Taupo District Flood Hazard Study

TONGARIRO 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 inflows, 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 Tongariro River. Of particular concern is the flood risk downstream of Poutu Pool, past Turangi, and across the Tongariro delta. The flood risk assessment is based on a comprehensive hydrometric analysis of catchment runoff processes and the results from a two-dimensional computational hydraulic model.

2 Tongariro catchment

2.1 Description of the Tongariro catchment

The Tongariro catchment drains the eastern slopes of Mts Tongariro, Ngauruhoe, and Ruapehu. The catchment also extends into the Kaimanawa Ranges and across the volcanic ring plain that exhibits mixed geology. The catchment contains a number of major tributaries including Waihohonu Stream, the Waipakihi River, and Poutu Stream (Figure 2.1).

Hydro-power development has altered the natural flow regime of the Tongariro River. Flows are augmented with water from the Moawhango River, via the Moawhango tunnel. Flows have also been diverted from the Tongariro River: to Lake Rotoaira via the Poutu tunnel and canal since 1973; and at Rangipo Dam to the Rangipo power station since 1983. Flows are returned from Lake Rotoaira to Lake Taupo through the Tokaanu Power Station (Figure 2.2).

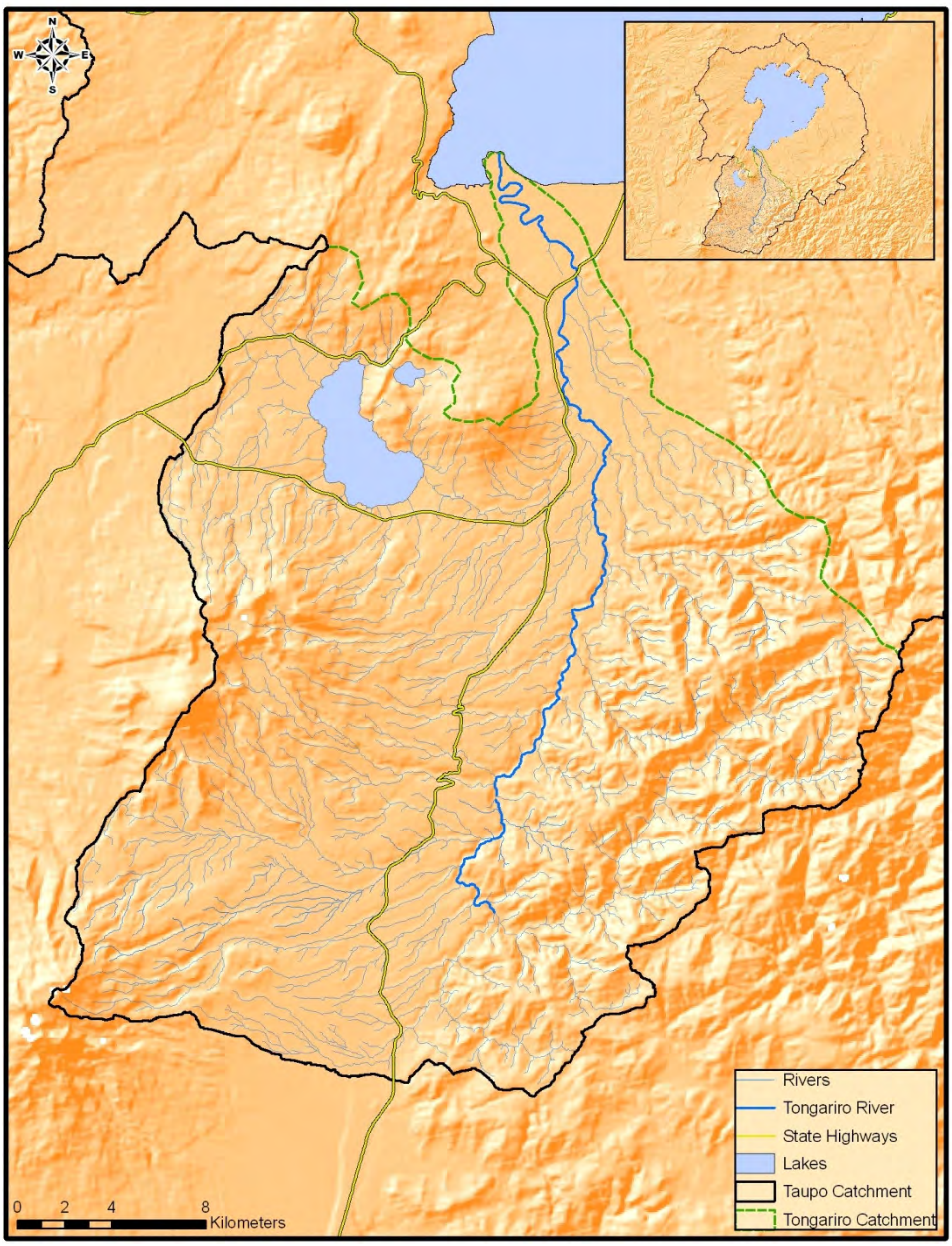

Figure 2.1: Location of the Tongariro River.

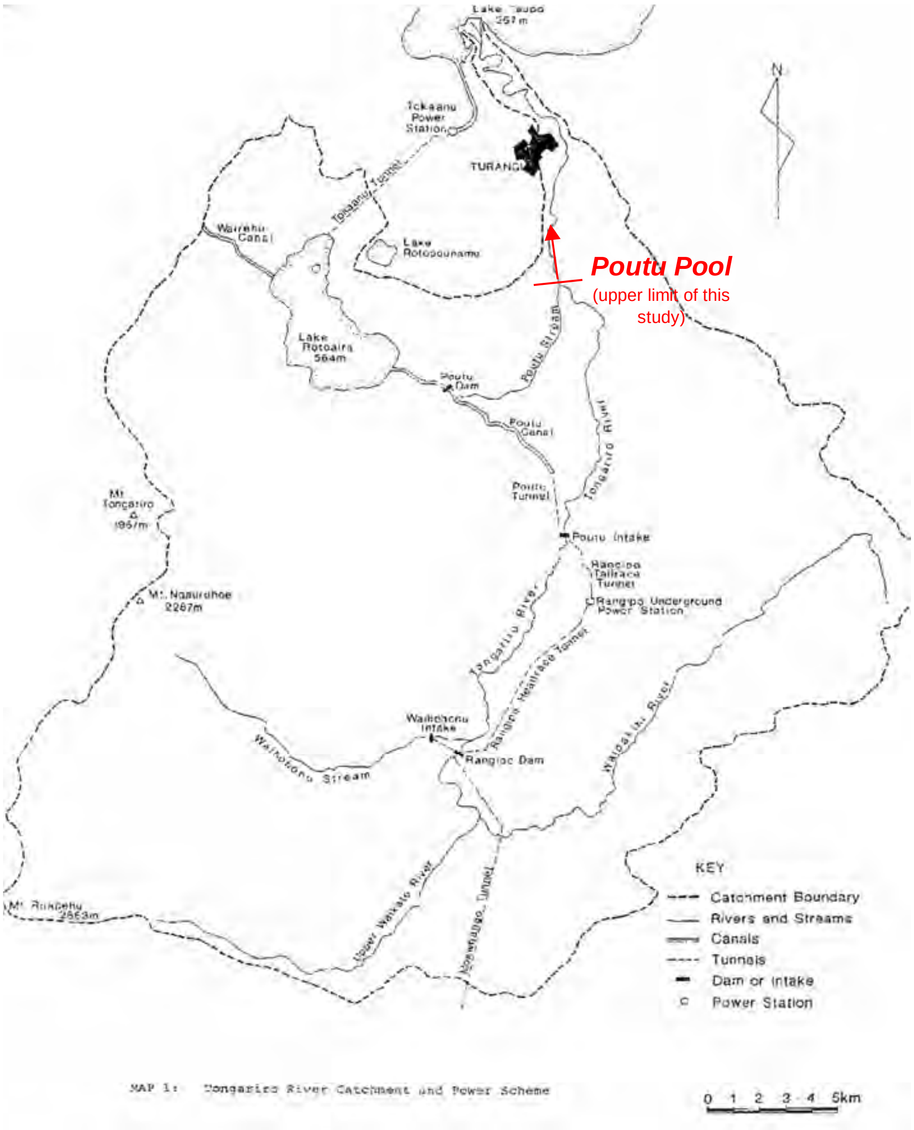

Figure 2.2: Tongariro River catchment and power scheme (*Davenport* et al*. 1988).*

The western side of the Tongariro catchment is comprised of young volcanic rock (andesite, dacite, and rhyolite) and soft and unconsolidated volcanic deposits of pumice and breccia erupted from the Ruapehu, Tongariro, Taupo, and Okataina volcanic centres (Hancox, 2002) (Figure 2.3). These porous volcanic soils and underlying lithology absorb the majority of any storm rainfall with only about 10% appearing as storm runoff. Most of the rainfall (~90%) recharges the soil moisture and groundwater. This tends to reduce any potential flood peak while increasing the more general baseflow (Hancox, 2002). Flood events, however, can still be significant because of the high rainfall totals and intensities and steep slopes.

The geology of the Kaimanawa Ranges in the east is basement rock, mainly indurated greywacke and argillite (Hancox, 2002). Greywacke, that underlies 28% of the catchment, is non-porous and relatively impermeable. Catchments within this material tend to respond rapidly to rainfall events creating storm hydrographs with distinct, relatively short and sharp flood peaks. Baseflows tend to be low because of the limited potential for groundwater storage.

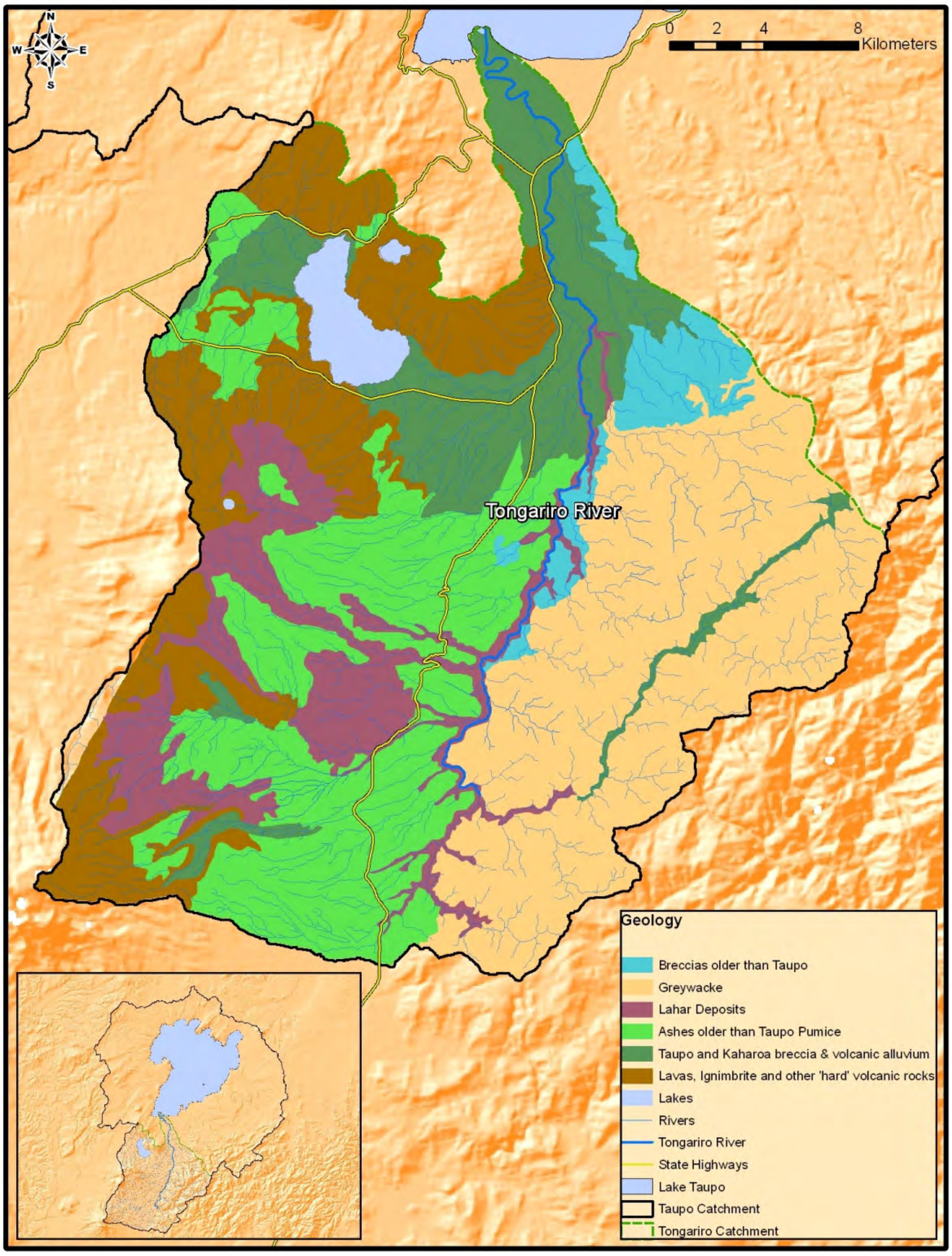

Figure 2.3: Catchment geology of the Tongariro River.

The soils on the slopes in the west of the catchment are very young and poorly developed. They also tend to be very shallow. Therefore although the soils are generally quite porous, their shallow depth reduces their moisture holding capacity. During prolonged or heavy rainfall events these soils quickly become saturated with water then running off rapidly into the Tongariro River.

Within the Kaimanawa Ranges the soils are better developed because of the extensive vegetation cover. However, they are still relatively thin because of the steep slopes. These soils also become saturated quickly, providing rapid runoff to the rivers and streams draining to the Tongariro River (Figure 2.4).

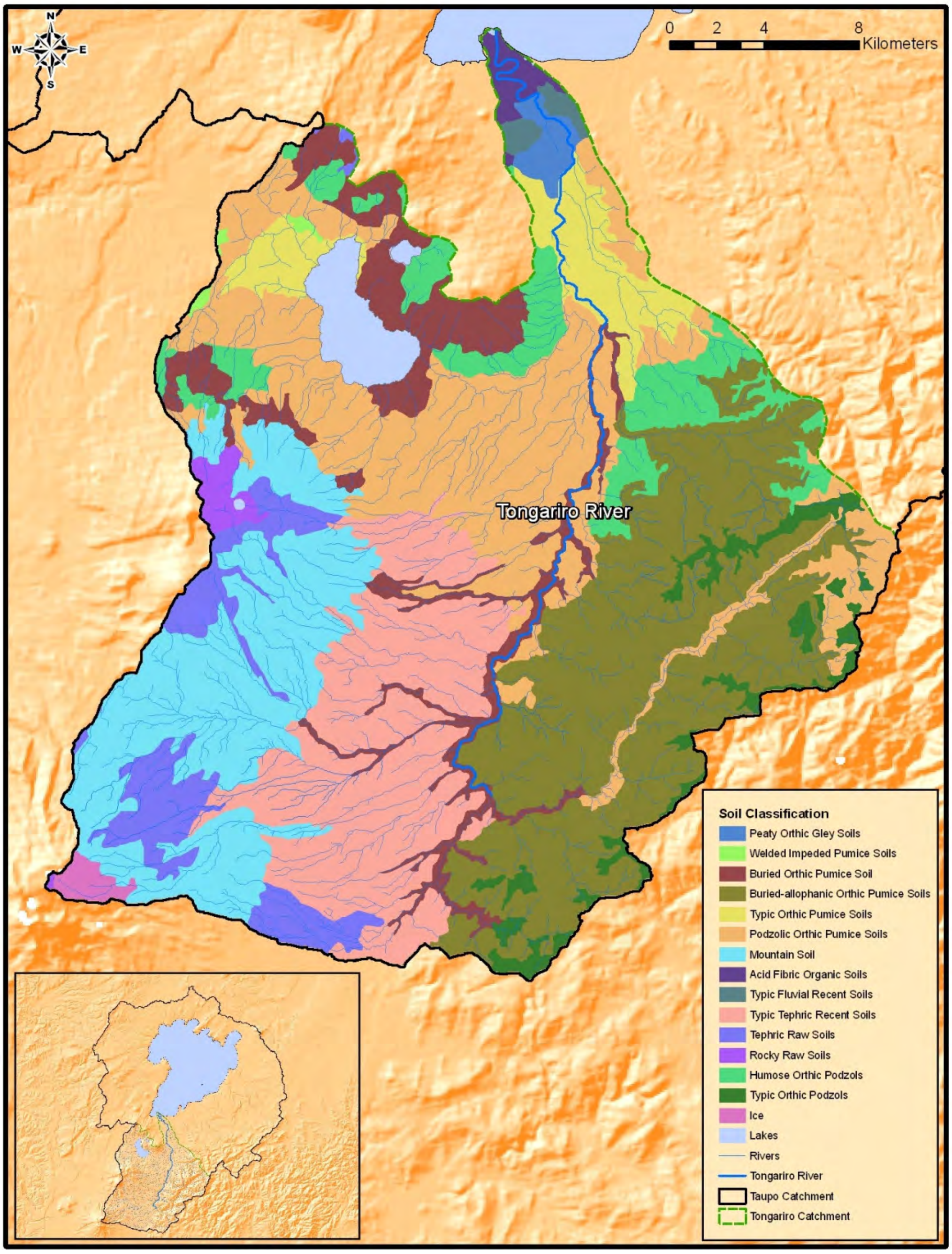

Figure 2.4: Soils of the Tongariro catchment.

Erosion is common in the upper Tongariro catchment because of the soft unconsolidated nature of the volcanic deposits, steep slopes, and high rainfall. This provides a large volume of material that is available to 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. The Tongariro River consequently carries a high sediment load. On average, approximately 11,700 tons of gravel and larger sized sediment is carried past Turangi each year. Ten times this amount of finer-sized material, including sand, is transported downstream (Smart, 2005). 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 in the channel and on the floodplain adjacent to the lower reaches of the Tongariro River.

As sediment is deposited in the lower reaches of the river (Turangi area) the riverbed builds up (aggrades). This reduces the capacity of the channel to contain flood flows. During large flood events the river can break out of its channel with flood waters then taking the lowest path to the lake. The wide floodplain, and extensive Tongariro delta where the river discharges into Lake Taupo, have formed from the river periodically changing its course in this manner. Sedimentation can be greater when the lake level is high as the river slope, and hence the energy to transport sediment, decreases. Likewise, sedimentation within the channel may be reduced when the lake level is lower because of increased energy through the lower reaches of the river.

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 increase the sediment supply to the river. Gravel extraction, as occurred from the 1960's to early 1980's, reduced aggradation and stabilised the river channel between Turangi and the delta mouth (Smart, 2005). Tectonic subsidence and the compaction of sediments in this location are also reducing the ground level and therefore the slope of the river. These processes are likely to be increasing aggradation.

Impeded drainage of the Tongariro River caused by subsidence of the delta, combined with mid to high lake levels, can also cause a backwater effect. This reduces the flow gradients even further, and may potentially affect the flood risk to the surrounding area. Significant flood protection and river management works have taken place in recent years to reduce the flood risk along the lower reaches of the river.

The alluvial deposits throughout the lower valley of the Tongariro River and across the delta indicate a significant and extensive flood history. They also provide evidence as to the potential extent of the flood hazard (Figure 2.4).

Much of the Tongariro catchment is under some kind of forest cover. This includes: indigenous native forest (~44%) within the Tongariro National Park and Kaimanawa Forest Park, managed by the Department of Conservation; and exotic plantation forestry (~10%). Urban land uses and the development of infrastructure increase in density on the lower floodplain. This development and capital investment is at risk from significant flood events (Figure 2.5). Land use within the catchment is summarised in Table 2.1 and Figure 2.6.

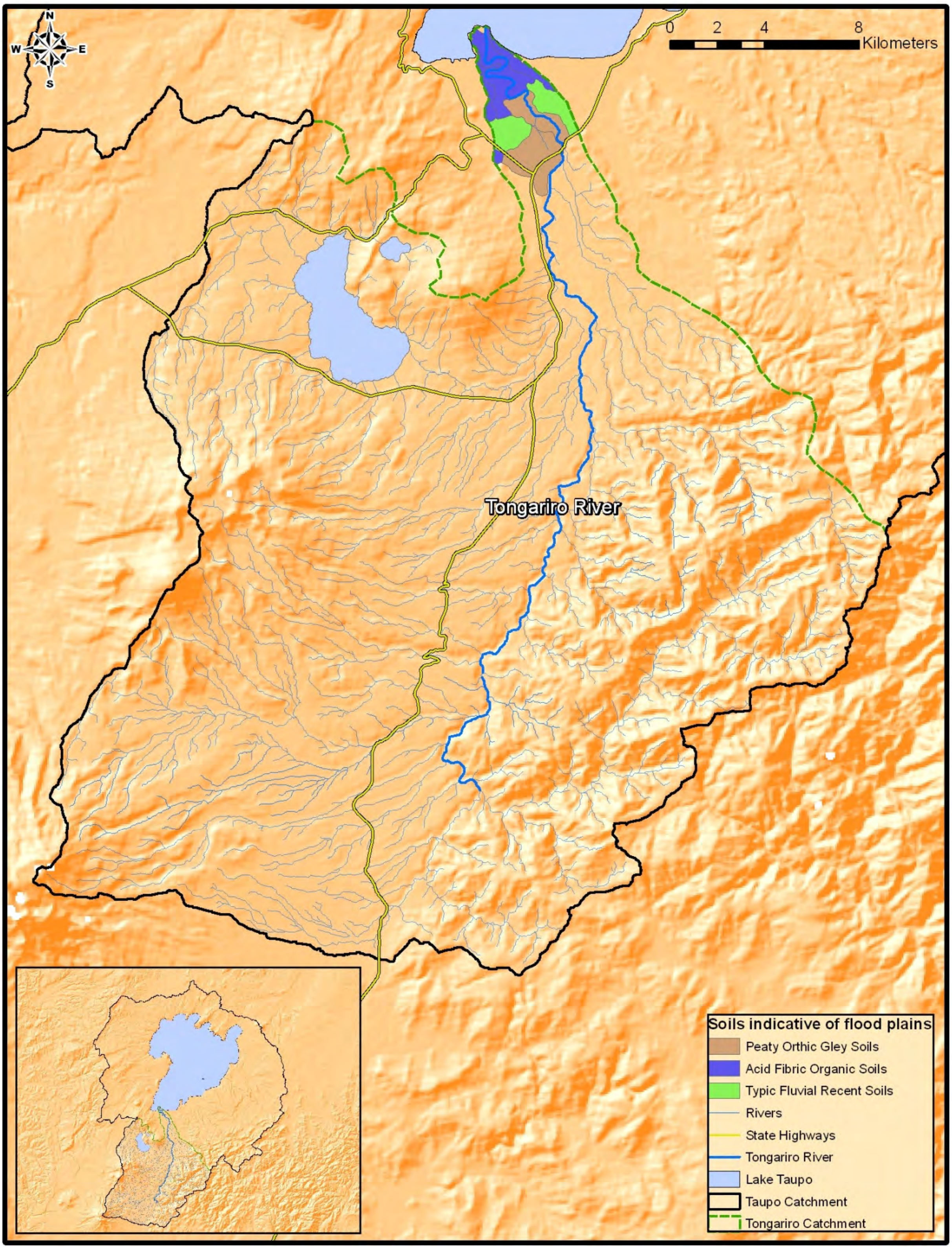

Figure 2.4: **Flood deposits of the lower Tongariro River.**

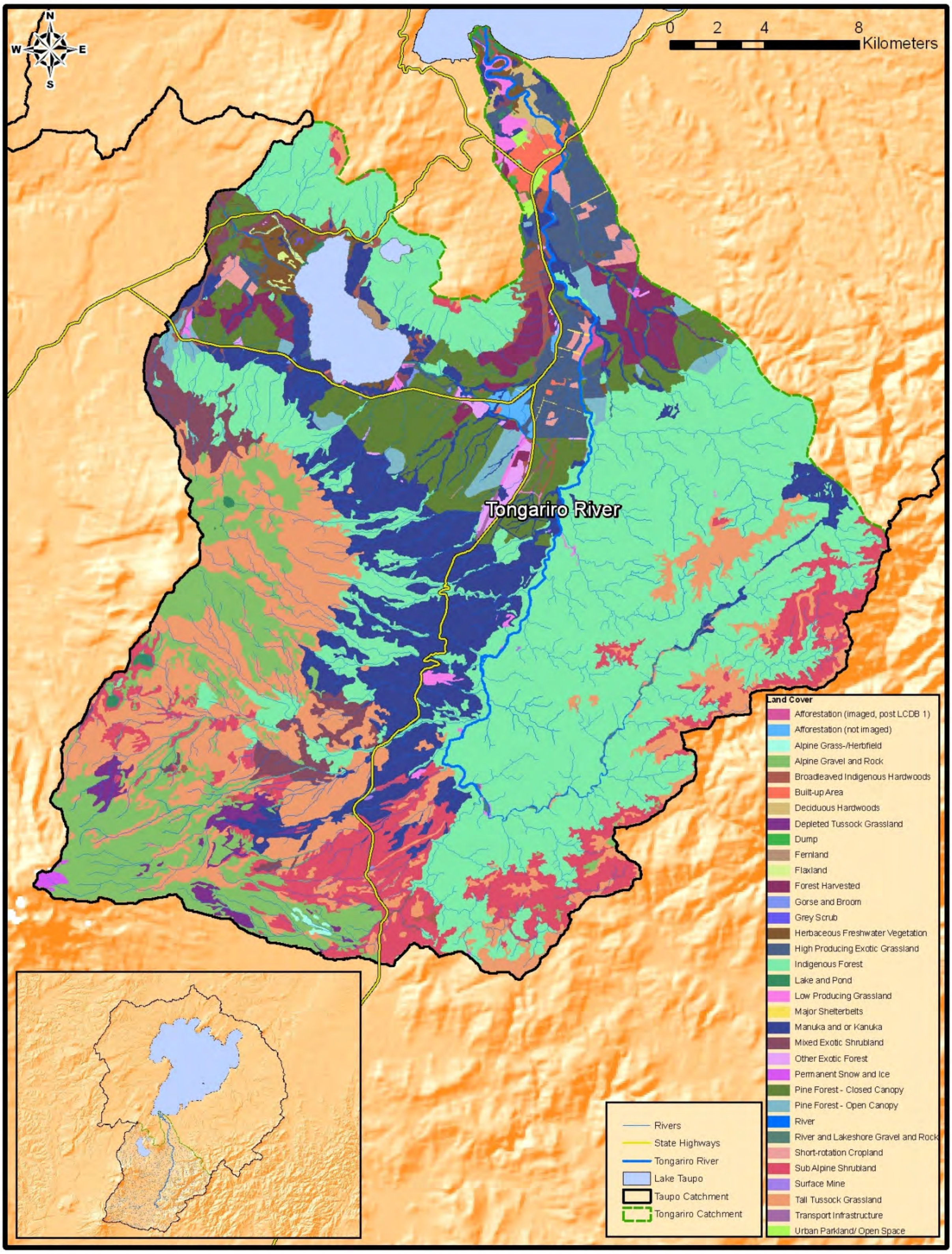

Figure 2.5: **Land use and vegetation cover within the Tongariro catchment.**

Table 2.1: Tongariro River catchment – land use.

Land use	Percentage
Lakes and ponds	2.3%
High producing exotic grassland	3.1%
Indigenous forest	34.5%
Broadleaved indigenous hardwoods	1.0%
Forest harvested	2.1%
Pine forest - Open canopy	1.3%
Pine forest - Closed canopy	6.2%
Manuka and/or kanuka	11.6%
Mixed exotic shrubland	2.5%
Sub alpine shrubland	7.4%
Tall tussock grassland	13.6%
Alpine gravel and rock	8.6%
Total	**94.3%**

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

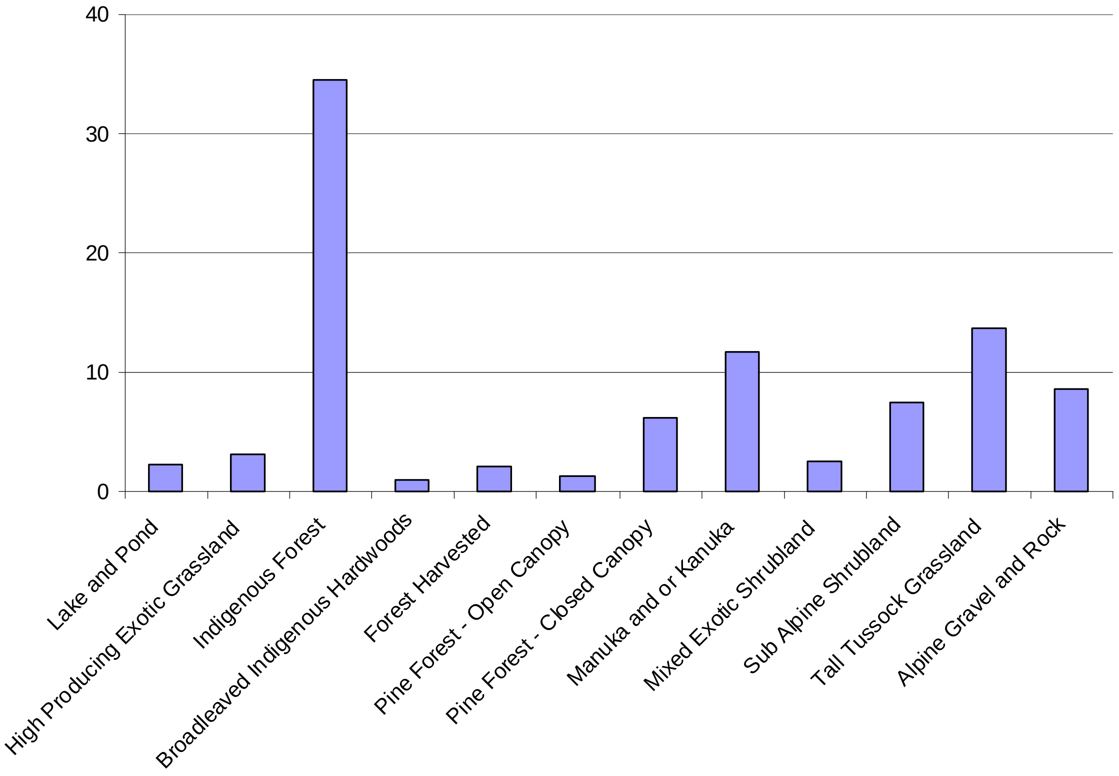

Figure 2.6: Distribution of major land uses (%) within the Tongariro catchment.

The Tongariro catchment has a very steep rainfall gradient. The mean annual rainfall in the headwaters, the area likely to produce the greatest runoff, reaches 4300mm on Mt Ruapehu (2800masl) and about 2800mm in the Kaimanawa Ranges (1600masl). Rainfall then decreases rapidly with altitude to be only approximately 1300mm at Lake Taupo. Those areas which experience the highest annual rainfall 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.

The flood risk to the lower Tongariro valley is exacerbated by the difference in slope angle between the upper and lower portions of the catchment. Those areas of the catchment that experience the greatest rainfall are also those with the steepest slopes (Figure 2.7). The thin permeable soil in these areas means that any water runs off rapidly, and is quickly concentrated in the Tongariro River. The steep gradient of the river channels in these areas also means that the water flows much more quickly than it can across the lower floodplain. As a result, flood waters spread out across the floodplain in the lower valley. This problem is compounded in the Tongariro River because the catchment behalves rather like a funnel. Runoff from the extensive upper catchment is channelled onto, and across, the relatively narrow and flat floodplain to Lake Taupo (Figure 2.7).

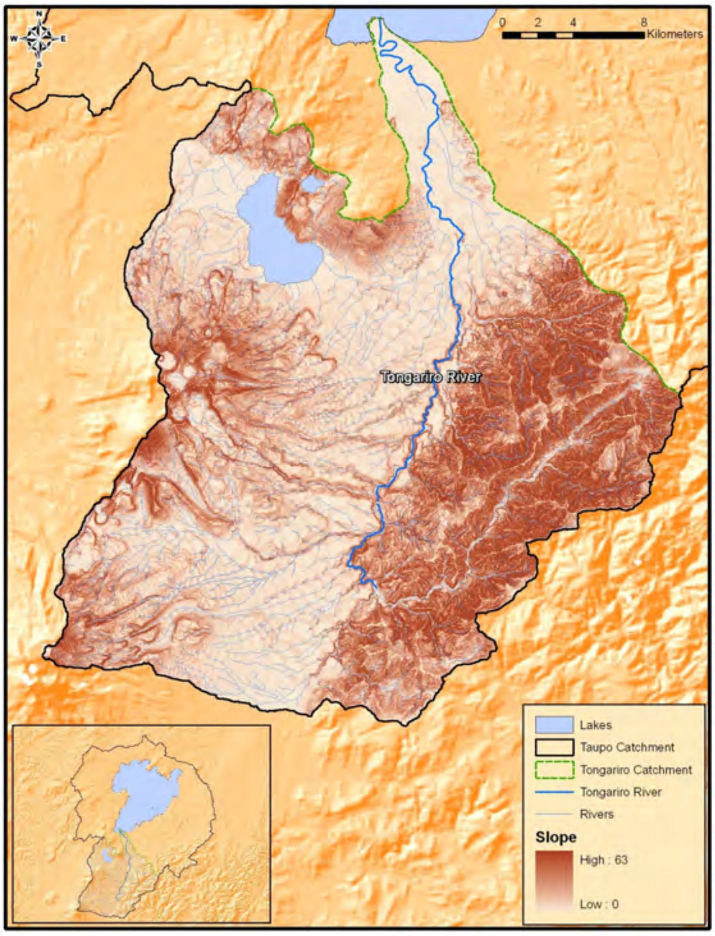

Figure 2.7: Slope within the Tongariro catchment.

Consequently, there are a number of physical characteristics of the Tongariro catchment that predispose the lower valley to having a high inherent flood risk. There are also a number of constraints affecting the lower valley which make it difficult to mitigate this flood risk.

2.2 Study area

The greatest flood hazard within the Tongariro catchment exists on the floodplain and delta of the lower valley. The river flows between relatively low banks composed of easily erodible material. This is also the area with the greatest capital investment, and density of people and infrastructure. The focus of this flood study is therefore the area downstream of Poutu Pool (Figure 2.8).

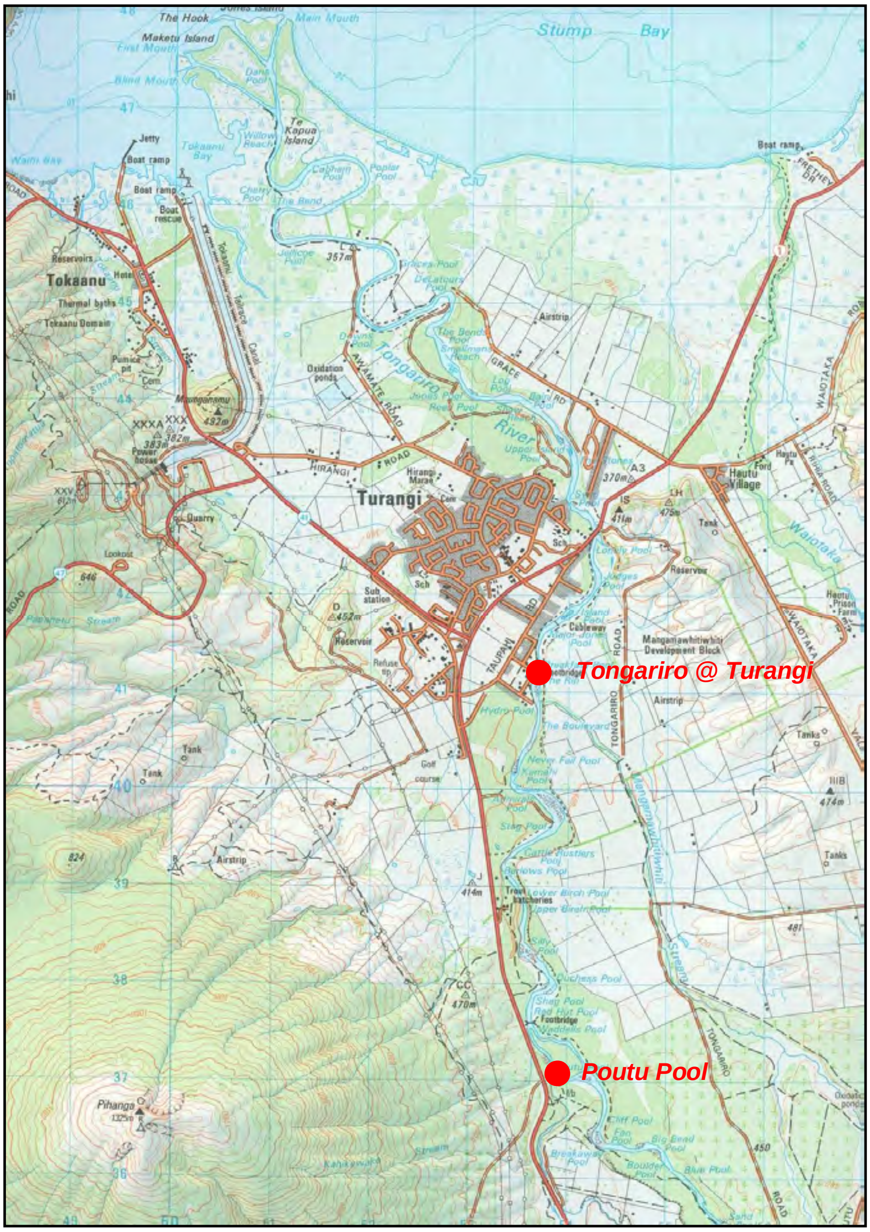

Figure 2.8: Tongariro River study area (*1:50,000 map series, sheet T19, 1994).*

3 Flow regime of the Tongariro River

3.1 Tongariro River @ Turangi

Flows of the Tongariro River have been continuously recorded since January 1957 by a gauge located at Turangi (Figure 3.1). There are a number of other recorder sites within the catchment, but the one at Turangi has the longest record and is the furthest downstream. There are no significant tributaries downstream of this recorder site. This site, which records the flow from a catchment of approximately 772km^2, therefore provides accurate estimates of flows that could potentially affect the lower valley and floodplain. The flow record from this site at Turangi therefore provides a robust measure of the flood magnitude and frequency history of the lower catchment.

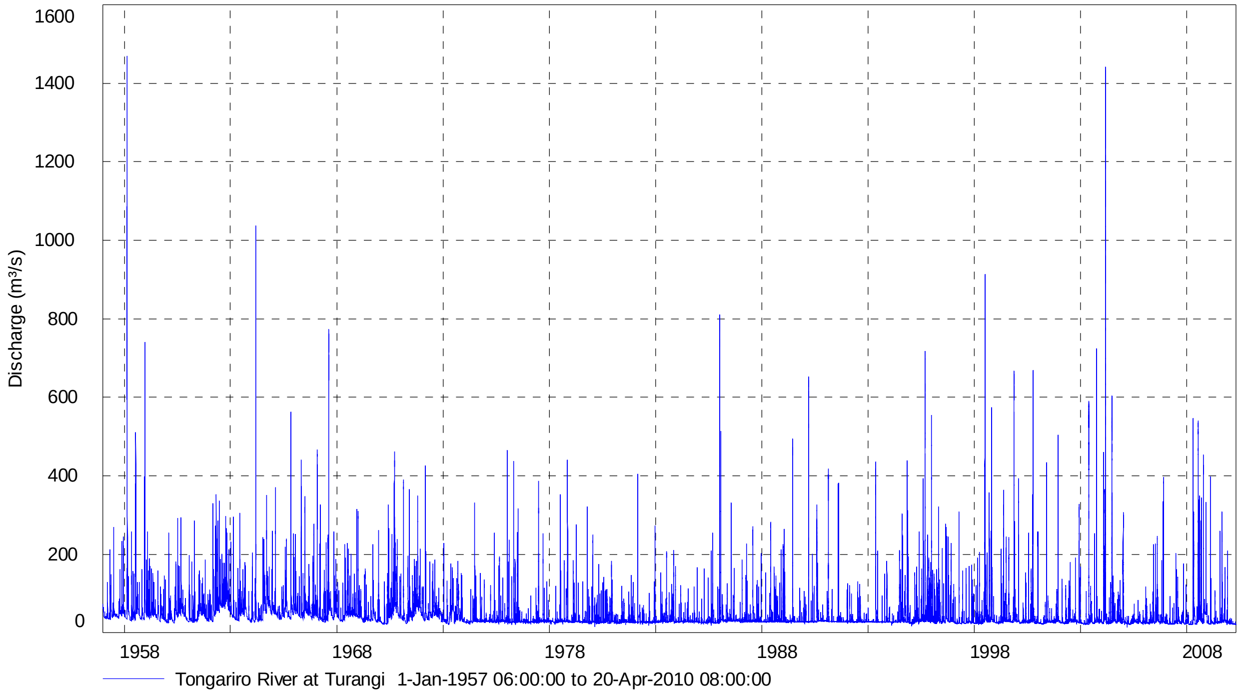

Figure 3.1: Flow record for the Tongariro River @ Turangi.

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 3.1 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 Tongariro River at Turangi appears to be of high quality, containing a complete record of all the major flood events since 1957.

Although there appears to have been a period of reduced flood activity between 1966 and 1996, the flow record shows a relatively consistent annual pattern of flow variation. This flow record (Figure 3.1) therefore provides a reliable and robust set of data for analysis.

The summary of flow statistics (Table 3.1 and Figure 3.2) show that the Tongariro 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 30% higher than the median.

Table 3.1: Summary of flow statistics for the Tongariro River @ Turangi (m^3/s) January 1957-April 2010.

Site	Minimum	Mean	Median	Maximum	Standard deviation	Coefficient of variation
Tongariro @ Turangi	13.97	38.67	29.52	1470	28.06	0.725

Table 3.2 lists the largest flood event in each year of record. It should be noted that in some years e.g., 2005, 1992, and 1981 the biggest recorded flood was a relatively small event. In these years the biggest flood recorded was less than 10% of the largest flood on record i.e., 1958 with a flood of 1470m^3/s.

This variability of annual flood events highlights a major difficulty when attempting to predict the magnitude of floods which can be expected over a particular period of time. Since the distribution of floods is essentially random in time, the use of different lengths of flow record can lead to significantly different estimates of the frequency and magnitude of particular flood events. The addition of period of record which contain few large floods will reduce the expected magnitude of extreme events; and any large events in the record will be predicted to occur less often i.e., what was a 50-year event might appear to become a 100-year event. Likewise, the addition of periods of record which contain a number of large flood events will increase the apparent magnitude of extreme events; and any large flood events in the record will be predicted to occur more often i.e., a 100-year event might appear to become the 50-year event.

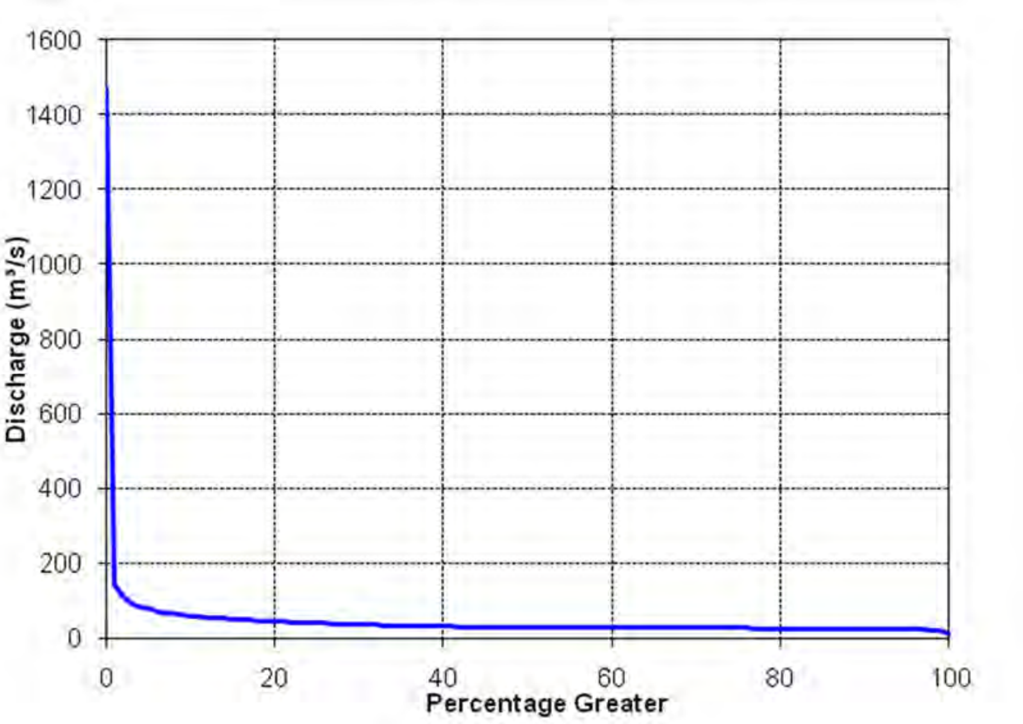

Figure 3.2: **Flow duration curve for the Tongariro River @ Turangi (1957-2010).**

Table 3.2: **Annual maximum flows recorded at Tongariro River @ Turangi (1957-2010).**

Rank	Year	Flow (m^3/s)	Rank	Year	Flow (m^3/s)	Rank	Year	Flow (m^3/s)
1	1958	1470	**19**	1978	441	**37**	1963	306
2	2004	1442	**20**	1994	439	**38**	1960	294
3	1964	1038	**21**	1993	436	**39**	1961	287
4	1998	913	**22**	1972	427	**40**	1988	282
5	1986	810	**23**	1991	417	**41**	1987	272
6	1967	774	**24**	1982	406	**42**	1957	270
7	2003	725	**25**	2009	398	**43**	1959	257
8	1995	718	**26**	2006	397	**44**	1975	255
9	2000	670	**27**	1971	391	**45**	1985	254
10	1999	667	**28**	1977	387	**46**	1980	249
11	1990	653	**29**	1962	352	**47**	1973	229
12	1965	563	**30**	1974	332	**48**	1983	211
13	2008	546	**31**	2002	329	**49**	2007	202
14	2001	504	**32**	1996	322	**50**	1984	166
15	1989	494	**33**	1979	321	**51**	1981	148
16	1976	466	**34**	1968	316	**52**	1992	132
17	1970	462	**35**	1969	311	**53**	2005	128
18	1966	442	**36**	1997	309	**54**	2010*	37

Note: 2010 only includes data up until April.

The flow record used in the current study extends from January 1957 until April 2010. Flood frequency and magntude estimates derived using this record may be different to those obtained using different periods of record.

Figure 3.3 shows the flood hydrograph for the second largest flow on record i.e., 29 February 2004. This flood was chosen for analysis because there is also a good record of rainfall for the event. This is not the case for the 1958 flood when no rainfall data were recorded. This hydrograph highlights a number of features of flood events in the Tongariro catchment. In general, it takes rainfall events of approximately 36 hours duration to generate a significant flood in this catchment. While this storm event produced a very high peak discharge, the flood peak lasted for only a relatively short time.

It is also apparent that during the flood peak the hydrograph was very irregular. This is likely caused by erosion of the bed and mobilisation of sediment within the channel, which changed the river cross section (on which the estimates of flow are based), rather than rapid changes in the actual amount of water in the river.

High intensity rainfall events in general produce sharp, short duration flood peaks which usually pose the greatest risk of causing flooding. Longer duration rainfall events tend to produce more sustained flows, but usually with a lower peak discharge. 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. The flood peak may actually be higher for less rainfall in this situation.

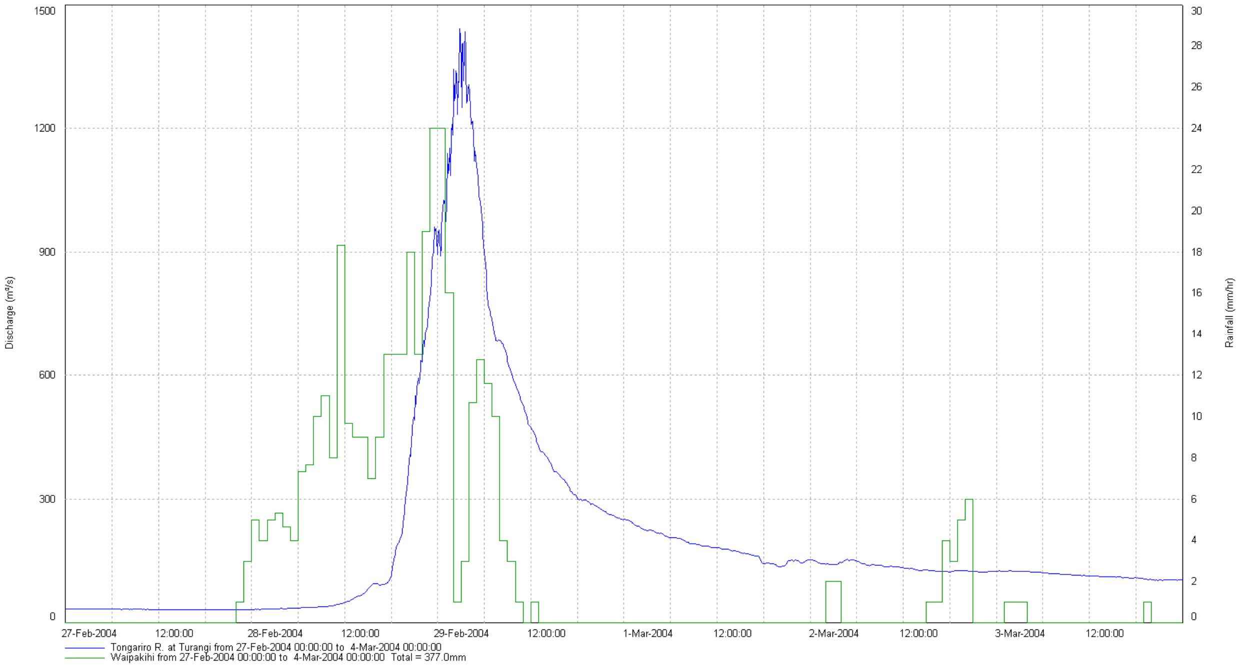

Figure 3.3: Flood hydrograph of the second largest flow on record (Rainfall is in mm/hour).

Despite the variability of specific storms, there is a high degree of similarity in flood response in the Tongariro River. Figure 3.4 compares the 2004 flood hydrograph with that from the 1958 storm. It should be noted that the peak discharges were very similar, but the 1958 flood contained three peaks and sustained higher flows for a much longer period of time. The flood risk of a particular event is a function of both the magnitude of the peak, and the duration of high flows. As a result, the 1958 event posed a significantly greater risk than the 2004 flood. Given the lower population and capital investment on the floodplain at the time, however, the cost of the 1958 flood is likely to have been significantly less than caused by the 2004 event even though the flood was bigger.

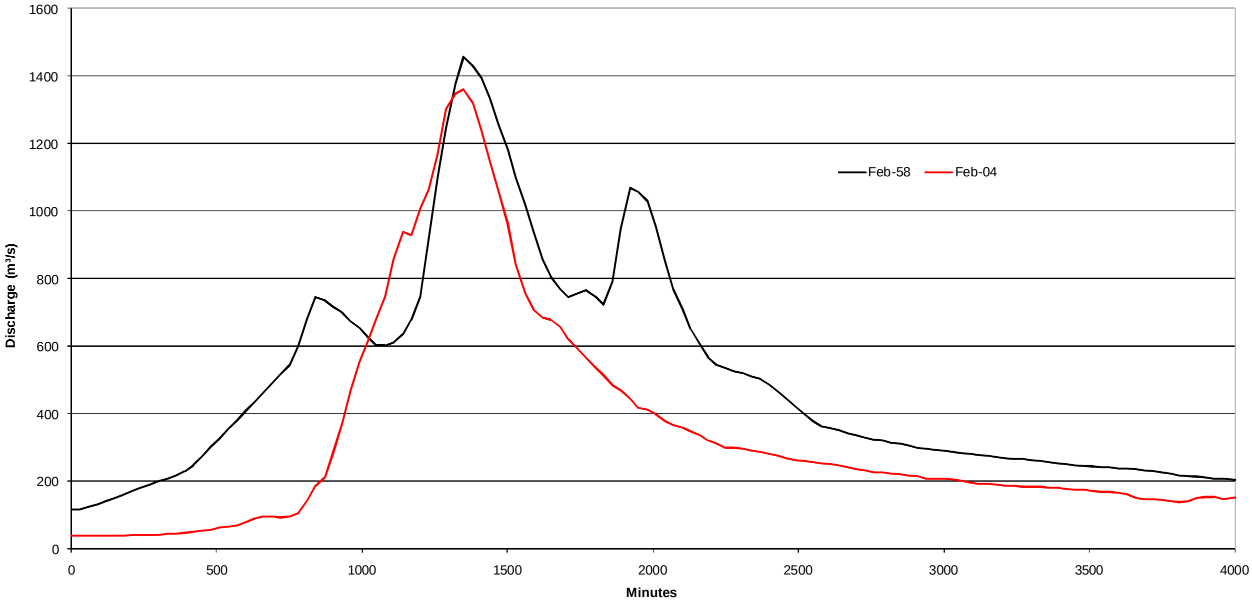

Figure 3.4: Comparison of the two largest floods on record i.e., 1958 (largest) and 2004.

Analysis of a series of flood hydrographs for the Tongariro River indicate a relatively consistent pattern of response. Rainstorm durations leading to significant flood events are usually over 36 hours in duration. The resulting floods typically have one major peak, and the body of the flood lasts for about 24 hours. These findings are consistent with those presented in Tonkin & Taylor (2004).

3.4 29 February 2004 flood

The 29 February 2004 flood was the second largest flood recorded on the Tongariro River, only slightly smaller than that of February 1958. This event resulted in the flooding of houses, significant property damage, and some dramatic changes in river morphology and channel position.

February 2004 was a very wet month, particularly in the Tongariro catchment and the Taupo basin. Some rainfall stations received up to 480% of their usual monthly rainfall. The 36-hour rainfall totals resulting in this flood event were particularly high on the western side of the catchment. Rainfall totals in this area were up to 289mm (Mangatoetoe); approximately twice the total monthly rainfall in just 36 hours. Peak rainfall intensities were not particularly high (23.5mm/hr) but the rainfall was persistent with intensities of 7mm/hr or greater for 20 hours (Bowler, 2004).

The peak flow estimated at Turangi was approximately 1420m^3/s. This is only slightly less than the peak flow in 1958 (i.e. 1470m^3/s). From a planning and management perspective, the 2004 flood peak was 36% higher than the next largest flood in the instrumental record (1038m^3/s in 1964).

Prior to the 2004 flood, the return period for an event of this magnitude was estimated at approximately 1 in a 100 years. Given that there were then two events of this magnitude in the previous 50 years, the return periods were revised after the 2004 event. The 2004 flood was subsequently thought to be a 1 in 55-year event, and the 1958 flood a 1 in 60-year event. These flood estimates have been revised again in 2010 using an additional six years of flow data. The relative lack of flood activity over this 6-year period has led to a reduction in the magnitude of specific design floods. For example, the 100-year event estimated in 2010 is 1451m^3/s; the 1958 flood becoming a 107-year event and the 2004 flood becoming a 97-year event.

The 2004 flood took approximately 2 hours to travel the 35km from the Waipakihi confluence to Turangi. Therefore, the flood wave was travelling at almost 5m/s which is high enough to keep boulders up to 400 mm in motion (Bowler, 2004).

The main residential areas affected by flooding were houses down Herekiekie St, Hirangi Rd, Awamate Rd, the river end of Koura and Poto Sts, Bridge Lodge, Tongariro Lodge, and farm land on both sides of the delta (Figure 3.5). On Herekiekie St, up to 90 persons were evacuated and at least one house was subsequently condemned (Bowler, 2004).

A flood of this magnitude has the ability to erode and transport large amounts of material. As a result, significant changes to the form and position of the river are to be expected. The most dramatic change was in an area known as the Breakaway Pool. Here the river created a new channel through what was previously a heavily vegetated island. While this new channel had been developing slowly during previous flood events, the river permanently changed its course during the 2004 flood. This change did not just affect the position of the river. The new channel is approximately 30% shorter than the old, and therefore the gradient of the river has steepened. This has increased the velocity of flow which has also increased the river’s ability to erode and transport material.

Bed degradation was common during the 2004 flood. The high flows during the event moved much of the lose material down stream. This material is likely to have been deposited on the Tongariro delta where river gradients and velocities decrease. Environment Waikato estimate that as much as 150,000m^3 of material may have been deposited downstream of the State Highway Bridge. This is consistent with the amount of bed degradation observed up stream where bed levels dropped by 300-500mm (Bowler, 2004).

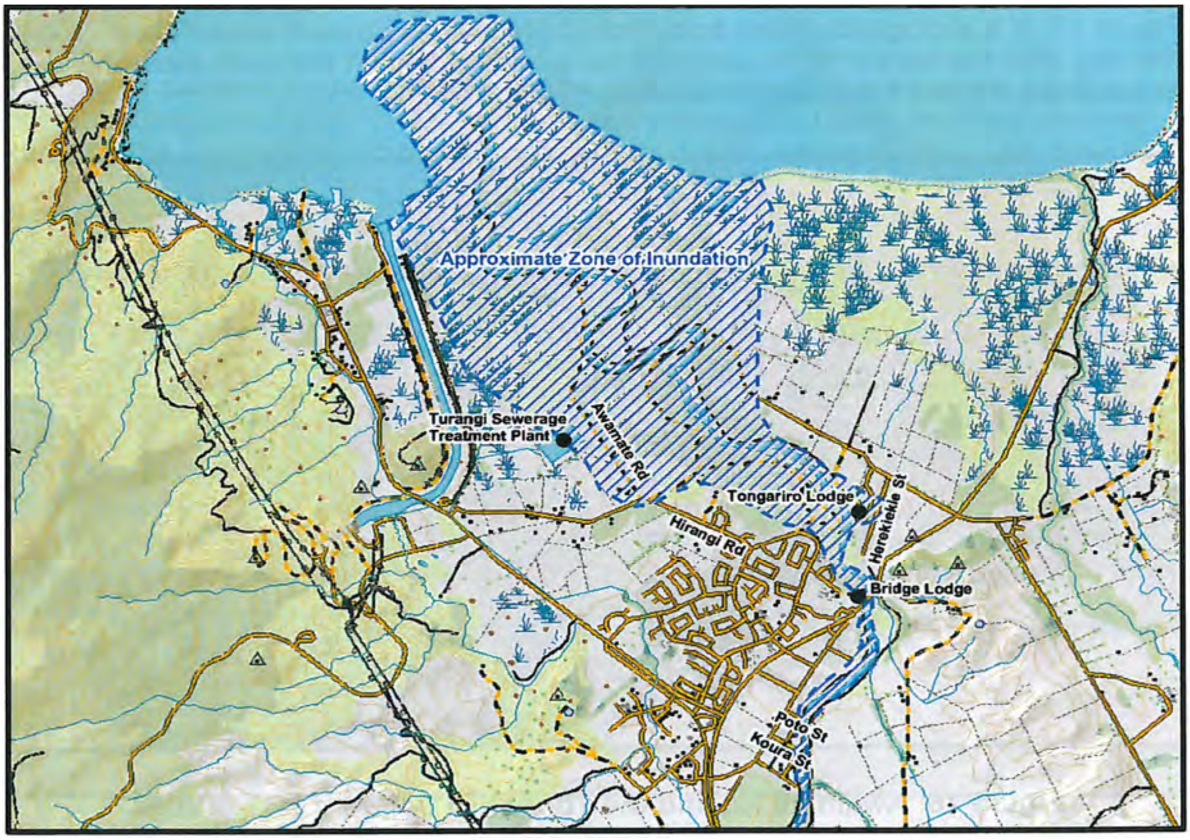

Figure 3.5: **Area affected by the February 2004 flood event in the lower river (Bowler, 2004).**

The instability of the lower reaches of the channel are indicative of potential future changes. It appears that the overflow channels down towards the river mouth (across Grace Rd to Stump Bay and across Awamate Rd towards Deep Stream) have become more established following the 2004 flood. Recent observations at Awamate Rd show that even during quite low flows (around 40m^3/s) water is flowing from the main Tongariro River channel towards Deep Stream. It is possible that during the next large flood the Tongariro River may move from its present course and cut a new channel to Lake Taupo (Bowler, 2004).

3.5 Flood protection

To mitigate the flood risk on the lower floodplain an extensive programme of works has been undertaken. This has included the construction of stopbanks, the provision of bank protection, the removal of riparian willow, and channel modifications. This protection is designed to protect those areas at greatest risk, often with high capital investment, from the 100-year flood event.

Considerable annual maintenance is required to ensure that the flood protection scheme operates to the levels for which it was designed.

3.6 Flood modelling

Tonkin and Taylor (2004) have undertaken a number of hydraulic modelling studies of the Tongariro River as part of river management investigations. Modelling of the 100-year flood levels in the lower Tongariro was undertaken in 1997, 2001, and 2004 using a one-dimensional MIKE 11 hydraulic model.

Prior to the current study, the latest modelling of the lower Tongariro was carried out using design flows of 1500 and 1700m^3/s. Upstream of the SH1 bridge the 2001 model produces higher water levels than the 2004 model. Downstream of the bridge, the 2004 model results are generally higher. These results reflect the changes in river bed levels, and consequently the channel cross sections, caused by movement of bed material during the 2004 flood. As discussed above, this event tended to erode the channel upstream of the bridge (i.e., this increased the channel capacity) and deposited material downstream (i.e., this decreased the channel capacity). The use of a design flow of 1700m^3/s produced very similar results to a flow of 1500m^3/s, with a maximum increase in water level of only 0.35m. Overall, the increase in flow creates the greater rise in water level in the upper part of the model (i.e., upstream of the SH1 bridge). As would be expected, given the less confined nature of the river channel below the SH1 bridge, the increase in water level over that experienced during a 1500m^3/s flow event gradually decreases down the river.

The results of this modelling has indicated those areas in which stop-bank crests need to be raised, and those where the current design is appropriate to manage the estimated 100-year event. Figure 3.6 shows the approximate limit of the area likely to be affected by the 100-year event in the vicinity of Turangi based on the Tonkin and Taylor modelling.

Figure 3.6: Area likely to be affected by the 100-year flood event (Tonkin & Taylor, 2004).

Some modelling has also been undertaken assuming a 500-year event flow of 2400m^3/s (Tonkin & Taylor, 2005). Such an event is likely to overtop the existing and proposed stop-banks throughout Turangi, with overtopping greatest immediately upstream of the SH1 bridge.

The design flood events used in the above analyses are slightly higher than those obtained using the latest flow information. This would suggest that the discussion above is conservative, and that the protection works may actually contain larger return periods events than suggested above (Table 3.3).

Table 3.3: Design flood events from different sources.

Return Period	Tonkin & Taylor reports (m^3/s)	Tongariro River 1957-2010 * (m^3/s)
100	1500 and 1700	1451
500	2400	1892

** This study – derivation discussed below.*

3.7 Channel stability

The Tongariro River carries thousands of tonnes of sediment each year. While some of this is boulders and gravel (on average about 11,700 tonnes per year) ten times this amount is sand-sized or finer. Some of this material comes from the Kaimanawa Range with large amounts of volcanic ash, pumice, and lava fragments coming from the volcanoes in the west of the catchment. Although the Tongariro is a gravel-bed river until just downstream of Turangi, the volcanic material is mainly sand-sized or finer and this tends to be washed onto the delta. The 1995-96 eruptions of Mt Ruapehu deposited nearly 7 million tonnes of material into the Tongariro catchment. Two-thirds of this was sand-sized or smaller. Much of this fine material has aready washed down to the Tongariro delta, but subsequent floods release new ‘waves’ of sediment into the river. Between eruptions, when sediment supply from upstream is reduced, floods can erode previous deposits along the bed and banks (Smart, 2005).

The Tongariro is therefore a highly dynamic river that undergoes significant changes in response to floods, and the input of sediment from erosion and eruptions in the headwaters. The river transports large amounts of sediment through the upper reaches and deposits this material on the river’s delta down stream of Turangi. Over the last 1850 years the Tongariro delta has grown at an average rate of 2.6 million tonnes per year. This is around twenty times the present rate. The relatively slow rate of growth under current conditions has important implications to the flood risk. The fact that the township of Turangi is located at the head of the delta, perhaps the most dynamic location in the entire catchment, adds significantly to the flood risk and the difficulties of managing this risk.

Prior to forming its present delta mouths, the Tongariro River flowed between Turangi and the oxidation ponds, significantly west of its current position. It then entered Lake Taupo along the line of the present Tokaanu Stream. Earlier river mouths can be seen in the bathymetry of Stump Bay. The river mouth and delta area are therefore highly dynamic. They have been subject to significant changes and shifts in the past, and are likely to change again at some stage in the future.

The lower delta currently shows that the river is close to breaking out of its present channel and forming a new path to Lake Taupo. This is a natural process that has occurred many times in the past. A significant volume of water is currently being lost from the present channel, even during relatively low flows as discussed above. Floodwaters spill from the river upstream of De Latours Pool. This water then flows east to Stump Bay, and west towards the Tokaanu tail race via Deep Stream. The most likely future breakout route for the river is from Downs Pool to Tokaanu Bay via Deep Stream (Smart, 2005).

Besides the impact of variable rates of sediment supply, the Tongariro delta is also affected by subsidence. This lowering of the delta is partly a function of the compaction of the sediments, but it is also caused by tectonic deformation. The net affect of these processes is that the delta is subsiding relative to the northern end of Lake Taupo by approximately 3mm a year. This has made, and is making, the southern shores of the lake and the Tongariro delta more flood prone.

The dominant controls on the growth and dynamics of the lower delta have been the frequency and magnitude of floods and eruptions, the level of Lake Taupo during flood events, and willow tree growth. The effects of these controls can be considered either beneficial or detrimental depending on whether one is considering wildlife habitat or human infrastructure on the delta (Smart, 2005).

3.8 Flood frequency analysis

A flood frequency analysis using the annual maxima of the flow series (Table 3.2) was undertaken to provide estimates of the flood magnitudes for events with various return periods. A PE3 statistical distribution provides the best fit to the annual maxima series (Figure 3.7). The results of this analysis are contained in Table 3.4.

Table 3.4: Flood estimates for the Tongariro River (assuming a PE3 distribution).

Return Period	Tongariro River 1957-2005 (m^3/s)	Tongariro River 1957-2010 (m^3/s)
2.33 (annual)	408	406
5	632	622
10	839	816
20	1047	1008
50	1324	1260
100	1534	1451
200	1746	1641
500	2022	1892

The results of this latest analysis are consistent with those of previous studies (e.g., Tonkin & Taylor, 2002; Environment Waikato, 2005b). The significance of the length of record and the actual occurrence of floods on the estimates of specific design flood magnitudes is clearly evident in Table 3.4. The addition of five more years of flood maxima reduced the estimates of the 100 and 500-year floods by approximately 1.5%. This is because these five years were relative benign with respect to flood events e.g., 2005 had the lowest annual flood in 53 years of record. While 2008 had the 13th largest flood on record, all other years since 2004 had annual floods less than the median.

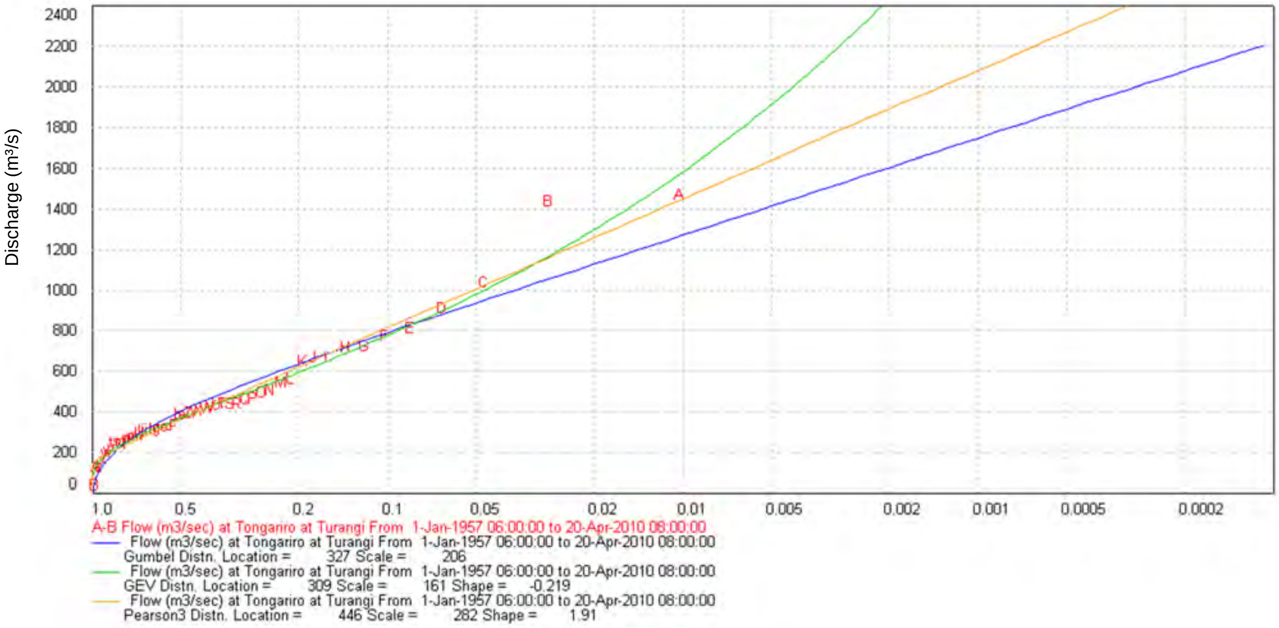

Figure 3.7: Flood frequency analysis of the Tongariro River.

3.9 Flood extent

Using the MIKE21 2-dimensional coupled hydraulic model discussed later, the area potentially at risk from the 100-year flood estimated from the current instrumental record can be determined (Figure 3.8). The flood waters are generally contained within the present channel and stop banks until Turangi township. Some minor overbank flow could be expected upstream of the State Highway bridge. From approximately 1km below the bridge, the flood waters start to spread out across the floodplain and delta. From approximately Smallmans Reach, the entire floodplain from the Tokaanu Tailrace to Stump Bay would appear to be subject to potential inundation. The flood extent predicted by the latest modelling is almost identical to that actually experienced during the February 2004 event. This provides some confidence in the hydraulic flood modelling undertaken for this study.

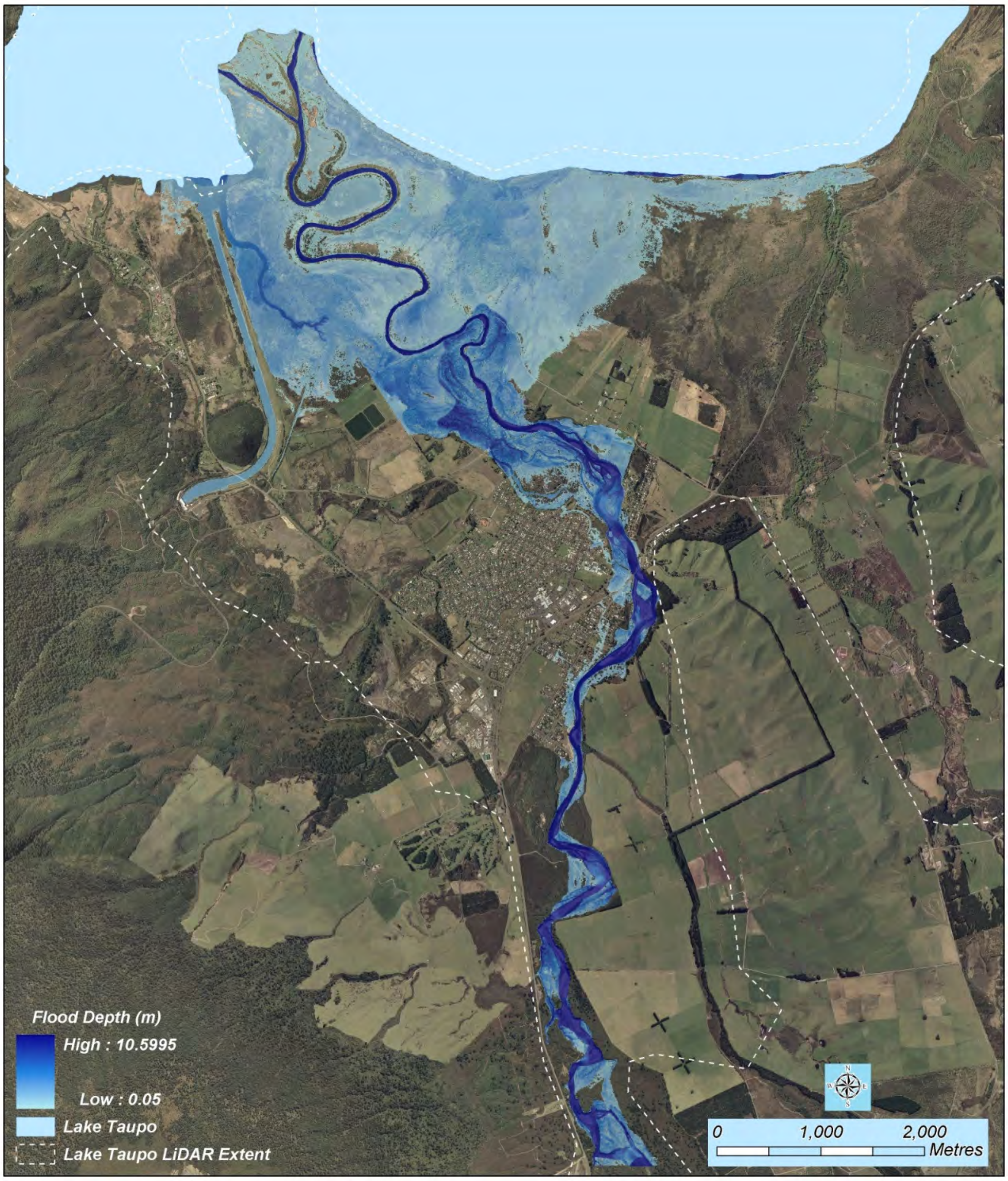

Figure 3.8: **Area at risk from the 100-year flood event in the lower Tongariro River.**

3.10 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 ($m^3 X 10^6$)***	***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 Tongariro catchment, the most dramatic land use change 'likely' would be the conversion of all the forestry lands to pasture. It must be recognised that such a land use change is actually extremely unlikely given the various constraints on land use within the catchment. There are at present 78km^2 under some kind of exotic forestry management within the Tongariro catchment (LCDB2 – 2004).

Using the information presented in Table 3.5, converting this 78km^2 from forestry to pasture could have the potential effects summarised in Table 3.6. It should be noted that most of the exotic forestry is on the lower porous and permeable soils. Conversion of this land would therefore have less dramatic consequences than would be likely should the conversion take place elsewhere within the catchment.

Table 3.6: Potential effect on the hydrologic regime if all 78km^2 of exotic forest lands within the Tongariro catchment were converted to pasture.

	Average increase in peak discharge per km^2 converted (m^3/s)	**Increase in peak discharge if all forestry areas converted to pasture (m^3/s)**	**Average increase in flood runoff volume per km^2 converted (m^3)**	**Increase in flood runoff volume if all forestry areas converted to pasture (m^3 X 10^6)**
2	0.18	14.0	0.019	1.5
10	0.40	31.2	0.033	2.6
20	0.54	42.1	0.042	3.3
50	0.78	60.8	0.057	4.4
100	1.03	80.3	0.072	5.6
200	*1.45*	113.1	*0.091*	7.1
500	*2.18*	170.0	*0.125*	9.8

Note: The estimates for 200 and 500-year RP events were not provided in the original report (Environment Waikato, 2006) and so have been estimated through curve fitting.

From the perspective of the flood hazard it is the increase in peak discharge that is most critical. The changes in the estimated flood peak as a result of converting all the area under exotic forestry to pasture would be 4.8% for the 50-year event and 5.5% for the 100-year event.

The changes in peak flood discharge as a result of land use change, assuming the complete conversion of all exotic forestry to pasture, are so small that they do not need to be considered in design flood estimates. This is because any effect of land use change is likely to be within the error limits of any flood estimate.

3.11 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 3.9). These data are summarised in Table 3.7.

Table 3.7: 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 3.8).

Earlier flood analysis in this report has shown that rain-storm durations of 36 hours and longer pose the greatest flood risk in the Tongariro 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.

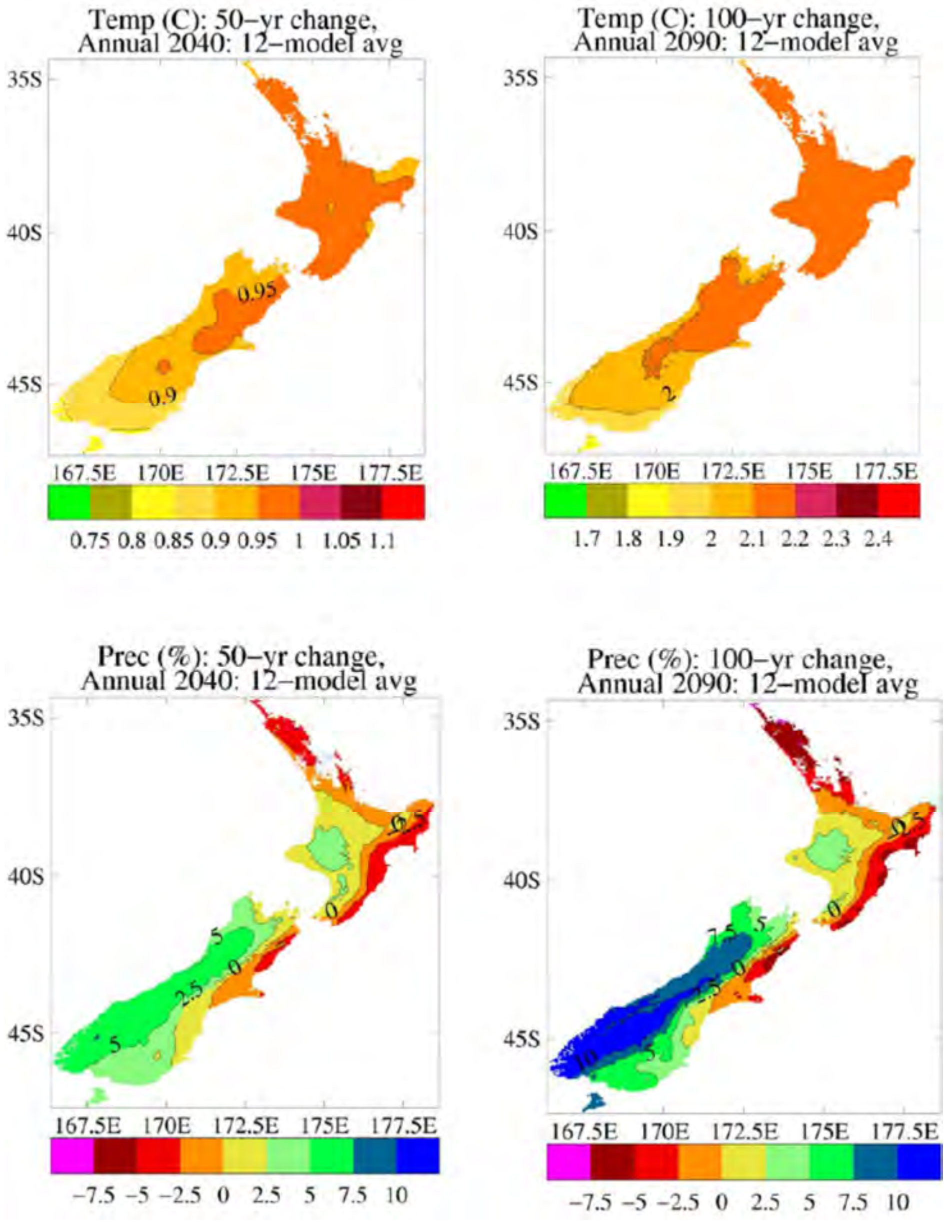

Figure 3.9: **Projections for increases in mean annual temperature and rainfall by 2040 and 2090 relative to 1990; average of 12 climate models for A1B emission scenario (Figure 2.3, Ministry for the Environment, 2008).**

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 3.9). 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 3.8: 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 3.9 Estimated percentage increase in 24-hour rainfall totals for the Tongariro 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 3.9 have been translated directly to percentage increases in flow.

Table 3.10 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 3.9). It should be noted, however, that the predicted flood peaks by 2040 using the highest temperature forecasts 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 3.10: Increased flood discharge for the Tongariro River as a result of predicted global warming.

Return Period	Flood peak discharge estimated from the current instrumental record (1957-2010)	Flood peak discharge 2040 – highest temperature prediction (m^3/s)	Flood peak discharge 2090 – average temperature prediction (m^3/s)
2.33 (annual)	406	448	443
5	622	703	692
10	816	939	924
20	1008	1182	1160
50	1260	1502	1472
100	1451	1730	1695

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 Tongariro 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 at least the delta. 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 mobilise significant quantities of bed load which is eroded from the upper catchment during these high energy events. While this material can be transported through the upper reaches, it is often deposited on the lower floodplain. The 2004 flood for example eroded material upstream of the SH 1 bridge, deepening the channel and increasing the freeboard before the stop-banks are overtopped. Downstream of the bridge the channel aggraded. This reduced the freeboard and as a result it has increased the flood risk. This risk is compounded by the relatively limited capacity of the main channel, and the erodible nature of the material forming the bed and banks.

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 limit the flood extent, duration, and inundation depth they are difficult to build into any flood hazard model. This is because they are essentially random occurrences in both time and place. Assuming that the river channel capacity is maintained in accordance with the Environment Waikato's Tongariro Flood Management Plan, any adverse effects of sedimentation within the channel should be minimised.

4.2 Lake level

The extent and depth of inundation caused by flooding of the Tongariro River is partly controlled by the water level in Lake Taupo. Higher lake levels can exacerbate flooding. Lower lake levels can also 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
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 Tongariro floodplain 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 in the vicinity of the Tongariro 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.

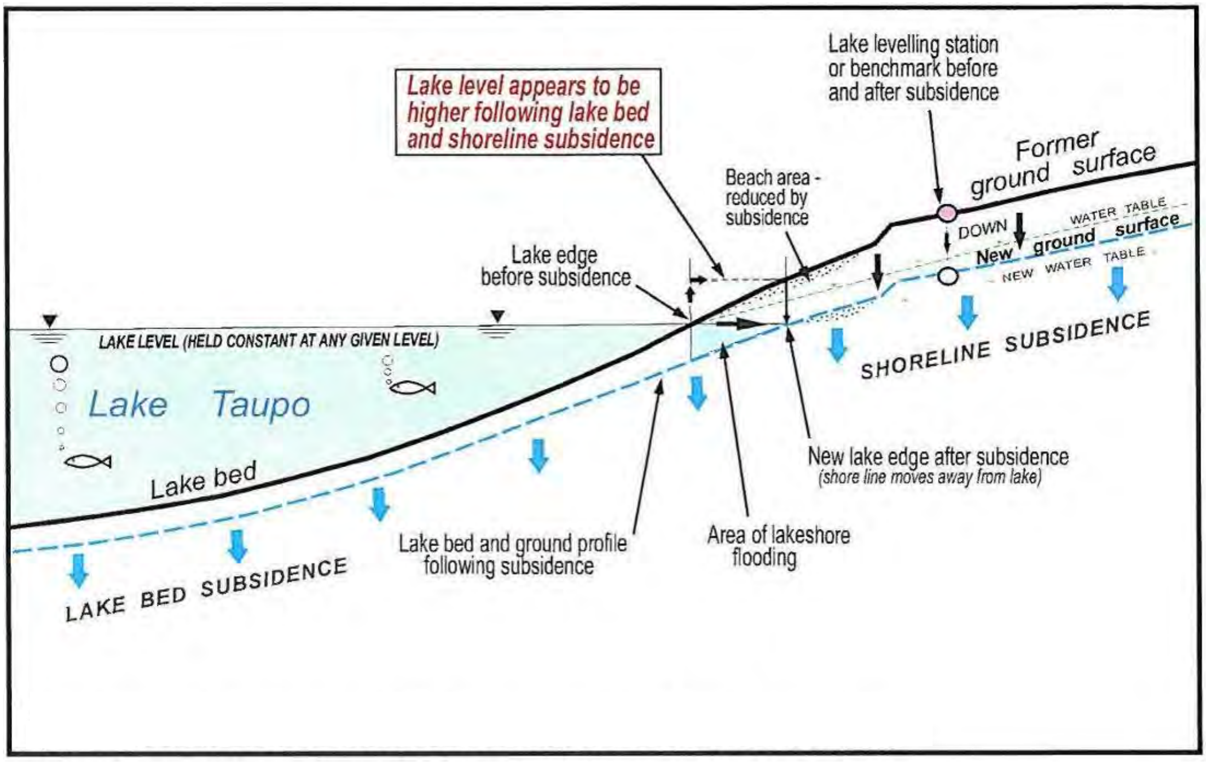

Figure 4.1: **Effect of ground level subsidence on relative lake levels (Hancox, 2002).**

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 Tongariro delta, 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.

Based on this tectonic deformation model, the area in the vicinity of the Tongariro delta is subsiding at between 2.6 and 3.0 mm/yr. Over a 100-year period therefore the Tongariro floodplain and delta is likely to subside 260-300mm. The effect of this on the flood risk is that lake levels will be relatively higher, and this, in combination with reduced channel slopes, will likely increase the extent, duration, and depth of flooding caused by large storm events.

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

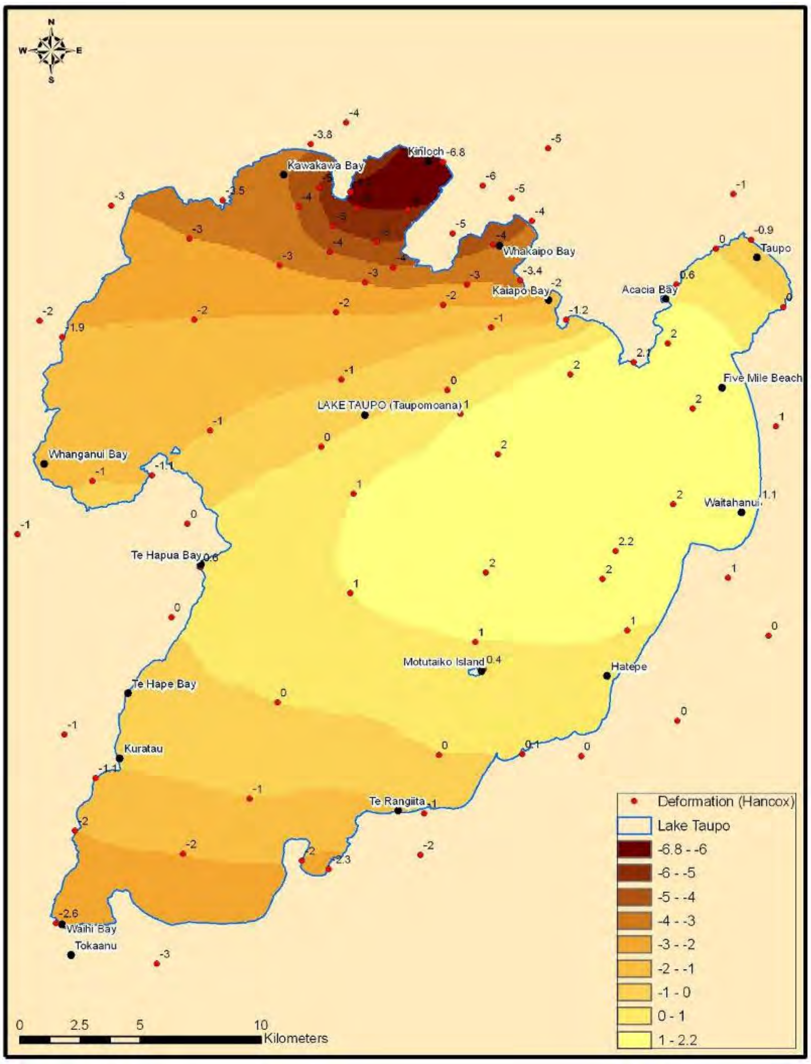

Figure 4.2: Average rates (mm/yr) of tectonic deformation between 1979 and 2002 (After Hancox, 2002).

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 Tongariro River delta is contained in McConchie *et al.,* (2008). The Tongariro River discharges into the Waihi wave environment (Figure 4.3).

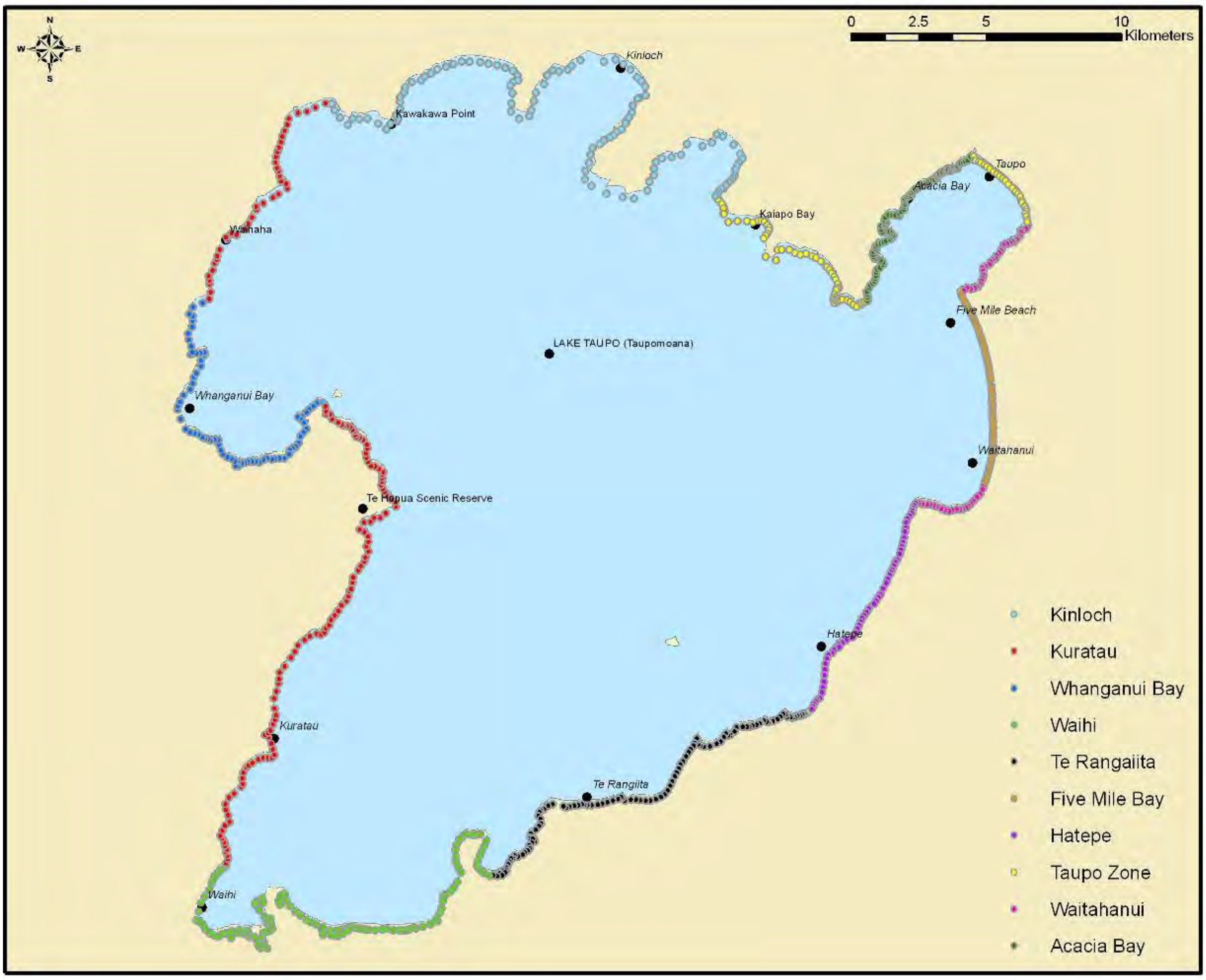

Figure 4.3: Wave run-up environments around the shore of Lake Taupo.

The frequency distribution for the 2% exceedance wave run-up for Waihi is summarised in Figure 4.4. It should be noted that Waihi is one of the lowest wind energy, and therefore lowest wave run-up, environments around Lake Taupo.

A frequency analysis of the wave run-up data for the Tongariro River delta shows that a PE3 distribution fits the data well. This statistical distribution therefore provides good estimates of the magnitude of wave run-up events for particular return periods (Table 4.3).

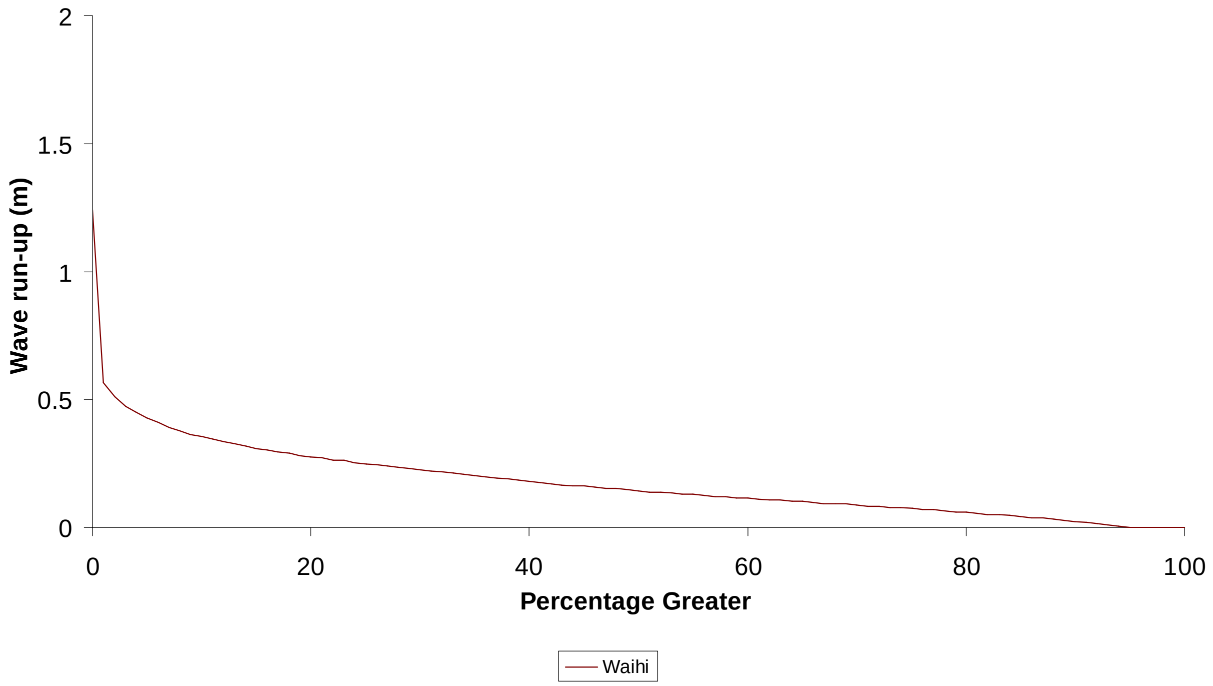

Figure 4.4: **Frequency distribution of wave run-up in the Waihi (i.e. the Tongariro delta) wave environment.**

Table 4.3: **Estimated 2% exceedance wave run-up height (m) for Waihi (i.e. the Tongariro delta).**

	Waihi
Distribution	*PE3*
Return Period	
2.33	0.74
5	0.85
10	0.94
20	1.03
50	1.14
100	1.22
200	1.30
500	1.41

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.

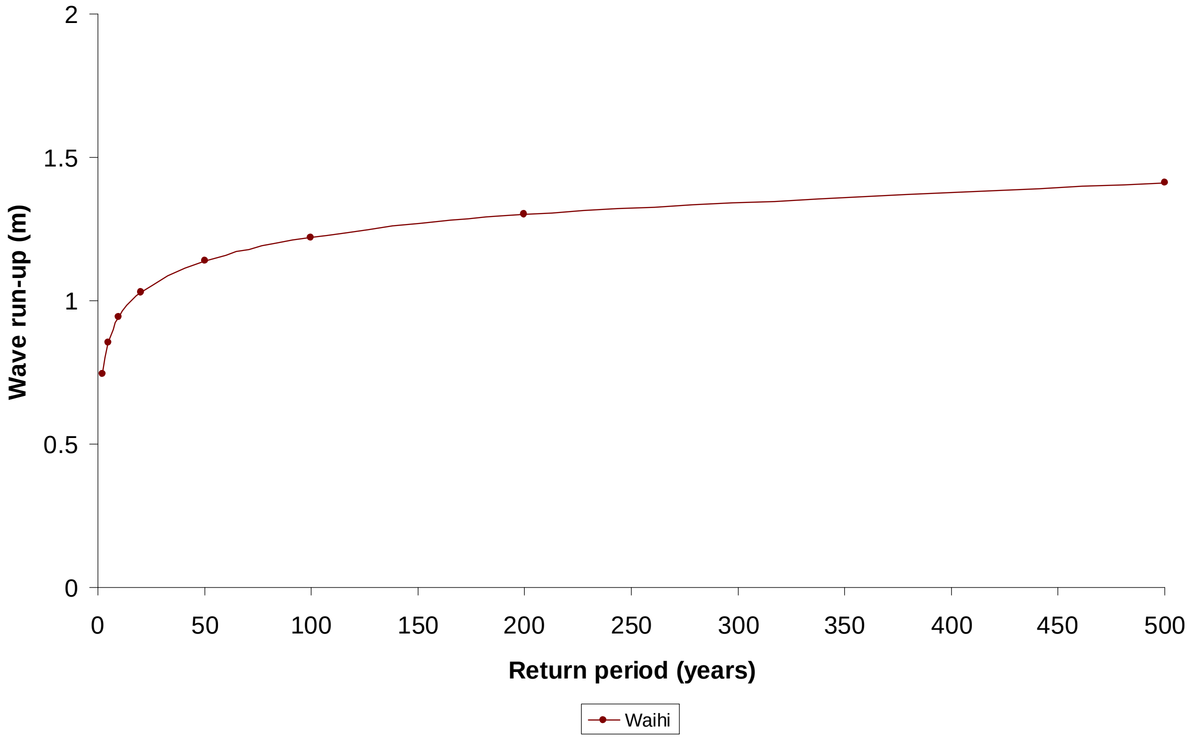

Figure 4.5 **Wave run-up height (m) for Waihi (i.e. the Tongariro delta).at different return periods.**

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 (0.300m at the Tongariro delta). 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 (Figure 4.6). 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 much of the Tongariro delta, Deep Stream, and the Tokaanu Tail Race are likely to be affected by flooding as a result of a combination of high lake levels and ongoing subsidence (Figure 4.6). Subsidence rates in this area are some of the highest around Lake Taupo. Since this area is subject to relatively small waves, the majority of the flood risk is the result of higher effective static water levels. The 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.

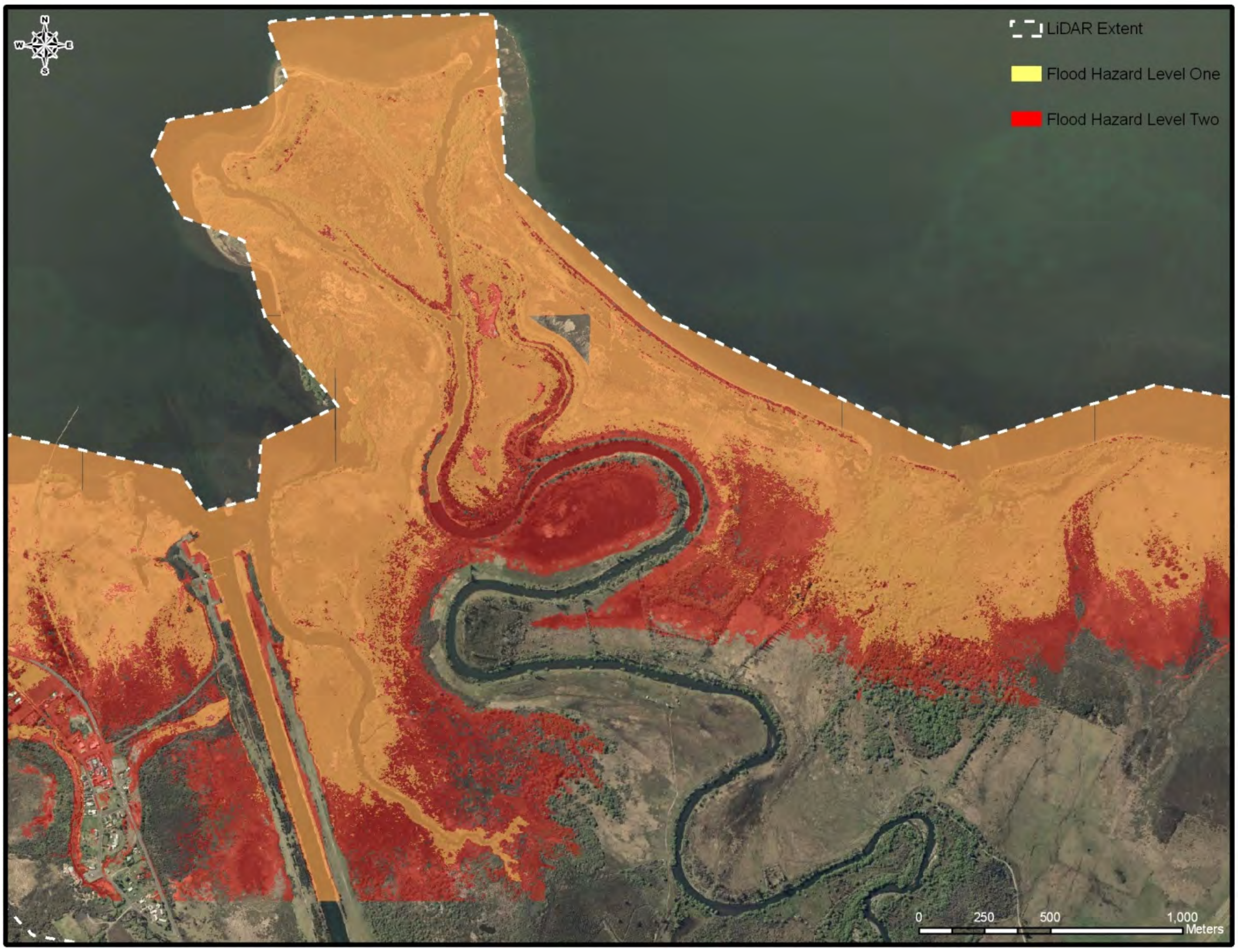

Figure 4.6: **Lake flood hazard zones from McConchie *et al.*, (2008). Note: The colours are slightly different from the legend because they are transparent so that the image underneath can be seen.**

5 Flood risk

The flood risk in the vicinity of the Tongariro River and delta 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 and waves is shown in Figure 4.6. The area likely to be affected by the 100-year flood in the Tongariro River, predicted from the instrumental record; is shown in Figure 5.1.

There is a high degree of consistency between the areas likely to be affected by flooding caused by either elevated lake levels or extreme river flows. 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 likely to be affected by the 100-year flood in the Tongariro River, predicted from the instrumental record and assuming a lake level of 357.5m.

There is also close agreement between the area likely to be affected under the various flood models, and the distribution of floodplain soils shown in Figure 2.4. This provides independent validation of the flood risk assessment.

The extent of the area at risk from flooding shown in Figures 4.6 & 5.1 is likely to be the minimum. It does not include either the potential effects of climate change on flood peaks, or the effect of higher lake levels on the river-related flooding. To assess the effects of these factors on the extent of flooding, a MIKE21 two-dimensional coupled hydraulic model was developed for the area.

6 MIKE21 flood model

6.1 Previous flood modelling

Since 1997 Tonkin and Taylor (T&T) have carried out a number of one-dimensional computational hydraulic modelling studies to predict flood levels along the Tongariro River past Turangi. The most recent study (Tonkin & Taylor, 2004) refined the calibration of the MIKE11 model using data from the February 2004 flood event. The model was then used to determine design flood levels for upgrading the stop-banks.

The MIKE11 model, however, only covers a 5.5km reach of the Tongariro River through Turangi. It does not cover the reaches either upstream or downstream of the township. These reaches have been included in a MIKE21 model, the results of which are presented later in this report. One-dimensional models are also not able to predict the path of floodwater which overtops the stop-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 MIKE21 hydraulic model therefore offers considerable advantages over a MIKE11 model when assessing the flood hazard of the lower Tongariro River.

6.2 Methodology

Using LiDAR topographic information gathered in 2004 and river cross-section data a two-dimensional MIKE21 model was established. The model covers an area of approximately 7.8km by 11.5km. It extends 19km down the Tongariro River from Poutu Pool to Lake Taupo. The digital terrain model (DTM) was adjusted so that it reflected the river and its floodplain prior to the flood event of 29 February 2004. The model was then calibrated against this event using post-flood debris mark data (Tonkin & Taylor, 2004), and an indicative flood extent map (Smart, 2005).

All the stop banks constructed since February 2004 were then added to the pre-29 February 2004 DTM so that it represents the present (2009) situation. This was then used to estimate the 100-year average recurrence interval (ARI) flood extent, both with and without the effect of predicted climate change. The development of the model, the use and correction of the LiDAR data, model calibration, and its advantages over previous hydraulic models are discussed in detail in Opus (2009).

6.3 Model calibration – February 2004 flood event

Calibration of the model was based on surveyed flood level data following the 29 February 2004 flood (Tonkin &Taylor, 2004). A map of the estimated flood spread was also used (Smart, 2005). The model was set up with the following boundary conditions to mimic those during this flood event:

- A constant Tongariro River inflow discharge of 1360m^3/s at Poutu Pool; and
- A constant Taupo Lake level of 357.21m.

The peak discharge of the river during the February 2004 event has also been estimated at 1420m^3/s. However, given the uncertainty in the accuracy of gauging station rating curve it was considered that a peak discharge of 1360m^3/s was a more suitable value for model calibration purposes. In any case, the difference in predicted flood levels using the two flow values would be only a few centimetres. This is within the accuracy of model calibration.

The flood extent during the February 2004 event (Figure 3.5) is in good agreement with the flood spread predicted by the MIKE21 model (Figure 6.1). The only major difference is that the MIKE21 model results suggest that Awamate Rd, north of Turangi, would have been high enough to prevent the flood waters from reaching the Turangi Sewerage Treatment Plant. This is contrary to what is shown in Figure 3.5

Environment Waikato has since provided confirmation that Awamate Rd was raised after the February 2004 event, and prior to the LiDAR survey. The MIKE21 model is therefore accurate, and its results are more appropriate for this kind of modelling than those from the earlier MIKE11 model. Detailed information regarding the calibration process, and a comparison between actual and modelled water depths is provided in Opus (2009).

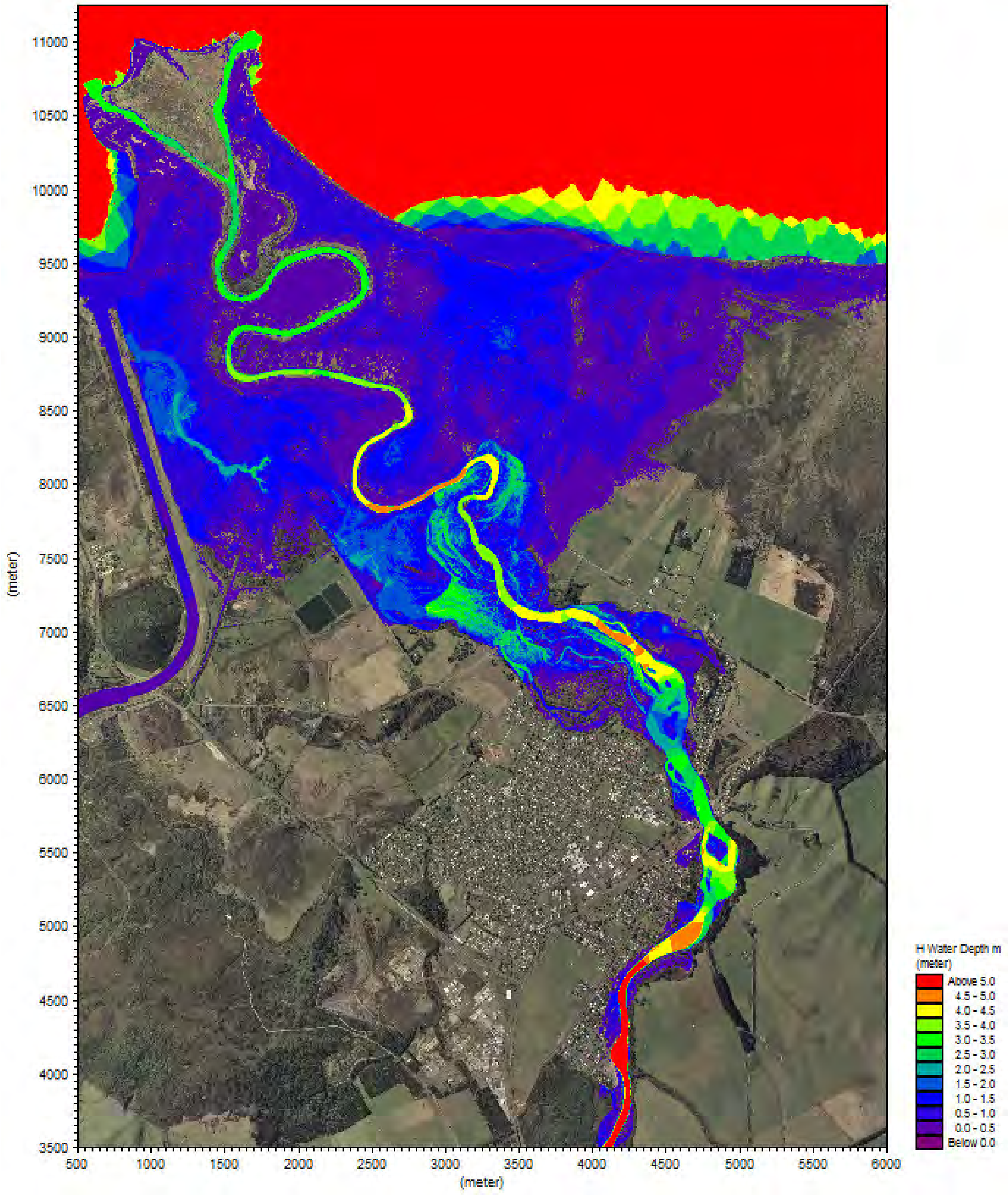

Figure 6.1: **Predicted flood extent of 29 February 2004 event using the calibrated MIKE21 model.**

7 Flood prediction

7.1 Description of scenarios modelled

The calibrated MIKE21 model was then used to simulate a number of different extreme flood scenarios. Table 7.1 summarises the boundary conditions used in each of these flood simulations.

The differences between results from modelling these different scenarios are most marked over the first 6 to 7km of the river modelled (upstream of the SH1 Bridge). Further downstream, the backwater effect of Lake Taupo gradually becomes more dominant. The difference in water levels between the two scenarios gradually reduces to zero towards the lake.

Table 7.1: Description of flood prediction scenarios.

Scenario	**Boundary Conditions**	
	Tongariro River Flow (m^3/s)	**Lake Taupo Level (m)**
100-year flood event predicted from instrumental record (1957-2007)	1511	357.5
100-year flood event predicted from instrumental record adjusted for the predicted effects of climate change	1810	357.5

Note: The flood estimates used in the hydraulic models were those derived using the flow record from 1957-2008. The past two years of data have reduced these estimates slightly as explained with reference to Table 3.4. This means that the results of the modelling are likely to be slightly conservative i.e. higher water levels.

7.2 Flood inundation maps

The flood inundation maps for the two scenarios are shown in Figures 7.1 & 7.2. These two maps show very similar patterns of inundation. The inundation predicted is also consistent with what actually occurred during the 29 February 2004 flood event. The maps show that, even when not considering the effects of climate change, some of the stop-banks are overtopped. This would potentially lead to the partial inundation of Turangi upstream of the SH1 Bridge.

The crest level of all stop banks and floodwall features were checked to ensure that they are correctly reproduced in the MIKE21 terrain model. Since the model is correct, these predictions of partial inundation of the township would appear to be reliable.

These inundation maps also show that a lake level of 357.5m floods the adjacent land. This is consistent with observations of lakeshore inundation during previous extreme flood events.

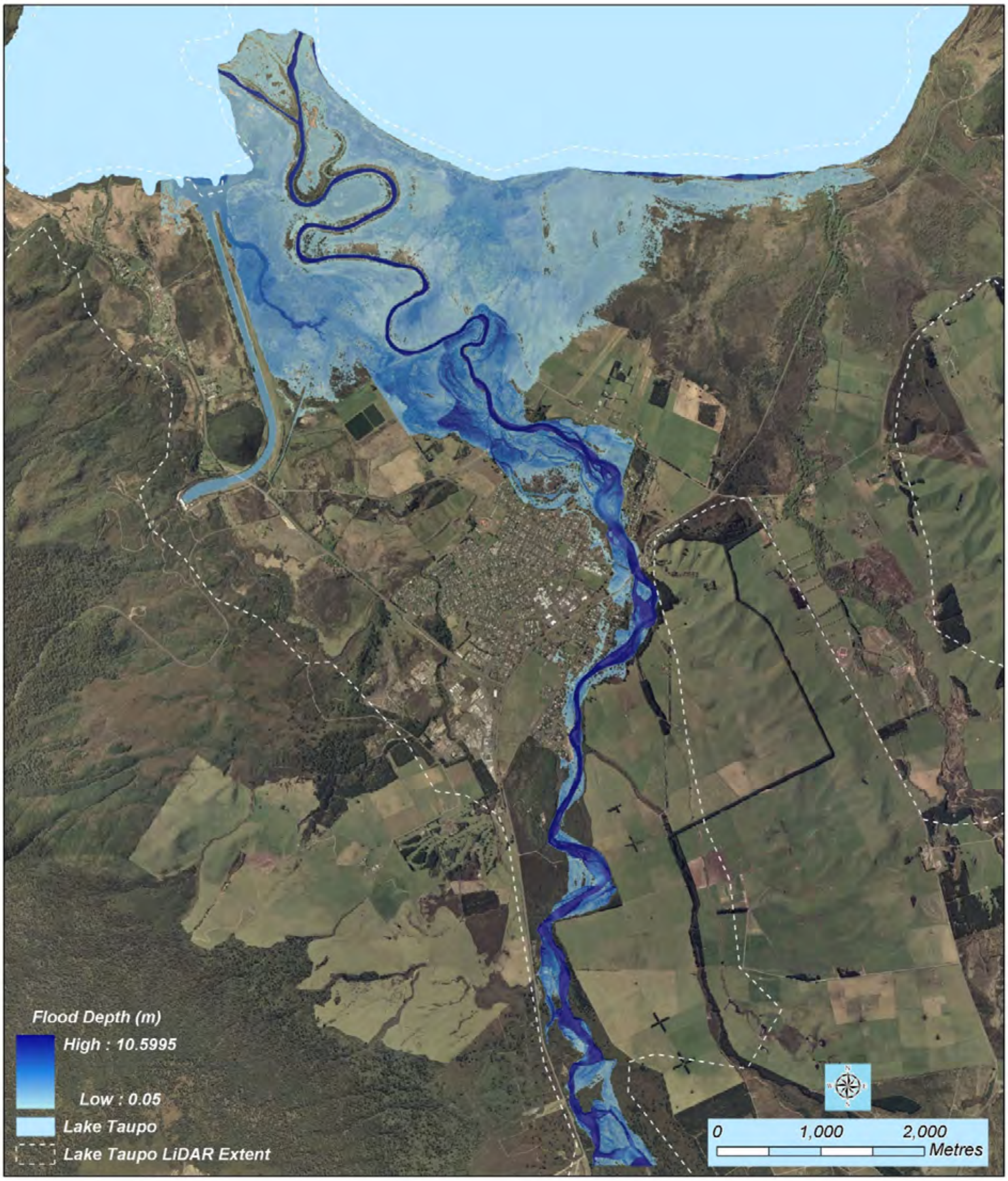

Figure 7.1: **Depth of inundation for the 100-year flood event predicted from the 1957-2010 instrumental flow record for the Tongariro River, and assuming a lake level of 357.5m.**

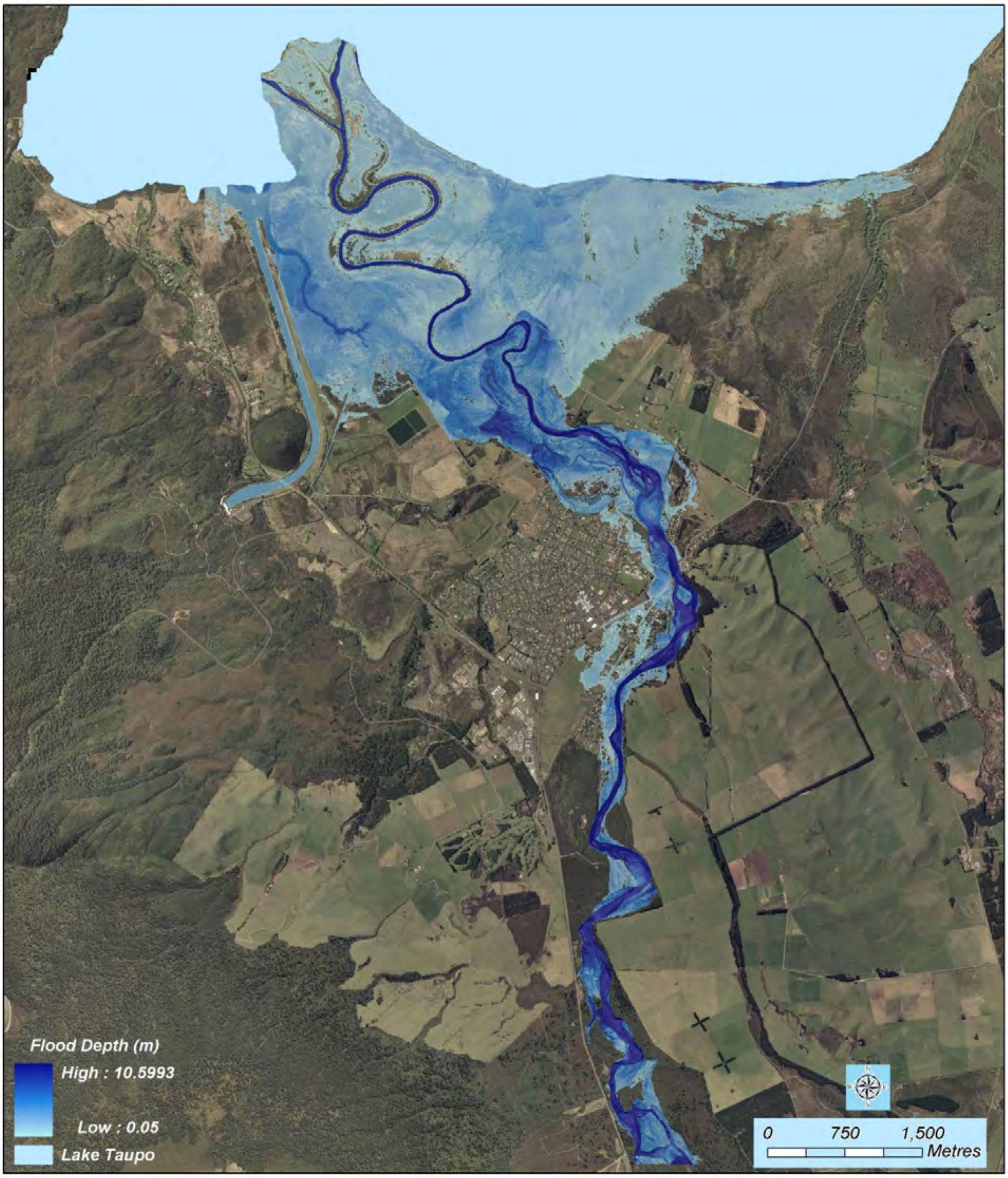

Figure 7.2: Depth of inundation caused by flooding of the Tongariro River; assuming the 'worst case' scenario modelled i.e., 100-year peak flood flow increased to allow for predicted climate change, and a lake level of 357.5m.

7.3 Maximum velocity maps

The maximum velocity of the flood water during each of the two flood hazard scenarios is also essentially identical. Higher flow velocities during the more extreme scenario (scenario 2) occur in the following locations (Figure 7.3):

- In the current river channel;
- In overland flow paths formed by old river channels;
- Where water flows around, or over, local obstacles such as roads and stop banks;
- Where water exits the river channel; and
- Where water enters Lake Taupo.

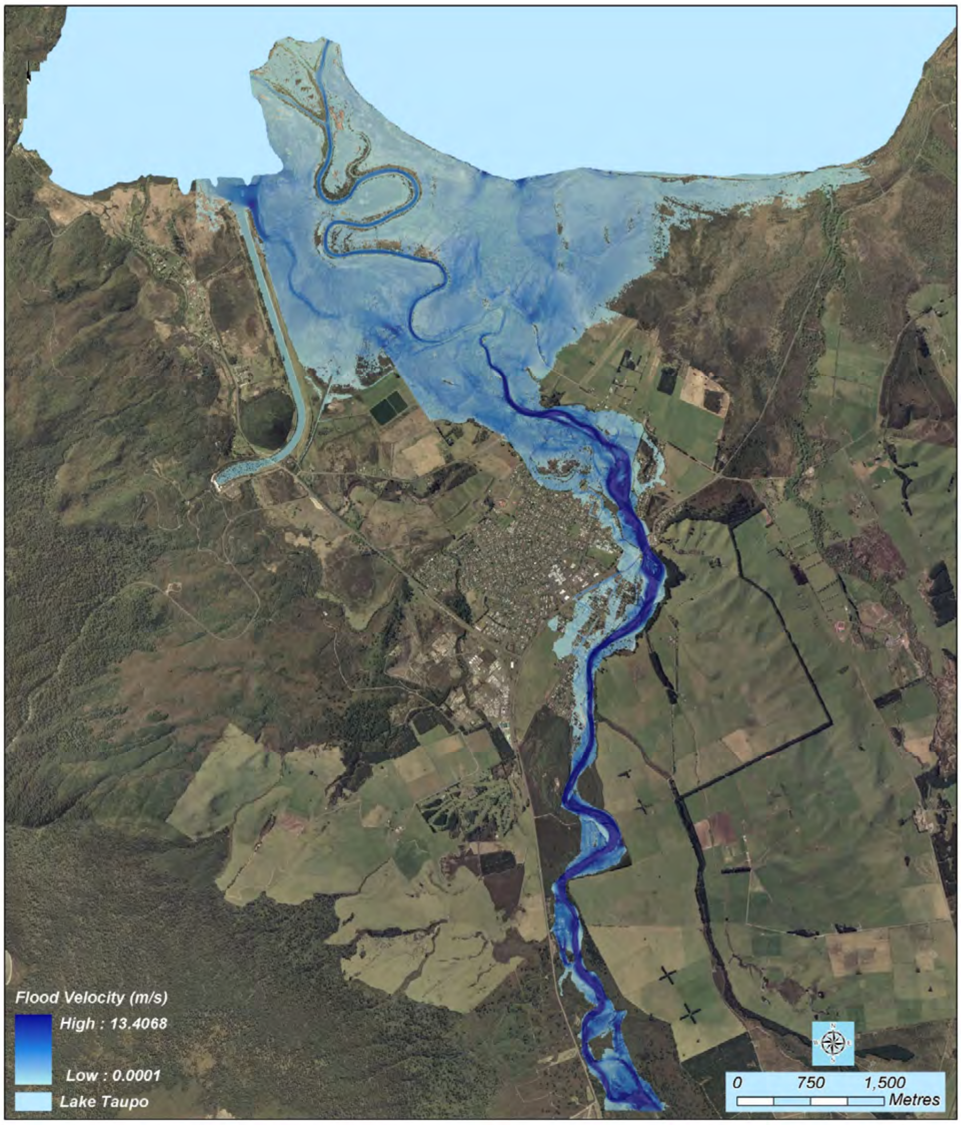

Figure 7.3: Velocity of flood waters assuming the 'worst case' scenario modelled i.e., 100-year peak flood flow increased to allow for predicted climate change, and a lake level of 357.5m. The extremely high velocity shown in the legend relates to one anomalous cell within the model.

8 Impact of flood hydrograph

8.1 Background

In the past there has been some discussion as to the potential effect of the upstream boundary used in hydraulic models on the results, in particular the appropriateness of using a constant peak discharge rather than a flood hydrograph.

A key consideration with regard to the modelling of the Tongariro River is that the calibrated model results show a high degree of similarity to the flood extent actually experienced during the 2004 flood event. As explained, the only difference was caused by the construction of a stopbank after the flood. Once this was removed to restore the floodplain to its pre-2004 condition, the model was accurate in reflecting the overbank flooding which occurred.

8.2 Nature of Tongariro River under flood conditions

The Tongariro is a steep gravel-bed river, and the largest tributary to Lake Taupo. It can experience very high flows under extreme situations. During large flood events substantial amounts of sediment can be eroded and transported. This causes significant changes in bed form, cross-sectional area, bed level, and channel gradient; and therefore water levels. These channel changes are usually greatest where water depth and velocity are highest. It is problematic that these dynamic changes to the channel form and cross-sectional area during a flood event cannot be modelled. Consequently, within any numerical model the channel is assumed constant over the flood event. This is a source of considerable uncertainty in the results of any model.

The steepness and nature of the Tongariro floodplain results in a channel that has a relatively low storage volume compared to the total volume of a flood hydrograph during extreme flow events. This was the initial reason for simplifying the MIKE21 model by using a constant inflow at the upstream boundary inflow. The effect was minor, and any error in the results caused by this assumption would be within that caused by other sources of uncertainty within the model. The use of a constant discharge also greatly simplified the inherent modelling, and therefore shortened the processing time required to complete each model run.

As explained above, a major assumption made in any model, either 1D or 2D, is that the channel cross-section and depth are constant throughout the flood event. It is well established that river beds such as the Tongariro can scour to a significant depth, and bank erosion is common. Therefore, in steeper reaches of the river (where the erosive potential of the flow is higher) it is difficult to obtain reliable estimates of flood levels using models that assume a constant bed profile.

The shape of the flood hydrograph recorded during the 2004 event as discussed previously shows that bed movement and scouring did occur, and that this had a significant effect on water levels. It is generally accepted that the rapidly changing, and apparently irregular, flow during the peak of the flood at the recorder station was a function of changing bed form, and not changing flow (Figure 3.3). It is worth remembering that recorder stations are usually located at the more stable locations so that there are less issues relating to the stability of the rating curve. As bed movement occurred at the recorder site, such movement is likely to have been greater elsewhere along the channel.

There are also other uncertainties in data, including:

- A lack of detailed information regarding some river cross-sections; particularly on the delta where assumptions were necessary; and
- Rapid oscillations observed in water level, and consequently flow data, from the gauging station where the inflow hydrograph was derived. This results in considerable uncertainty regarding the peak discharge estimate.

Considering these uncertainties, assuming a constant discharge at the upstream boundary appeared reasonable. Subsequent analysis summarised below shows that this assumption has very little, less than minor, effect on the MIKE21 model results.

8.3 Effect of varying the upstream boundary

To investigate the effect of using either a constant peak discharge or a flood hydrograph on the results an alternative MIKE21 model was run. This model used a smoothed inflow hydrograph from the 2004 flood event, which approximated the mean of the oscillations caused by the dynamics of the bed discussed earlier, rather than the peak discharge as a constant input. The peak flow was the same as that used in the previous model run. The only significant difference in the model set up parameters was that the time step was reduced from 0.5s to 0.25s to increase the model's numerical stability.

A map was produced showing the difference in peak water levels between the two different model runs (Figure 8.1). Over the vast majority of the model, the water levels predicted using the 'flood hydrograph' are slightly lower, but within 0.1m of the water levels estimated using a 'constant discharge'. A difference of 0.1m is likely within the margin of uncertainty of the hydraulic model and its various inputs. While it may represent a significant difference in the volume of flood water it is probably not significant from the perspective of providing planning guidelines. There is only one area where the predicted peak flood levels depart noticeably between model runs (up to 0.5m). This is over a 1km reach of the Tongariro River upstream of Turangi. This is a steep and constrained reach where high velocity flow is likely to occur. The models predict localised velocities exceeding 7m/s, although mostly velocities are less than 5m/s (Figure 8.2). At such high velocities in a gravel bed river it is unrealistic to assume that the bed level is constant. Therefore only slight differences occur between the two sets of model results. However, it is impossible to determine which results are the more correct without accurate and detailed calibration data.

The convergence of the peak flood level backwater profile along the river for the unsteady flow (flood hydrograph) model run with the corresponding profile for the steady flow (constant discharge) model run is not surprising. A steady flow water surface profile represents an equilibrium profile for a river channel of given size and frictional characteristics. Where that channel is hydraulically steep (as it is for the Tongariro), and the primary force resisting gravity which is 'driving' the river flow is channel friction, the influence of the unsteady flow components of the governing equations of motion is small. Consequently, the peak flood level profile for a flood hydrograph with a peak flow of Q_{pk} tends towards the flood level profile for a constant discharge of the same value.

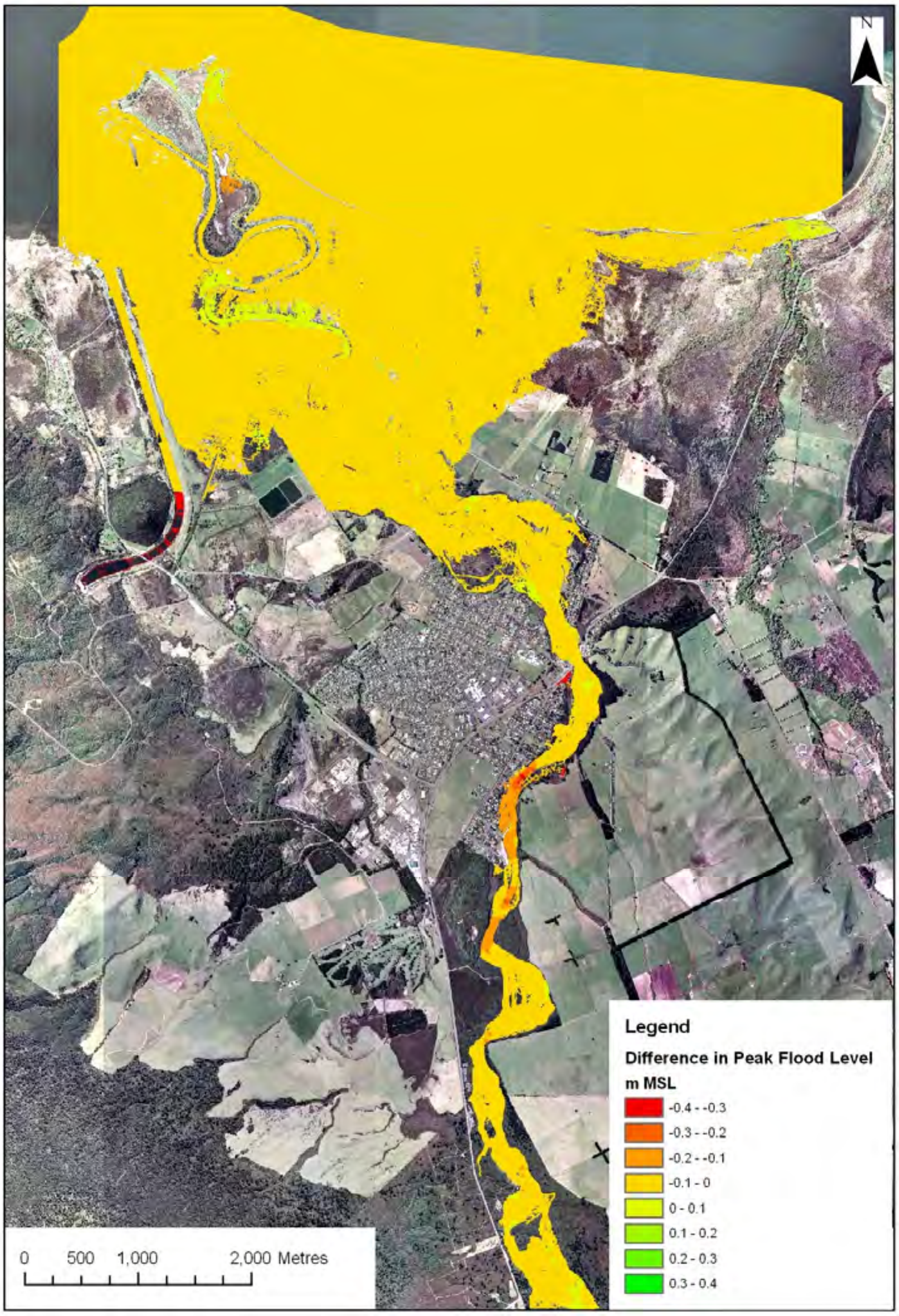

Figure 8.1: The difference in peak water level between the MIKE21 models assuming different upstream boundary conditions (i.e. yellow to red colours correspond to the peak flood level being lower in the 'hydrograph' model than the 'constant flow' model.

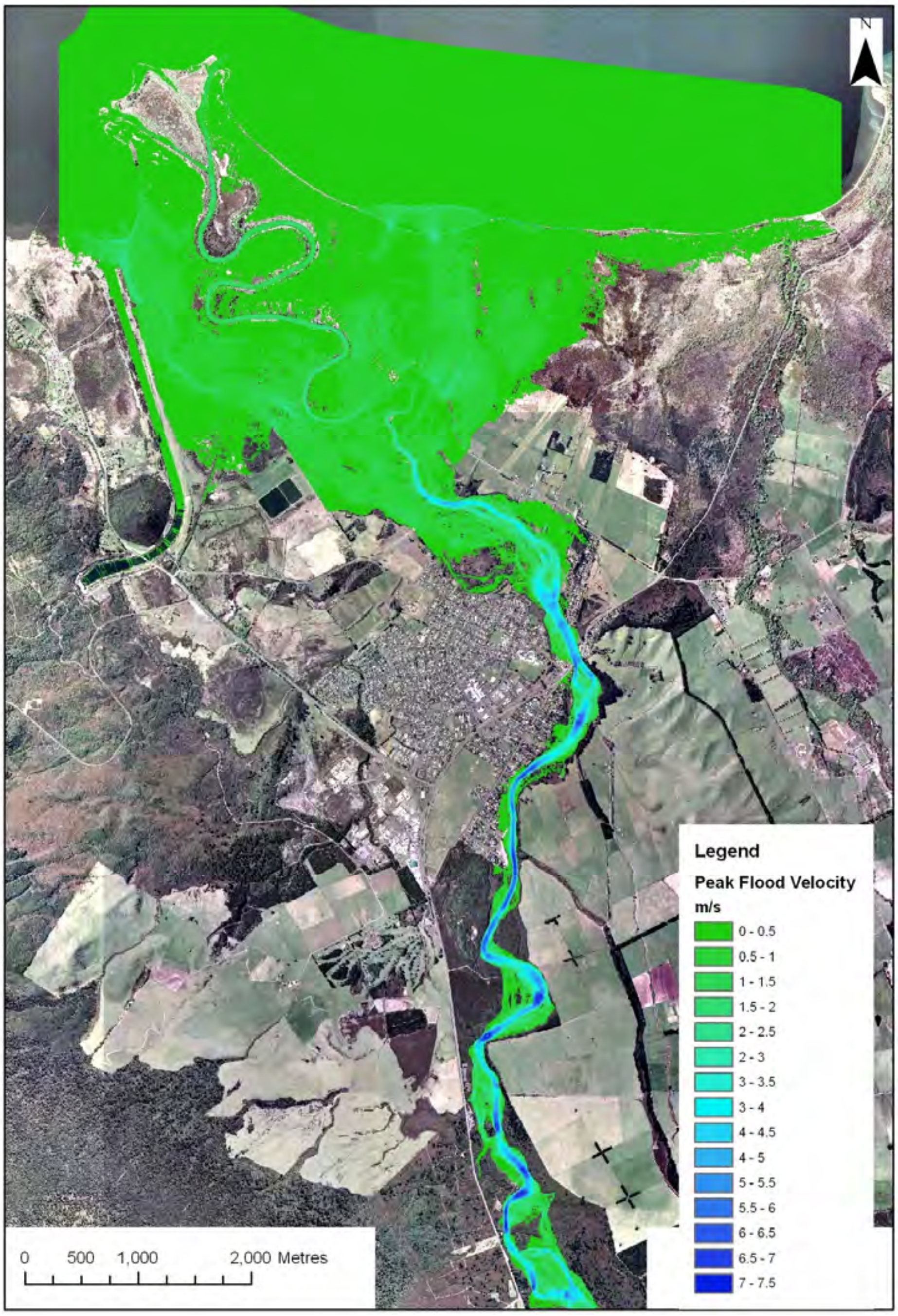

Figure 8.2: Peak velocities in the MIKE21 simulation of the Feb/Mar 2004 flood for the 'hydrograph' model.

8.4 Conclusion

Overall, the two model runs produce very similar results. Whether a constant discharge or a flood hydrograph is used makes very little difference to the results. Both results are well within the bounds of the accuracy of the various inputs. Overall, a constant discharge at the upstream boundary produces slightly more conservative flood levels.

9 Effect of lake level

9.1 Context

In the past there has also been some discussion as to the potential effect of the level of Lake Taupo on the potential impact of any flood within the tributary streams. In this case the water level in the lake determines the downstream boundary condition in the hydraulic model.

Figure 9.1 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.

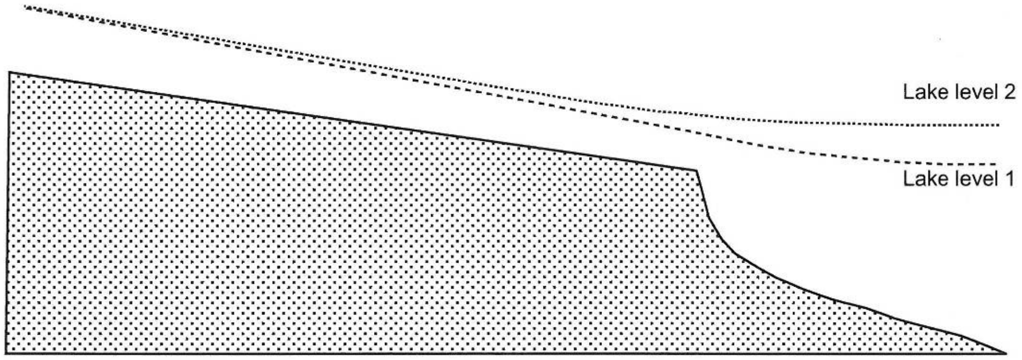

Figure 9.1: Backwater profiles for river flow discharging into a lake (constant discharge).

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 9.1, 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 9.1 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.

9.2 Example

Figure 9.2 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 357.24m. 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.

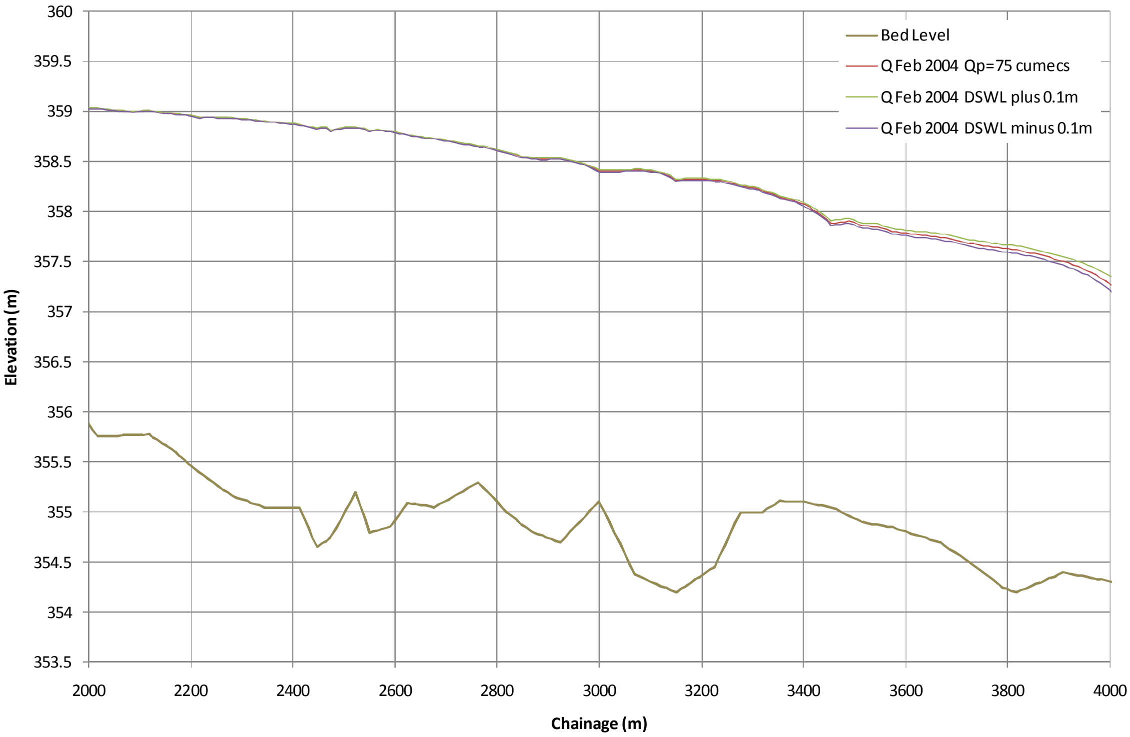

Figure 9.2: **Backwater profiles simulated at 29 February 2004 flood event showing the effect of both increasing and decreasing the downstream boundary water level (i.e. lake level) by 0.1m.**

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 on a relatively small river. 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, in the Tongariro River 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.

10 River flood hazard classification

10.1 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).

10.2 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 10.1 (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 10.1).

Table 10.1: 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.	

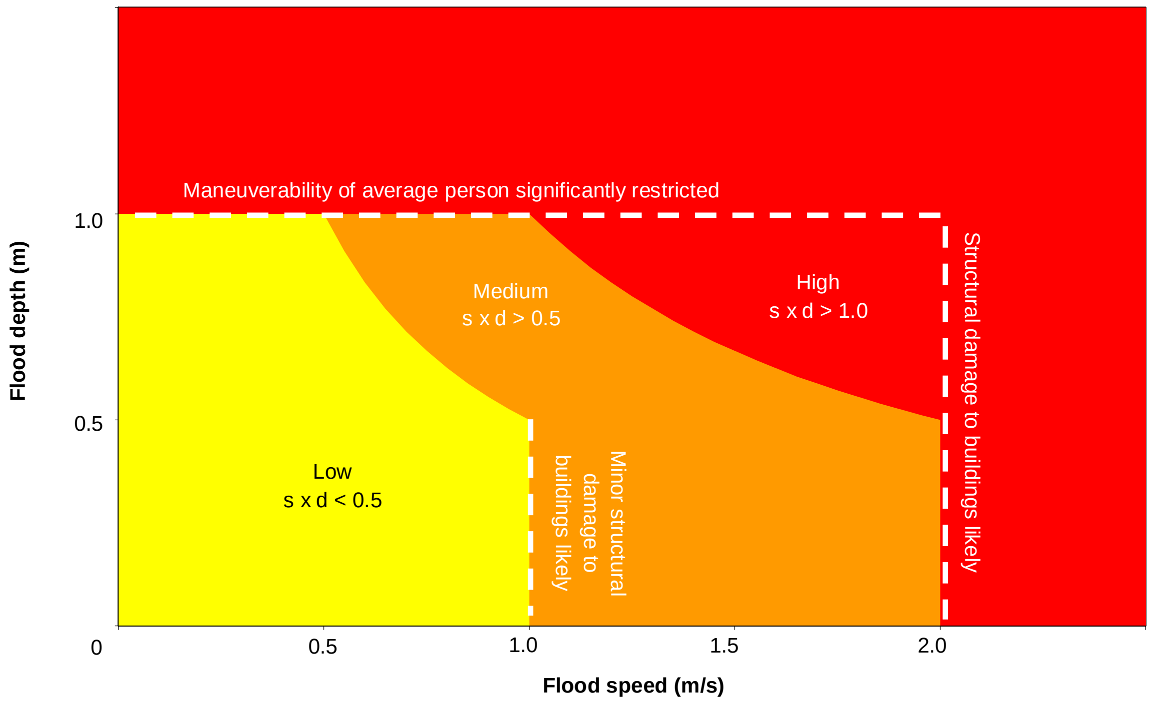

Figure 10.1: River flood hazard classification matrix (Environment Waikato, 2008b).

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).

10.3 Flood hazard assessment

The analysis of flood water levels highlights the fact that the extent and depth of flooding of the Tongariro River are relatively insensitive to the level of Lake Taupo. Therefore the flood hazard posed by the Tongariro 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 10.2, and the flow velocity is shown in Figure 10.3.

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 10.4). 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 significant proportion of the Tongariro floodplain is prone to flooding, the risk to life and property over much of this area is low. This is because of the relatively shallow overbank flows, and their low velocity. Once the flood waters break out of the channel of the Tongariro River they can spread out over the extensive low lying floodplain. Consequently, even 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 and secondary flow paths across the delta. The two major secondary flow paths are: west of the main channel towards the Tokaanu Tail Race; and north to Stump Bay. As discussed earlier, one of these channels may become the dominant flow path during some future flood event. The risk outside of the channel upstream of the State Highway bridge is generally low. The risk is also low across most to the delta outside of the secondary flow paths discussed above.

Therefore, although a large area of the Tongariro floodplain 'gets wet' during the 100-year event, the hazard outside of the obvious channels and flow paths is generally low. A significant portion of the 'urban area' is subject to a risk of flooding despite the presence of stopbanks and protection works. However, while the cost of flooding and inconvenience may still be high, the actual risks to life and property are not great.

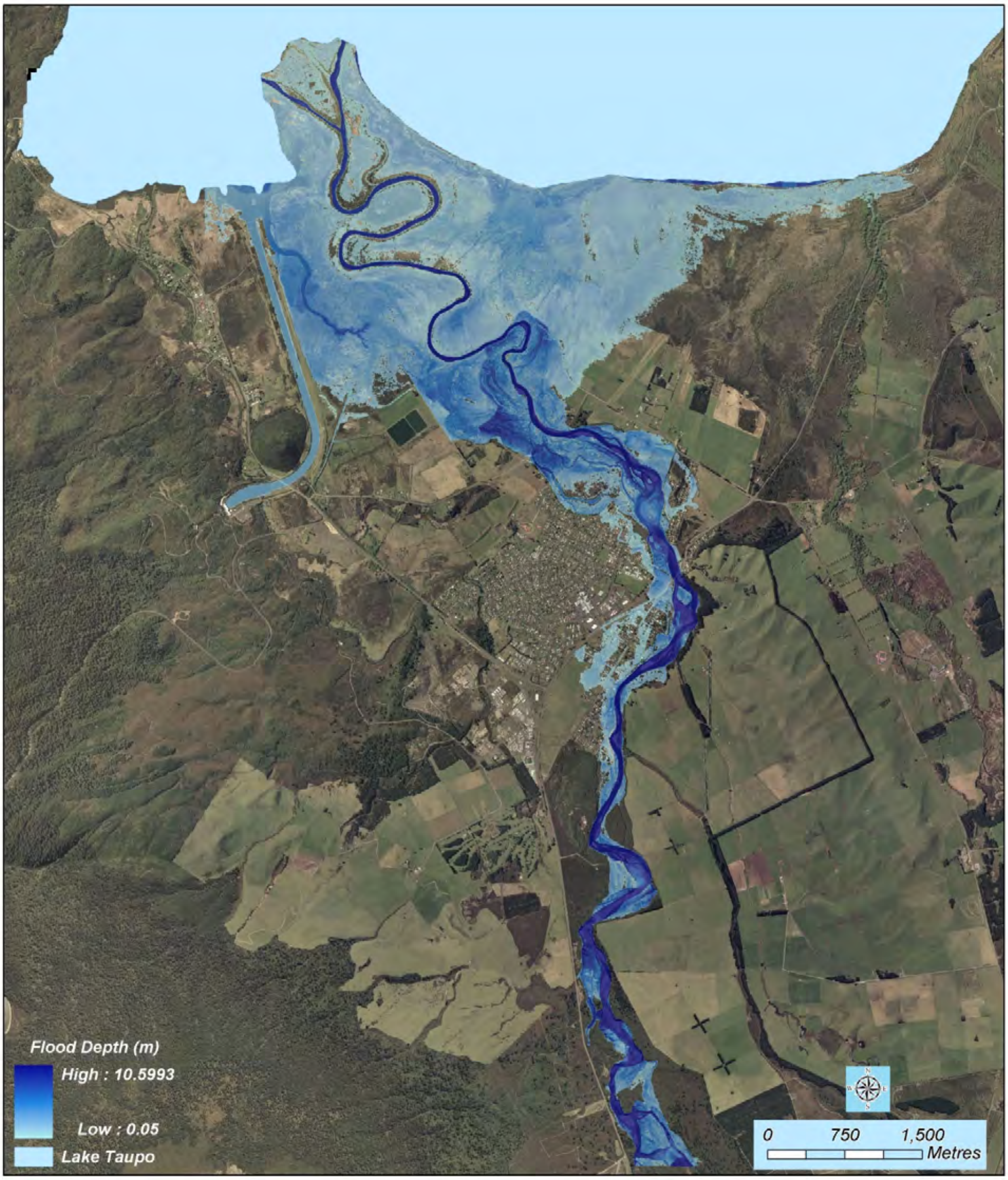

Figure 10.2: Water depth during the 100-year flood event in the Tongariro River allowing for the effects of climate change on runoff from the catchment. Lake level assumed to be at 357.5m.

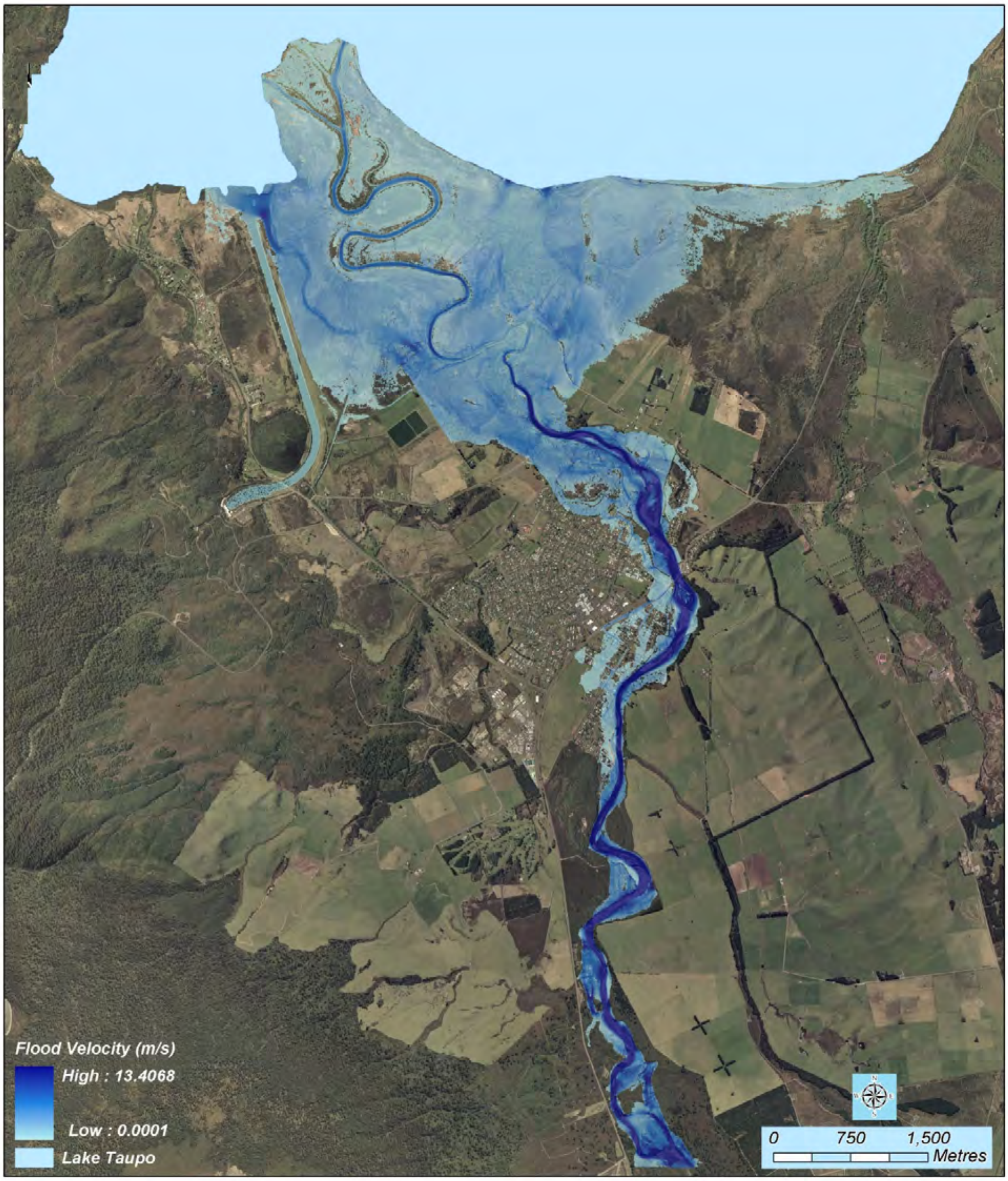

Figure 10.3: **Water velocity during the 100-year flood event in the Tongariro River allowing for the effects of climate change on runoff from the catchment. Lake level assumed to be at 357.5m.**

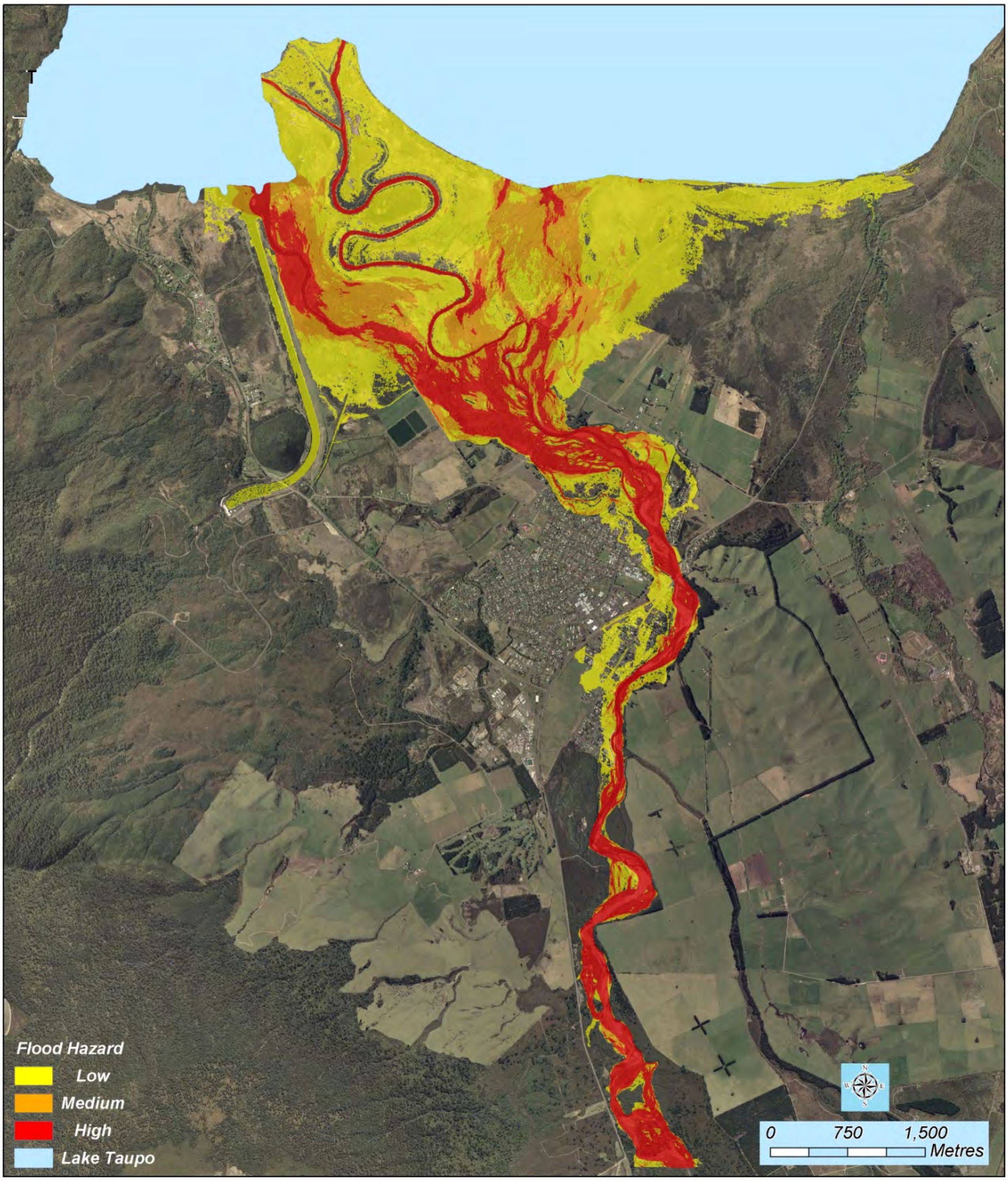

Figure 10.4: **Flood hazard classification during the 100-year flood event in the Tongariro River allowing for the effects of climate change on runoff from the catchment. Lake level assumed to be at 357.5m.**

10.4 Summary

A MIKE21 hydraulic model was established for the Tongariro River from Poutu Pool to Lake Taupo, and across the adjacent delta. The topography of the channel and floodplain was based on both LiDAR and river cross-section data. The model was calibrated against the 29 February 2004 event. Calibration used surveyed flood level data and an observed flood extent map.

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

The results show that the increased water levels arising from the predicted increased flood flows caused by climate change are more marked over the first 6 to 7km of the river modelled (upstream of the SH1 Bridge). Beyond that, the backwater effect of Lake Taupo gradually becomes more dominant. The increase in water levels potentially caused by climate change diminishes downstream towards the lake. The results also indicate some flooding of Turangi upstream of the SH1 Bridge during the 100-year event estimated from the current instrumental record. The extent of inundation increases when the predicted effects of climate change are incorporated.

The MIKE21 hydraulic model offers considerable, and significant, advantages over previous MIKE11 models. It more accurately represents channel velocities, and allows for super-elevation around the bends in the river. It also allows the extent, depth, velocity, and potential impact of any out of channel flow to be quantified. Now that the model has been established and calibrated, it can quickly be ‘re-tuned’ to explore any scenario; such as climate change, channel works, flood protection options etc.

11 Conclusion

Flooding in the Tongariro River is a persistent and ongoing process. The extensive floodplain in the lower valley shows that flooding is not new, and is a natural occurrence. Turangi has also been subject to recent flooding, despite extensive protection works.

The risk of flooding, and the potential extent and depth of inundation of land near the Tongariro 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.

11.1 The river flood hazard

The Tongariro River has a highly variable flow regime characterised by long periods of low flow, interspersed with short duration high energy flood events. This flow regime is complicated by both flow augmentation and abstraction relating to the Tongariro Power Scheme. The largest flood since 1957 was 1470m^3/s in 1958, followed by a flood of 1442m^3/s in 2004. Analysis of the largest floods recorded over the past 53 years indicates that a flood of 1451m^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 1730m^3/s by the 2040s.

Modelling of an extreme event of this magnitude (i.e., 1730m^3/s) shows that the flood would likely extend across the entire floodplain downstream of Smallmans Reach, between the Tokaanu Tailrace and Stump Bay. Some areas of Turangi would also be affected by floodwaters, despite the current stop banks and protection works. 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 is inundated will be subject to a relatively low flood hazard. Although a large area of the floodplain is inundated, the risks to life and property in the urbanised areas are generally low. The highest flood hazard is within the currently active river channel, within the stop banks, and within the secondary flow paths across the Tongariro delta.

11.2 The combined flood hazard

The flood hazard in the vicinity of the Tongariro 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 is 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 Tongariro 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.

11.3 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.

11.4 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 constraints regarding precise calibration, 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 of the Tauranga Taupo River.

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13 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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