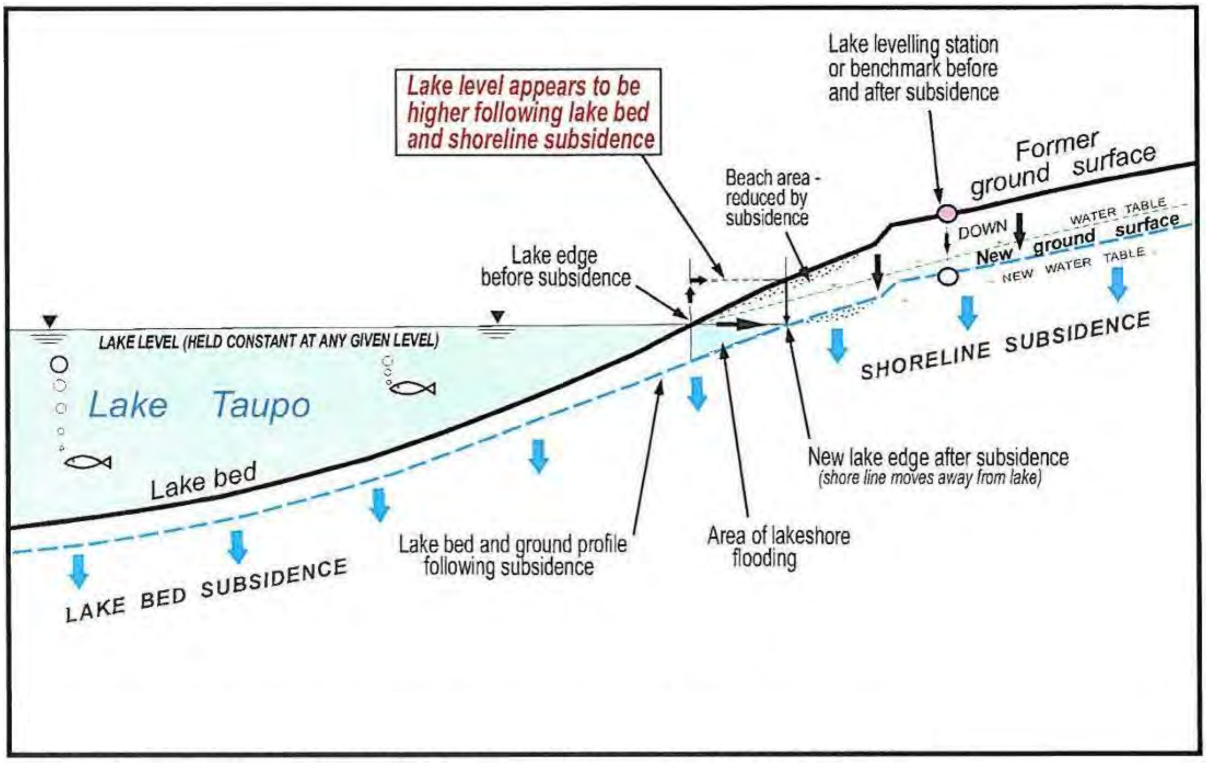

Figure 4.1: Effect of ground level subsidence on relative lake levels (Hancox, 2002).

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, such as the lower Kuratau, the total amount of ground surface lowering over various time periods needs 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 various 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 cumulative 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	-16	-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

Based on this tectonic deformation model, the area in the vicinity of the Kuratau delta is estimated to be subsiding at approximately 1.1mm/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 Kuratau flood plain is likely to subside by 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.

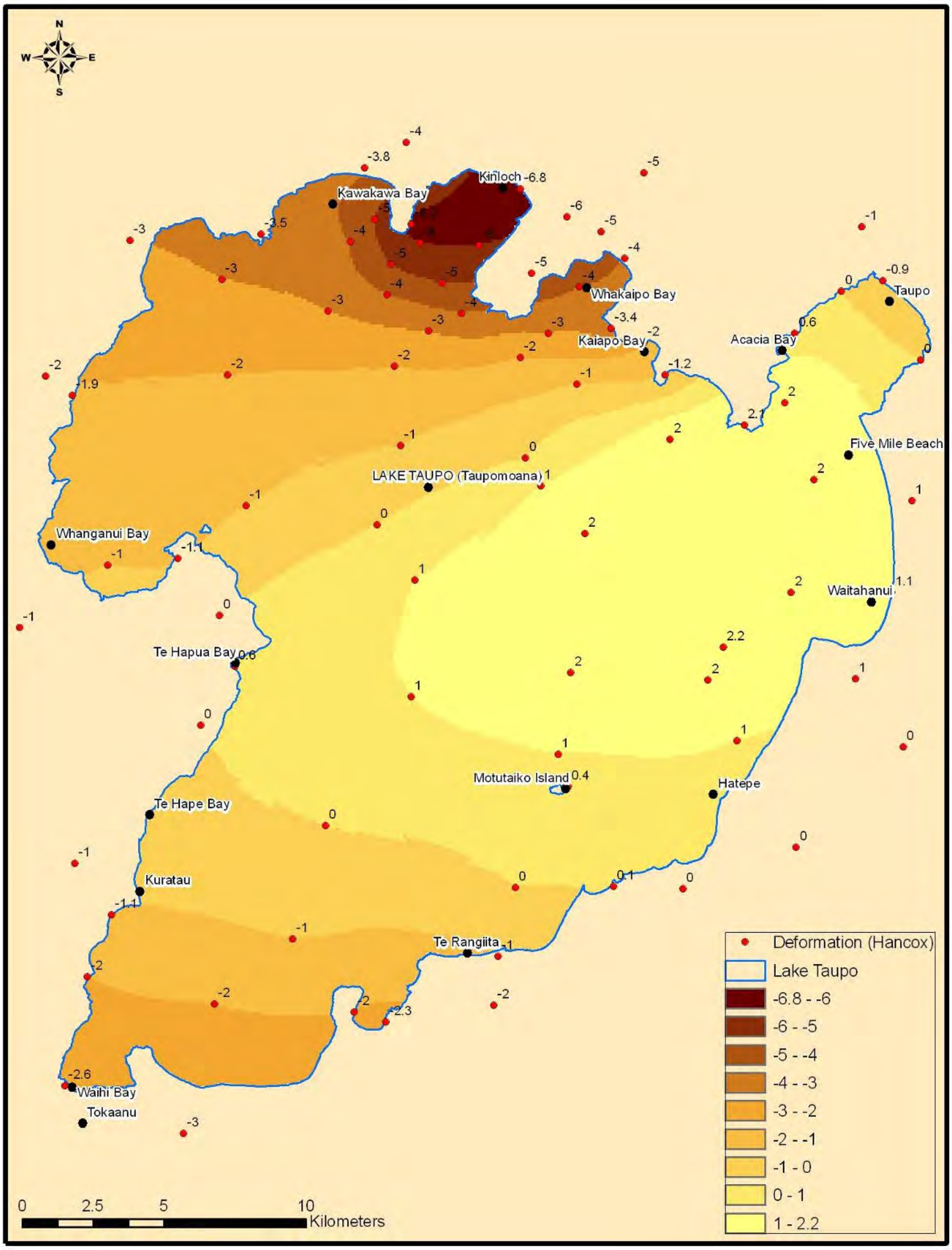

Figure 4.2: **Average rates (mm/yr) of tectonic deformation between 1979 and 2002 (After Hancox, 2002).**

4.4 Waves

Although waves do not affect the river level and flooding directly they can increase the effects of high lake levels. A full discussion of the wave environment and their likely effects in the vicinity of Kuratau River delta is contained in McConchie *et al.,* (2008). The Kuratau River discharges into the Kuratau wave environment (Figure 4.3).

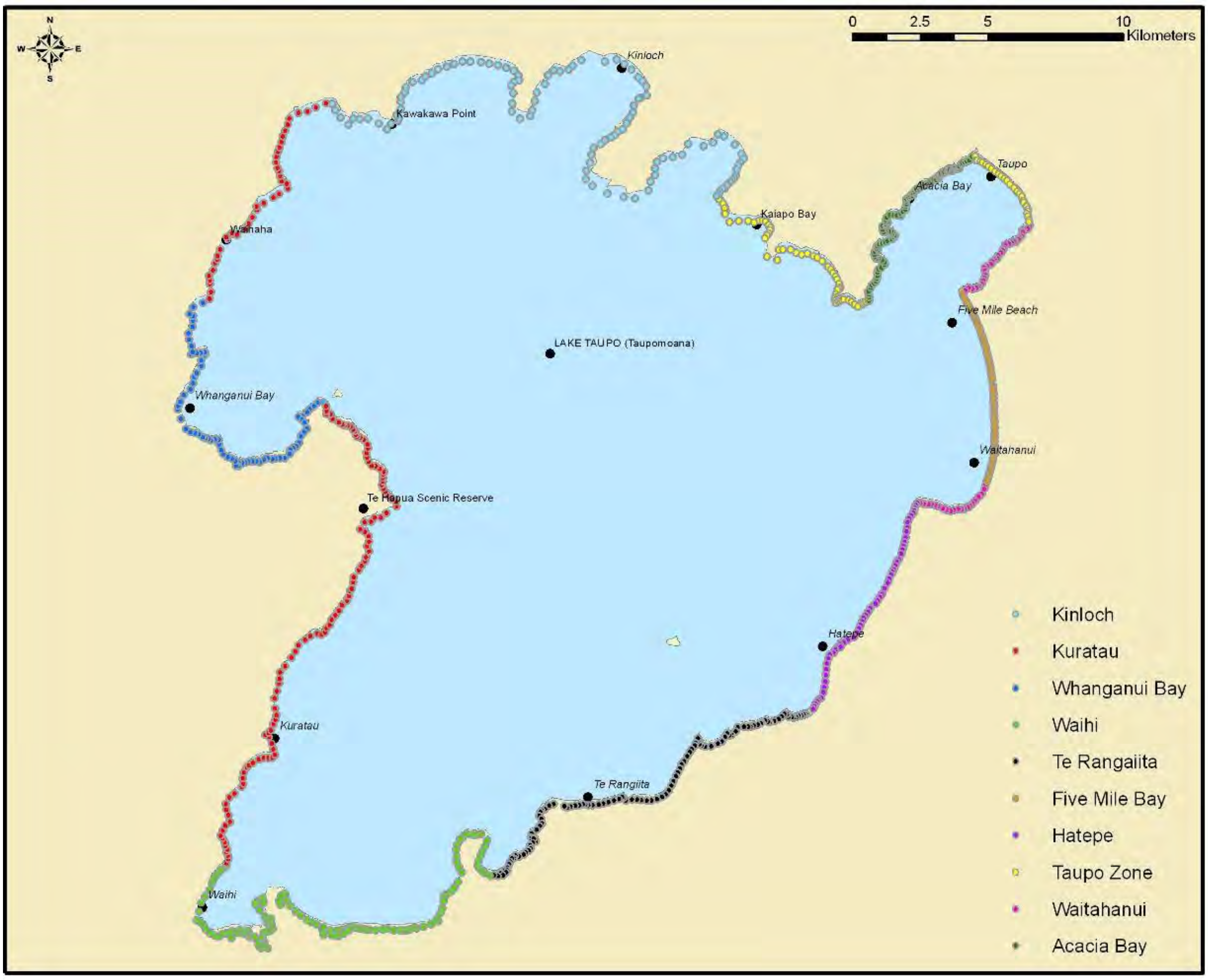

Figure 4.3: **Wave run-up environments around the shore of Lake Taupo.**

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

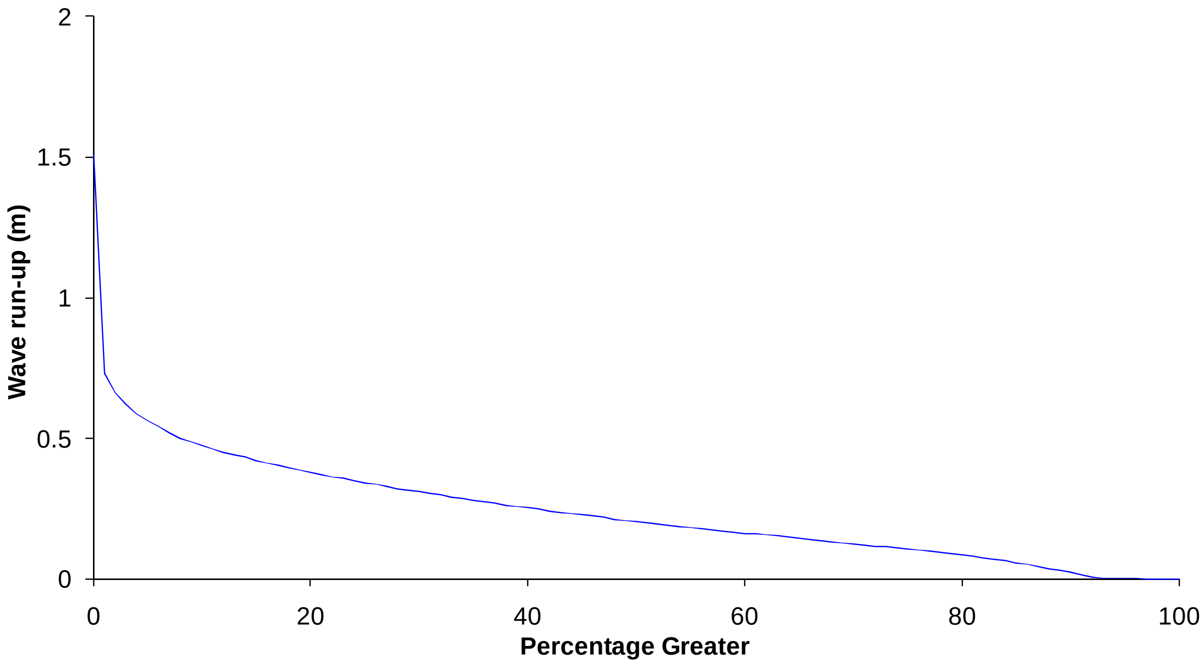

Figure 4.4: Frequency distribution of wave run-up in the Kuratau wave environment.

A frequency analysis of the wave run-up data for Kuratau shows that a Gumbel 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.

Return Period	Wave run up height (m)
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.

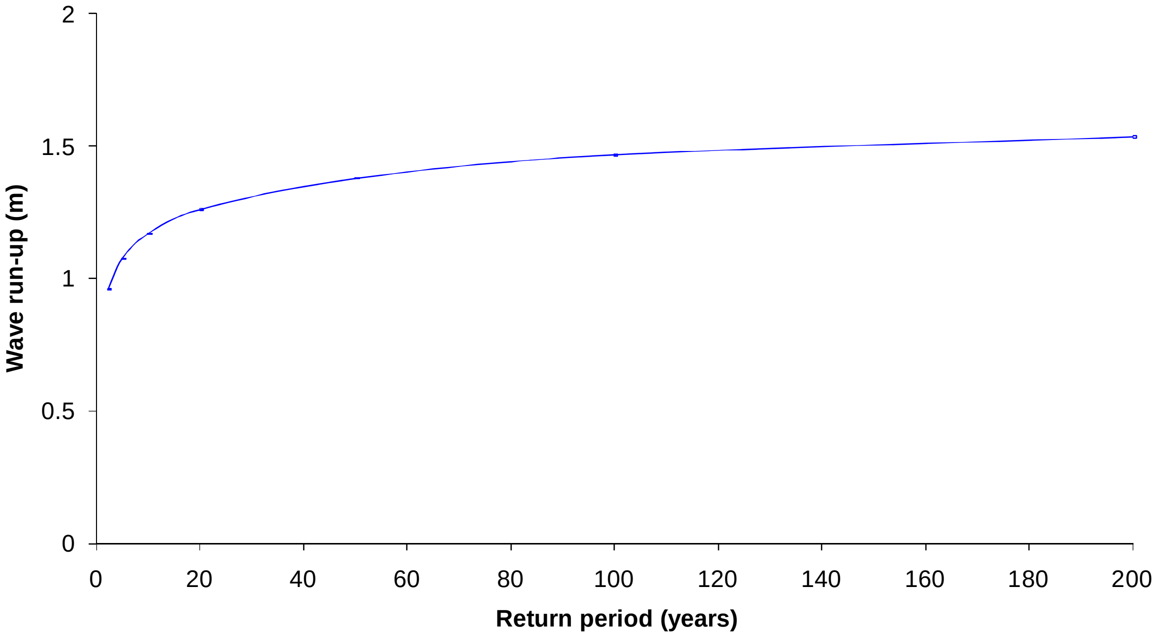

Figure 4.5: Wave run-up at different return periods.

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 event (0.18m); the 100-year seiche (0.11m); and 100 years of accumulated tectonic deformation (0.110m at Kuratau). 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.

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 Kuratau settlement 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 flood 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 a considerable 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 Kuratau River 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 potentially affected by high lake levels over the next 100 years is shown in Figure 5.1. Water levels will actually be 110mm higher than shown if subsidence of the area continues at the present rate.

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; however, it also provides confidence in the results of the two distinct modelling exercises.

Figure 5.1 Area affected by a lake level of 357.8m (MSL Moturiki).

To assess the likely extent, depth, and velocity of a 100-year flood event in the Kuratau River, and the potential effects of predicted climate change on the flood event, 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 Kuratau River 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 cell) 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 Previous flood modelling

Cheal Consultants carried out a flood assessment of the lower Kuratau River using a one-dimensional HEC-RAS model (Brand 2009). HEC-RAS is a software tool that models the hydraulics of water flow through natural rivers and other channels in a simple one-dimensional framework. The program was developed by the US Department of Defence, Army Corps of Engineers and it has found wide international acceptance since its public release in 1995. Modelling was carried out over the lower 2km of the Kuratau River upstream of Lake Taupo.

Opus carried out a peer-review of the validity and appropriateness of the hydrological inputs to the model (McConchie and Maas, 2009). The review also considered: the hydraulic parameters and boundary conditions; the theory and practice behind the model; areas of uncertainty; and the confidence that can be placed in the results and conclusions.

Following the peer review, calibration of the HEC-RAS model against a major flood event in 2004 was undertaken. This resulted in an adjustment of Manning’s n, and a closer fit between the modelled and actual water levels. The model results, however, remained conservative i.e., higher than observed. No calibration of the flood extent was carried out, as the necessary 2D spatial data were not available.

The Cheal model only covers the lower 2km section of the Kuratau River. It does not cover the entire reach upstream of the township where there are many sharp bends and areas with the potential for overbank flow. These areas could potentially affect the flood peak. Consequently, a longer reach of the river was modelled using MIKE Flood.

One-dimensional models are also not able to predict the path of floodwaters which overtop the banks, or break out of the channel under extreme flood conditions. A two-dimensional MIKE21 model, however, can simulate these scenarios when combined with high-resolution topographic information, such as that from a LiDAR survey.

A MIKE Flood hydrodynamic model, combining both MIKE11 and MIKE21, therefore offers considerable advantages over a simple HEC-RAS model when assessing the flood hazard of the Kuratau River.

6.2 Methodology

Using LiDAR topographic information and river cross-section data, a one-dimensional MIKE11 model was established. The model covers approximately 4km of the river from the mouth at Lake Taupo, to the narrow confined channel about 3km downstream of Lake Kuratau. The LiDAR data was augmented with cross-sections extracted from the previous Cheal Consultants HEC-RAS model. These were generated from a terrain model derived from GPS survey contours.

When raw LiDAR information is processed, part of the purpose is to remove the effects of any vegetation cover. Over heavily vegetated areas this is difficult and may lead to errors in the final inferred topography. Thus water levels in heavily vegetated areas should be analysed with caution.

LiDAR data also does not contain information beneath water bodies such as lakes, rivers and ponds. Cross-sections derived using LiDAR data were therefore compared to those where survey data were also available. A conservative depth was then added to the channel so that there was a smooth transition along the channel between zones where survey data were available (lower catchment) and those where only LiDAR data were available.

Using LiDAR topographic information a two-dimensional MIKE21 model was established of the flood plain. The model covers an area of approximately 18km^2 along the river; including the majority of the Kuratau Settlement that could be potentially impacted by the river. The MIKE11 and MIKE21 components were dynamically linked using MIKE Flood.

A number of different resolution terrain models were produced and tested in the hydraulic model. It was found that a grid size of 5m provided an adequate resolution for modelling the flood response in this catchment.

The MIKE Flood model was calibrated to the February 2004 flood, using the hydrologically derived inflow described in Section 3. A number of sensitivity tests on various parameters were carried out to assess the potential effects of any errors on the resulting flood levels and extents. The MIKE Flood model was then used to estimate the 100 year average return interval (ARI) flood extent both with and without the effect of predicted climate change out to 2090.

6.3 Model calibration – February 2004 flood event

The February-March 2004 flood, while the second largest on record, is the largest event for which there are observed water levels. A simulation of this event was therefore undertaken to compare the results of the MIKE Flood model with the very limited observed water levels available.

A press release was issued by Taupo District Council during the December-January 2010-2011 holiday period in an attempt to gather information on past flood events at Kuratau and their extents. No replies were received. The only information therefore available to calibrate the MIKE Flood model is the very limited data from Brand (2009). They used anecdotal evidence of the flood provided by residents at two locations (Figure 6.1):

1. Calibration site 1 is located close to the river mouth, approximately 200m upstream of the lake.
2. Calibration site 2 is located approximately 1700m upstream. The exact location of this site relative to the main river channel is unknown.

The anecdotal nature of this evidence means that there is some uncertainty regarding its accuracy. Additional evidence may become available in the future which will allow more robust calibration of the MIKE Flood model. Important calibration values, such as Manning's n can, however, be estimated from experience with similar rivers during past flood events.

For the upstream boundary conditions used in the MIKE11 component of the model a hydrograph created for the 2004 flood event, described in Section 3, was used. The downstream boundary condition for the MIKE11 component was the level of Lake Taupo measured at 15 minute intervals. Consequently, there is a high level of confidence in the model inputs relative to the calibration data available from the 2004 flood event.

The MIKE21 model component uses an open boundary off-shore from Kuratau to simulate flooding which may occur from high lake levels. A water level of 357.35m in Lake Taupo was used. This is approximately the highest water level recorded during the 2004 flood event. All other boundaries in the MIKE21 component were closed. The boundary conditions are summarised in Table 6.1.

Table 6.1: Summary of boundary donditions used in MIKE Flood model.

Boundary	**Calibration event 2004**	**100-Year ARI**	**100-Year ARI + climate change**
Peak discharge at upstream boundary (m^3/s)	75.7	97.8	114.2
Water level at downstream boundary (m MSL Moturiki)	357.35*	357.5	357.5

*Refers to the maximum water level in Lake Taupo recorded during the 2004 calibration event.

The model gives a good fit to the water levels estimated at both calibration sites. Table 6.2 shows that the MIKE Flood model estimated water levels at the two calibration sites to within 0.1m.

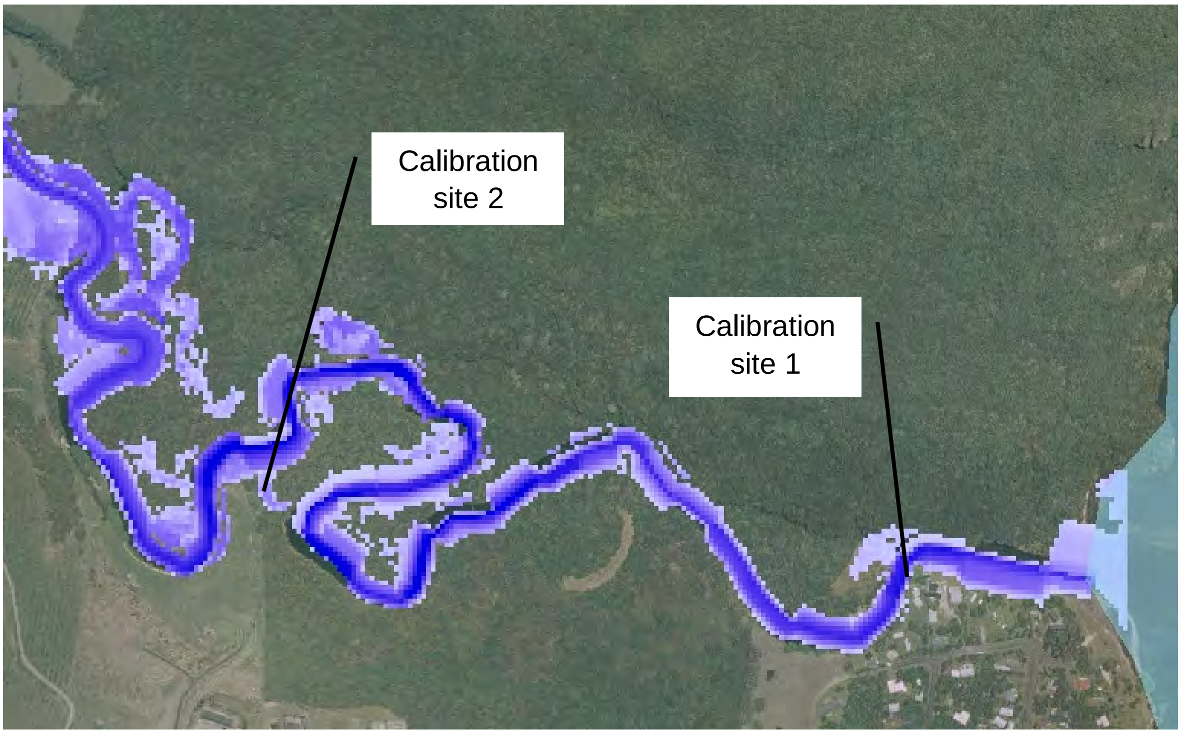

Figure 6.1: **Approximate location of the calibration water levels obtained from the February 2004 event.**

Table 6.2: **Summary of simulated and calibration water levels.**

Location	**Simulated water level (m MSL Moturiki)**	**Anecdotal observed level (m MSL Moturiki)**
Location 1: 200m upstream of river mouth	357.6	357.5
Location 2: 1700m upstream of river mouth	358.8	358.8

Figure 6.2 shows that in the upper part of the modelled reach the main channel is overtopped and the flood waters 'short-cut' some of the river bends. Some abandoned meanders have also filled with flood water. This would likely have a small effect on the routing of the flood peak down the river. However, this is not likely to affect flood levels significantly as the volume of water potentially stored would be very small compared to the total volume of water discharged during the flood peak. This is because the Kuratau has a relatively steep and narrow river channel.

Figure 6.2: **Predicted flood extent during the 29 February 2004 event using the calibrated MIKE21 model.**

6.4 Sensitivity analysis

A sensitivity analysis using the 2004 flood simulation was carried out on several hydrodynamic modelling parameters, as well as the input data. This was to assess the potential impact of any errors in the various data sources, and the confidence that can therefore be placed in the model outputs. The various inputs were adjusted by amounts corresponding to the range that could be realistically expected when modelling a catchment of this nature.

The sensitivity analysis confirmed that over the range of values tested, Manning's n (the friction parameter) is the most sensitive parameter. As was expected, varying the flood discharge has more effect on water levels in the upstream reach, while varying lake level has more effect on flood depths near the river mouth.

The flood depth was also more sensitive to Manning's n when it was reduced than when it was raised. Therefore, using a slightly conservative estimate of Manning's n has a less significant effect on flood levels than under-estimating Manning's n.

The sensitivity of the other parameters tested was so low that their variation did not result in any significant change to the flood level or extent beyond that caused by inaccuracies in the hydrological and topographic data.

The Mike Flood model produced a good fit to the calibration data. Considering the accuracy of the input data, together with the anecdotal nature of the calibration data, the sensitivity analysis showed that the model produces sensible and realistic results. Therefore, the model can be relied on to give a good estimate of the potential flood hazard in the catchment.

6.5 Effect of lake level on Kuratau River flooding

Figure 6.3 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.

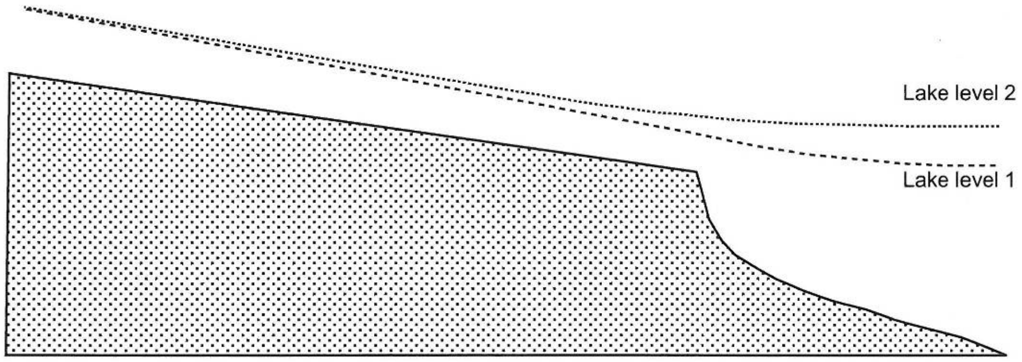

Figure 6.3: **Backwater profiles for river flow discharging into a lake (constant discharge).**

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 damps any surface waves on the lake. As illustrated in Figure 6.3, 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 of our New Zealand rivers, 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. 3 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 6.4 shows the predicted backwater profile along the Kuratau River for the 29 February 2004 flood event which had an estimated peak discharge of 75m^3/s. The backwater profile is based on the lake level at the time of the flood peak which was about RL 357.35m. The shape of the backwater profile is slightly different from that shown in Figure 6.3 in that it is concave downwards towards the mouth of the river. 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.

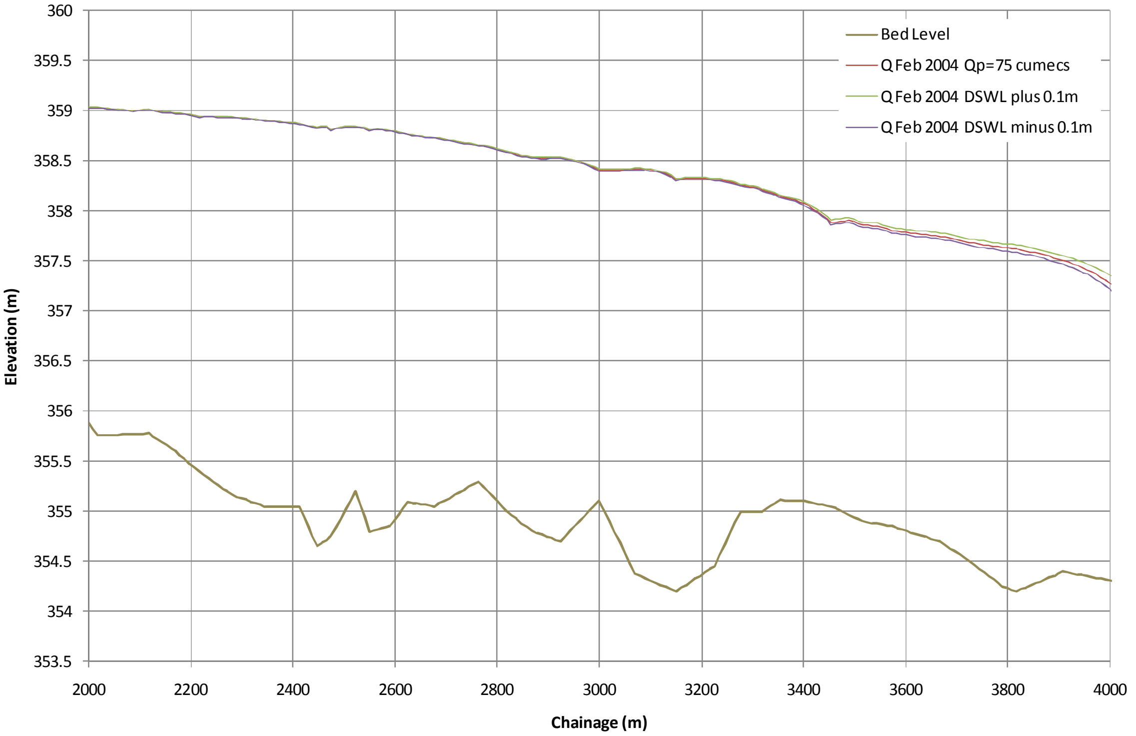

Figure 6.4: Backwater profiles simulated at 29 February 2004 flood event showing the effect of both increasing and decreasing the downstream boundary water level (i.e. lake level) by 0.1m.

Sensitivity tests were carried out with the model for this calibration flood event, and with the downstream lake level record arbitrarily shifted vertically upwards and downwards by 0.1 metres. The results confirm that the backwater profile only changes noticeably with varying lake levels over the lower 600 metres of the Kuratau River from the river mouth. For example, 200 metres upstream of the mouth a 100mm difference in lake level causes a shift in the backwater profile of less than 30mm. This effect is likely to be within the range of the other uncertainty within the hydraulic model.

It should also be noted that this relatively small movement of the backwater profile caused by varying the lake level is apparent for a small flood event. The shift in the backwater profile decreases with increasing discharge as the energy of the flow becomes more dominant. Consequently, when modelling the 100-year ARI event discharge, with climate change, there would be significantly less movement in the backwater profile in response to changes in lake level. The precise lake level used as the downstream boundary condition therefore has only a little effect on the extent, depth, and velocity of inundation during major flood events.

6.6 Description of scenarios modelled

Two major flood hazard scenarios were simulated using the calibrated MIKE Flood model. The estimated 100-year ARI flood event was modelled with an inflow hydrograph produced as described in Section 3. The other scenario simulated was for a 100-year ARI event but also including the predicted increase in discharge caused by climate change.

For the downstream boundary condition, the 100-year ARI lake level was assumed. This results in a conservative estimate of the flood depth in some areas adjacent to the river. However, overall the approach provides a realistic estimate of 100 year ARI flood depth as areas near the river mouth are more affected by the lake level than river discharge. The same lake level boundary condition was used for both 100-year ARI scenarios for the reasons discussed in McConchie *et al.,* (2008).

Table 6.3 summarises the boundary conditions used in each of the modelled scenarios simulated using the calibrated MIKE Flood model.

Table 6.3: Description of flood prediction scenarios.

Scenario	Boundary Conditions	
	Kuratau River peak flow (m^3/s)	Lake Taupo level (m)
100-year flood event scaled to mouth of Kuratau River	97.8	357.5
100-year flood event scaled to mouth of Kuratau River, adjusted for the predicted effects of climate change	114.2	357.5

6.7 Flood inundation maps

The flood inundation maps obtained by modelling both scenarios are shown in Figures 6.5 & 6.6. These maps show very similar patterns of inundation. Compared to the 2004 flood, more inundation occurs in the upper reaches of the river around the tight bends in the channel. Also, more inundation occurs in the area on the true right bank around the second to last bend before the river mouth (Whiowhio Reserve). This is to be expected given the significantly higher discharge, and higher lake level. This would potentially lead to the partial inundation of areas near the river mouth. Predicted water levels at the two calibration sites are shown in Table 6.4.

Table 6.4: Flood levels at the two calibration sites.

Location	Level 100-Year ARI (m MSL Moturiki)	Level 100-Year ARI + climate change (m MSL Moturiki)
Calibration site 200m upstream of river mouth	357.9	358.0
Calibration site 2 1700m upstream of river mouth	359.1	359.3

6.8 Accuracy

The accuracy of the hydraulic model should be considered when analysing areas at risk of flooding. The horizontal resolution of the data used in the model was 5m. Preliminary testing of the model showed that a DTM with a 5m resolution produced almost identical results to a 2m resolution DTM. This means that when considering the horizontal flood extent a ±5m 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 error may be exacerbated in areas with dense vegetation cover as discussed earlier.

Figure 6.5: **Depth of inundation predicted for the 100-year flood and assuming a lake level of 357.5m.**

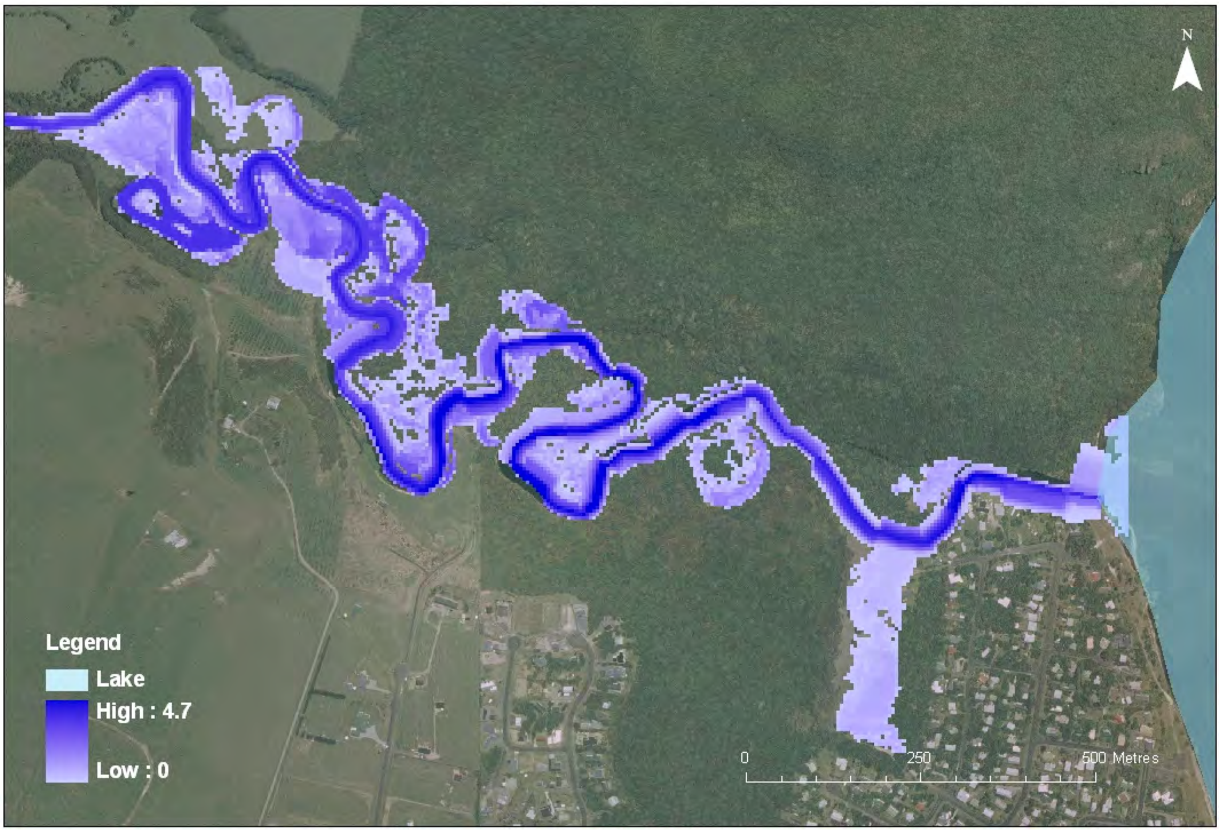

Figure 6.6: **Depth of inundation adjacent to the Kuratau River assuming the 'worst case' scenario modelled i.e., 100-year peak flow increased to allow for predicted climate change, and a lake level of 357.5m.**

6.9 Maximum velocity

The maximum velocity of the flood water estimated during each of the two flood hazard scenarios is also almost identical (Figures 6.7 & 6.8). The higher flow velocities occur in the current river channel, particularly in places where the channel is narrow. Higher velocities also occur within the 're-activated' abandoned channels.

Figure 6.7: **Velocity of flood waters predicted for the 100-year flood event and a lake level of 357.5m.**

Figure 6.8: **Velocity of flood waters assuming the 'worst case' scenario modelled i.e., 100-year peak flood flow increased to allow for predicted climate change, and a lake level of 357.5m.**

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 0.5, with a significantly greater risk to life when the same product exceeds 1.0.

- *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. These levels are outlined in Table 7.1 (Environment Waikato, 2008b).

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 floodplain 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.	

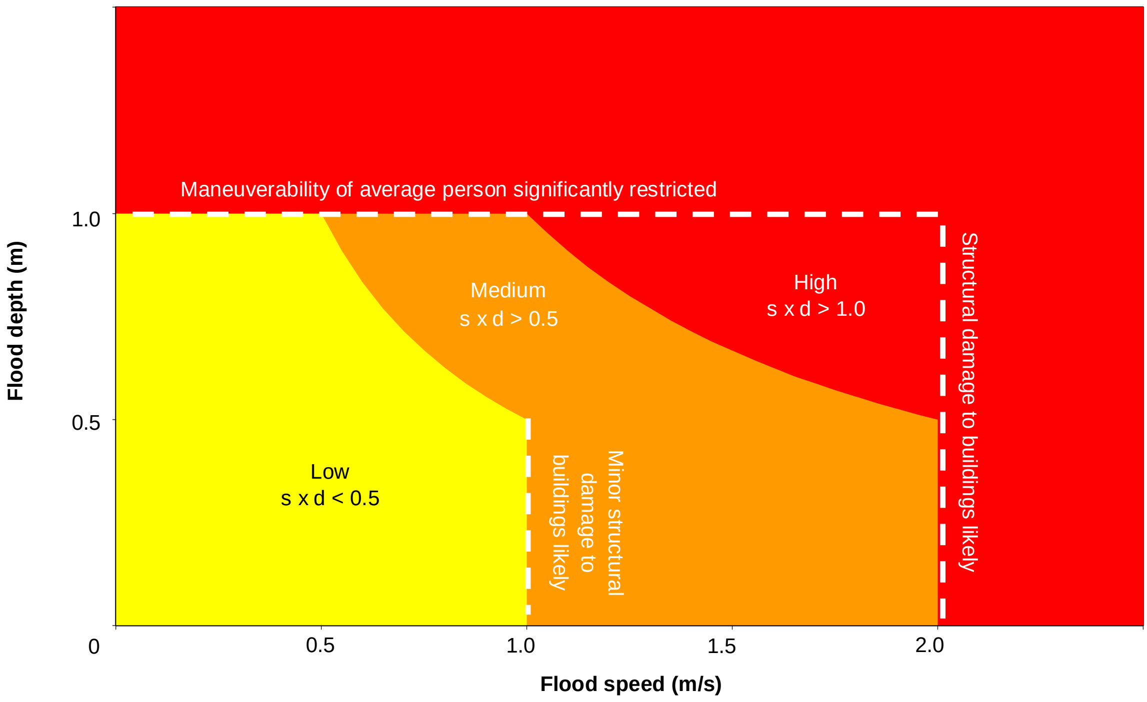

Figure 7.1: River flood hazard classification matrix (Environment Waikato, 2008b).

7.3 Flood hazard assessment

The analysis of flood water levels highlights the fact that the extent and depth of flooding of the Kuratau River are relatively insensitive to the level of Lake Taupo. Therefore the flood hazard posed by the Kuratau River during the 100-year event was assessed assuming a lake level of 357.5m, but with river flows increased to allow for the potential effects of climate change. The magnitude of these effects was discussed previously.

The water depth during this scenario is shown in Figure 7.2, and the flow velocity is shown 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). 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 the 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 while a proportion of the Kuratau flood plain is prone to flooding, the risk to life and property is generally low. This is because of the relatively confined nature of the river. The areas that are prone to flooding lie at 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 of the river flow over river bends and occupy adjacent low-lying areas. A large volume of water can be accommodated by inundation to a relatively shallow depth. Furthermore, 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.

7.4 Summary

A MIKE Flood hydraulic model was established for the Kuratau River, extending 4km upstream from Lake Taupo. The topography of the channel and flood plain is based on both LiDAR and river cross-section data. The model was calibrated on observed and anecdotal evidence of flooding from two locations during the 29 February 2004 event.

The calibrated model was then used to estimate inundation during a 100-year flood; both with and without the effect of predicted climate change.

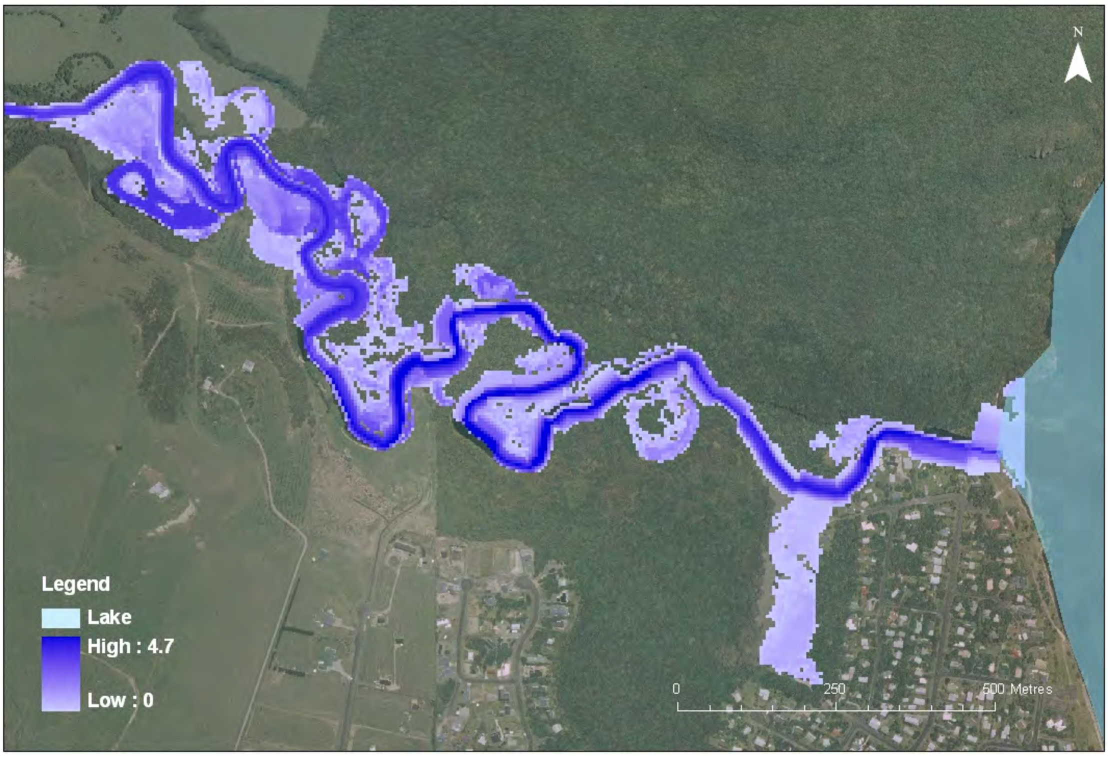

Figure 7.2: **Water depth during the 100-year flood event in the Kuratau River allowing for the effects of climate change on runoff within the catchment. Lake level is assumed to be at 357.5m.**

Figure 7.3: **Water velocity during the 100-year flood event in the Kuratau River allowing for the effects of climate change on runoff within the catchment. Lake level is assumed to be at 357.5m.**

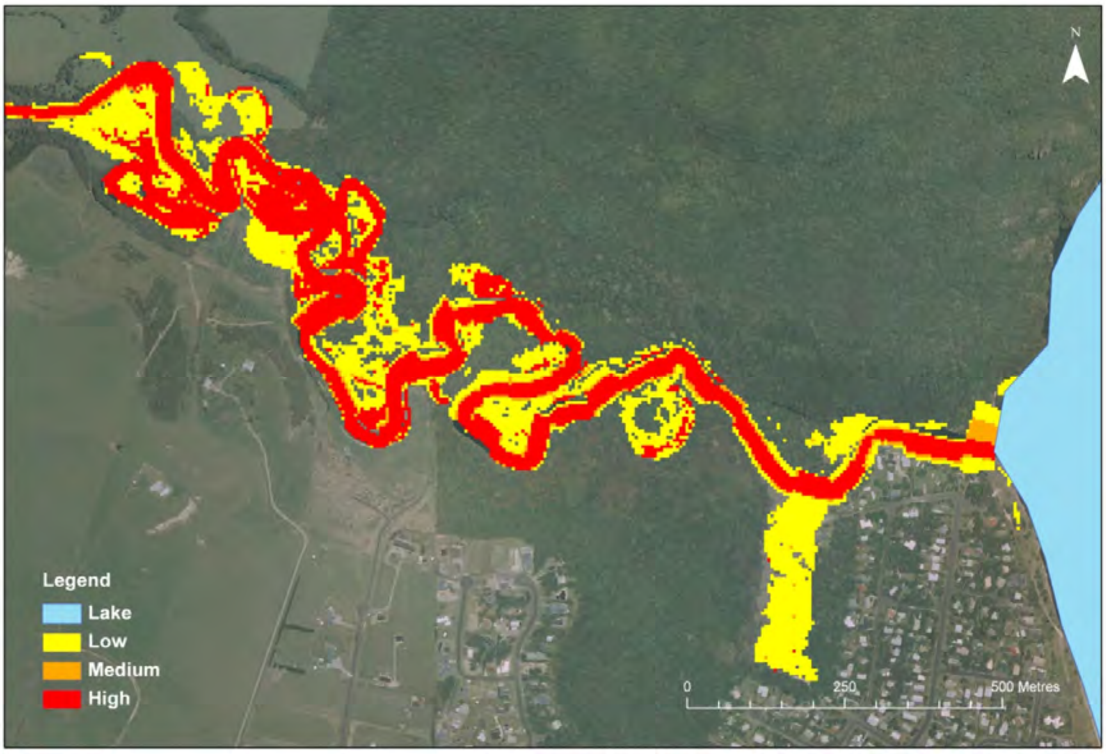

Figure 7.4: **Flood hazard classification during the 100-year flood event in the Kuratau River allowing for the effects of climate change on runoff from the catchment. Lake level is assumed to be at 357.5m.**

The results show that increased water levels arising from increased flood flows caused by climate change are more marked over the first 2 to 3km of the river modelled. Beyond that, the backwater effect of Lake Taupo gradually becomes more dominant. The difference in water levels potentially caused by climate change diminishes downstream towards the lake. The extent of inundation during the 100-year ARI increases when the effects of predicted climate change are incorporated.

The MIKE Flood model accurately represents channel velocities. It also allows the extent, depth, velocity, and potential impact of any out of channel flows to be quantified. Now that the model has been established and calibrated, it can quickly be re-tuned to explore any scenario; including climate change, channel works, flood protection options etc.

8 Conclusion

Flooding in the Kuratau River is a persistent and ongoing process. The main river channel has migrated over its lower reaches as can be seen by the old ‘ox bows’ and abandoned channels visible in aerial photographs.

A previous flood assessment by Cheal Consultants, using a one-dimensional HEC-RAS model, covered only the lower 2km section of the Kuratau River. It did not cover the whole reach upstream of the township where there are many sharp bends, and the potential for overbank flow. These areas have the potential to affect the passage of the flood peak. A larger reach of the river was modelled using MIKE Flood.

One-dimensional models are not able to predict the path of floodwater which overtops the banks, or breaks out of the channel under extreme flood conditions. A two-dimensional MIKE21 model can, however, model these scenarios when combined with high-resolution topographic information from a LiDAR survey. A MIKE Flood hydrodynamic model combining MIKE11 and MIKE21 therefore offers considerable advantages over a simple HEC-RAS model when assessing the flood hazard of the Kuratau River.

The risk of flooding, and the potential extent and depth of inundation of land near the Kuratau River, 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 Kuratau River indicate a consistent pattern of response. Rainstorm durations leading to significant flood events are usually from 24-36 hours in duration. The resulting floods typically have one major peak, and the body of the flood lasts for about 24 hours.

Analysis of the largest floods recorded since 1978 indicates that a flood peak of 97.8m^3/s or greater might be expected every 100 years. Based on the latest estimates of the potential effects of climate change on the rainfall regime, the magnitude of the 100-year flood might increase to 116.6m^3/s by the 2040s and 141.6m^3/s by the 2090s if the highest predicted temperature increases eventuate.

Modelling of an extreme event of 114.2m^3/s showed that the flood would likely cause the river to breach its main channel, and by-pass several bends between 4km and 3km from the river mouth. Some of the Whiowhio Reserve would likely be flooded, and it is possible that some properties close to the river mouth may become inundated. The fastest and deepest flood waters would 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 may be inundated will be subject to a relatively low flood hazard. The risks to life and property in the urbanised areas are generally low. The highest flood hazard is within the currently active river channel and within the secondary flow paths across the Kuratau delta.

8.2 The combined flood hazard

The total flood hazard in the vicinity of the Kuratau River is the result of the combined effect of the risk from high lake levels and waves; and the risk from overbank flows from the river. 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 Kuratau River. 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 is likely to increase 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.

Given the preliminary and 'screening' nature of this flood study, and the fact that the Kuratau flood model could not be calibrated to a high level, 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 may be appropriate to undertake a revision of the design flood estimates. If the revised design flood estimates are significantly different to those used in this study then consideration should be given to re-running the hydraulic model for Kuratau Stream.

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10 Glossary

One-Dimensional Model – A computational hydraulic model involving averaged depth and cross section flows and velocities.

Two-Dimensional Model – A computational hydraulic model involving depth averaged flows and velocities.

Computational Hydraulic Model – Mathematical representation of waterways with the use of computers to solve equations governing water flow.

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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