Taupo District Flood Hazard Study

TOKAANU STREAM

Taupo District Flood Hazard Study

TOKAANU STREAM

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

June 2012

Prepared Sheryl Paine & Hamish Smith

Reviewed Dr Jack McConchie

Opus International Consultants Limited
Environmental
Level 9, Majestic Centre, 100 Willis Street
PO Box 12 003, Wellington 6144,
New Zealand

Telephone: +64 4 471 7000
Facsimile: +64 4 499 3699

Date: June 2012
Reference: 350665.00
Status: Final A

Executive Summary

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

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

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

The limited availability of flow measurements in Tokaanu Stream is a significant constraint on flood estimation. However, a realistic synthetic series of flood hydrographs was derived using appropriately scaled data from adjacent catchments.

A range of extreme flood scenarios were analysed using a MIKE21 two-dimensional hydraulic model of the lower Tokaanu catchment. The lack of specific information relating to significant flood events and the resulting inundation made it difficult to calibrate the hydraulic model using empirical data. The MIKE21 model can, however, be further calibrated when such information becomes available.

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

The modelled extreme water levels were overlaid on a high resolution digital terrain model (DTM) to identify those areas which would be flooded by a particular combination of factors, and the depth of any resulting inundation. As well as illustrating the overall effect of particular parameter combinations, the risk from flooding at specific sites down to 2.5m resolution was analysed using the DTM.

The results from the hydraulic modelling also identified the importance of channel maintenance, vegetation removal from the channel, and ensuring adequate freeboard of bridges over the Tokaanu Stream in mitigating the flood risk.

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

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

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

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

Contents

1 Overview

1.1 Purpose

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

This study has been prompted by:

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

The primary objective of this phase of the *Taupo District Flood Hazard Study* was to assess the flood risk to land adjacent to Tokaanu Stream. Of particular concern is the flood risk downstream of the Tokaanu Power Station tailrace, and between the foot of the slopes draining Tihia and SH41 (Figure 1.1). This area is essentially the flood plain of Tokaanu Stream and the various alluvial fans which have formed at the confluences of its tributaries.

The flood risk was assessed using detailed hydrometric analysis and a two-dimensional computational hydraulic model. Various scenarios were modelled, including the potential effects of the latest predictions of climate change to 2090. For each scenario the extent and depth of inundation were quantified, together with the velocity of the flood water. From this information the flood risk across the flood plain was quantified.

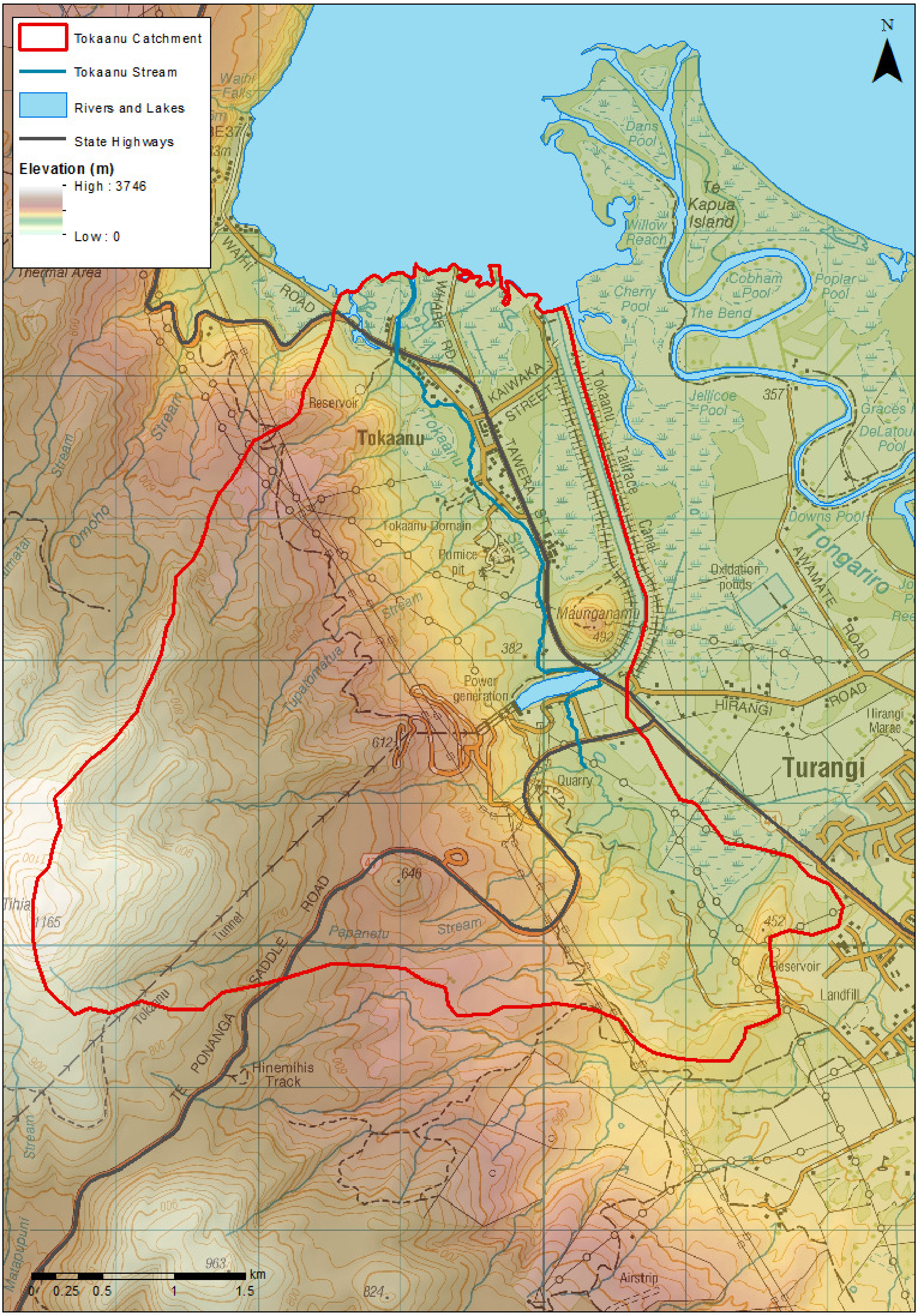

Figure 1.1: Location of the Tokaanu Stream and the catchment.

2 Tokaanu catchment

2.1 Description

The headwaters of the Tokaanu Stream lie essentially west of Turangi Township (Figure 1.1). The catchment, with an area of 18km², reaches elevations of approximately 1165mASL at Tihia with slopes dropping steeply towards the main stem of Tokaanu Stream. The two main tributaries, Tupatomatua and Papanetu Streams, flow northeast to Tokaanu Stream which then flows essentially north to discharge into Lake Taupo between Waihi and Tokaanu Bays.

The main stem of the Tokaanu Stream, across the low-lying valley floor, is approximately 4.5km long. Over this distance the river drops just 10m in elevation. The fact that numerous small steep tributaries discharge onto this flat, generally swampy, flood plain exacerbates the flood risk (Figure 2.1). Runoff arrives at the main stream faster than it can discharge into Lake Taupo resulting in potential inundation of the flood plain. Tokaanu Village lies directly adjacent to the main river channel, approximately 1.2km from Lake Taupo.

The geology of the Tokaanu catchment is mainly Kaharoa and Taupo ashes, breccias and volcanic alluvium associated with the 181AD Taupo eruption (Figure 2.2). These igneous rocks are highly porous and relatively permeable. These properties mean that the surficial deposits can absorb the majority of rainfall under all but the more extreme events. This has the effect of moderating and attenuating flood peaks. This moisture is then released from groundwater more slowly resulting in broad flood hydrographs, with high baseflows and low coefficients of flow variation.

Soils in the catchment include both organic podzols and pumice, with firm, fibric, organic soils close to the lake shore (Figure 2.3). Land cover in the catchment is predominantly broadleaved indigenous hardwoods and indigenous forest in the upper reaches, with mixed land cover closer to the lake; there are also isolated patches of manuka and kanuka scrub (Figure 2.4). Land use within the Tokaanu catchment is summarised in Table 2.1.

Table 2.1: Land use within the Tokaanu catchment.

Land use	Percentage (%)
Indigenous Forest & Alpine Tussock	81.6
Exotic Production Forest	1.3
Pasture	6.4
Urban / Settlements	1.2
Roading	<0.1
Shrub	7.3
Other	2.2
Total	**100**

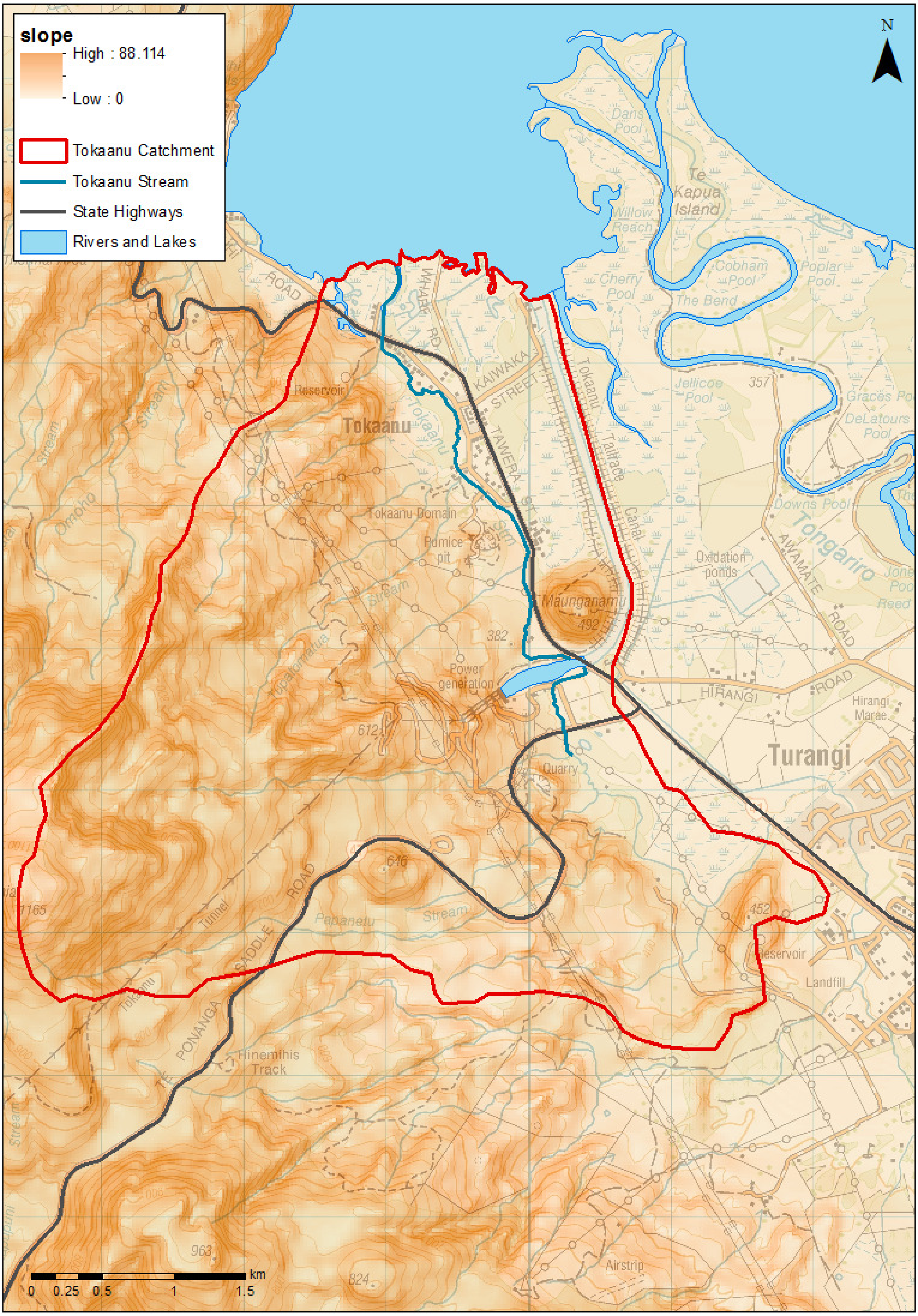

Figure 2.1: **Distribution of steep slopes within the Tokaanu catchment.**

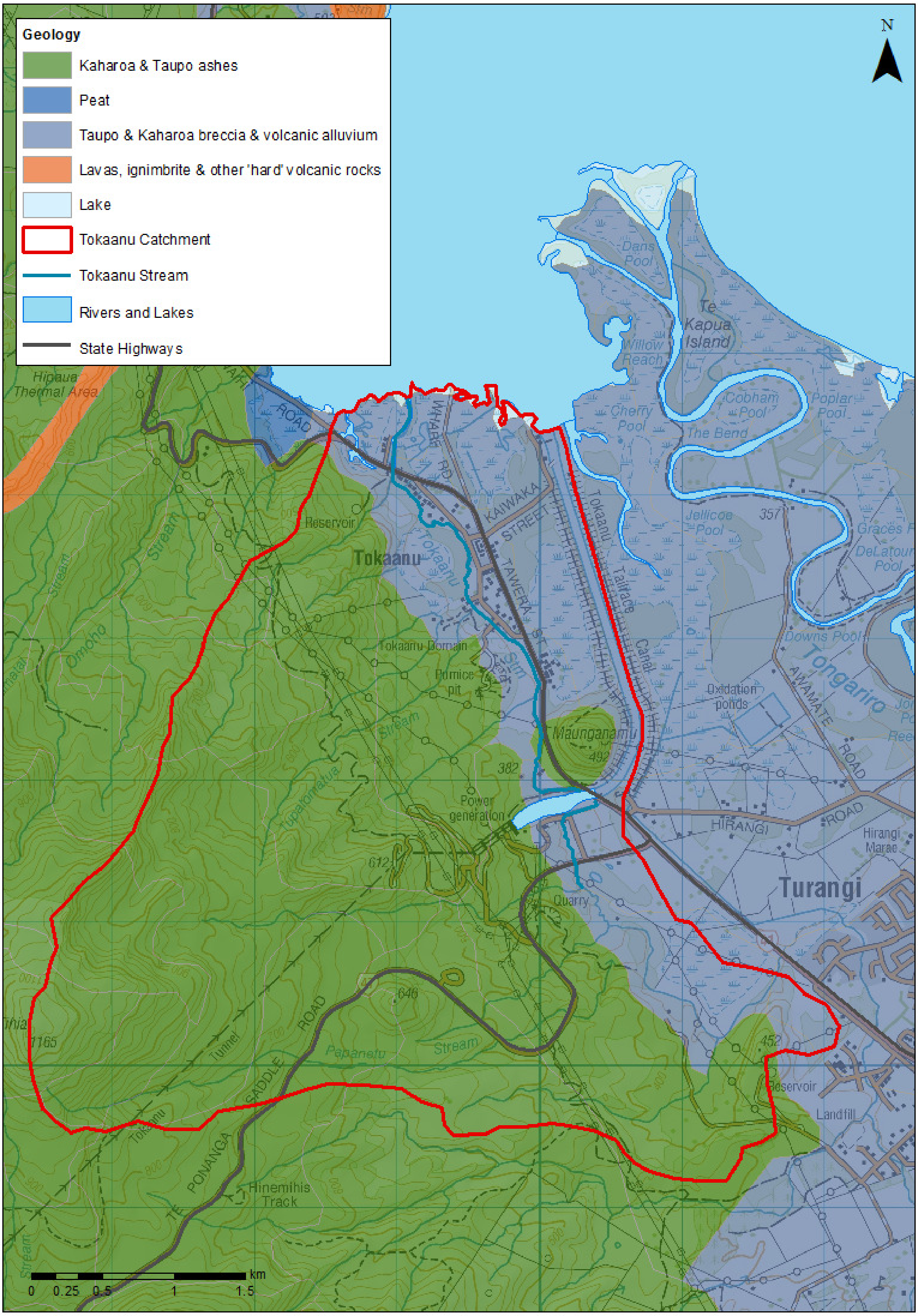

Figure 2.2: Geology of the Tokaanu catchment.

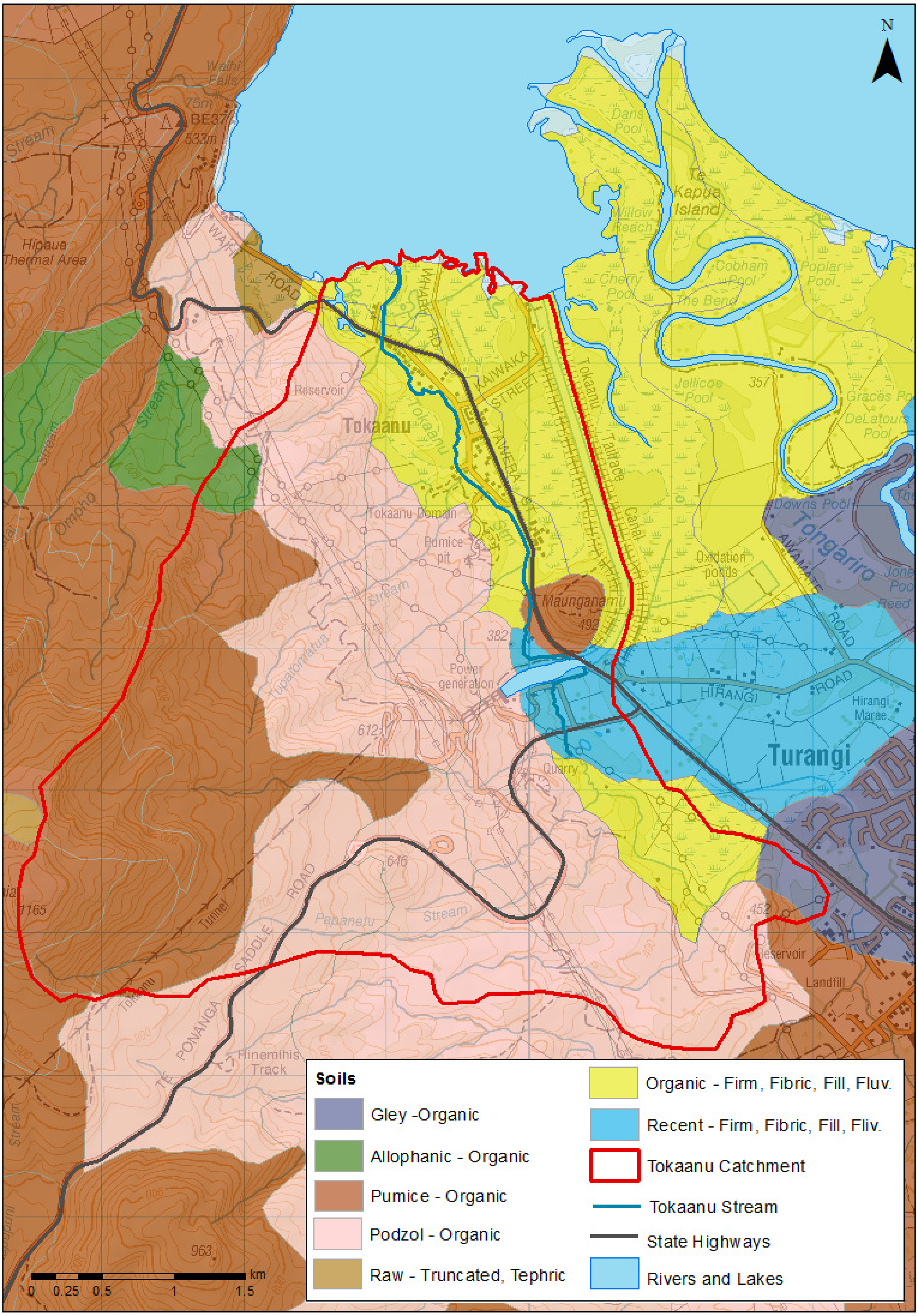

Figure 2.3: **Soils of the Tokaanu catchment.**

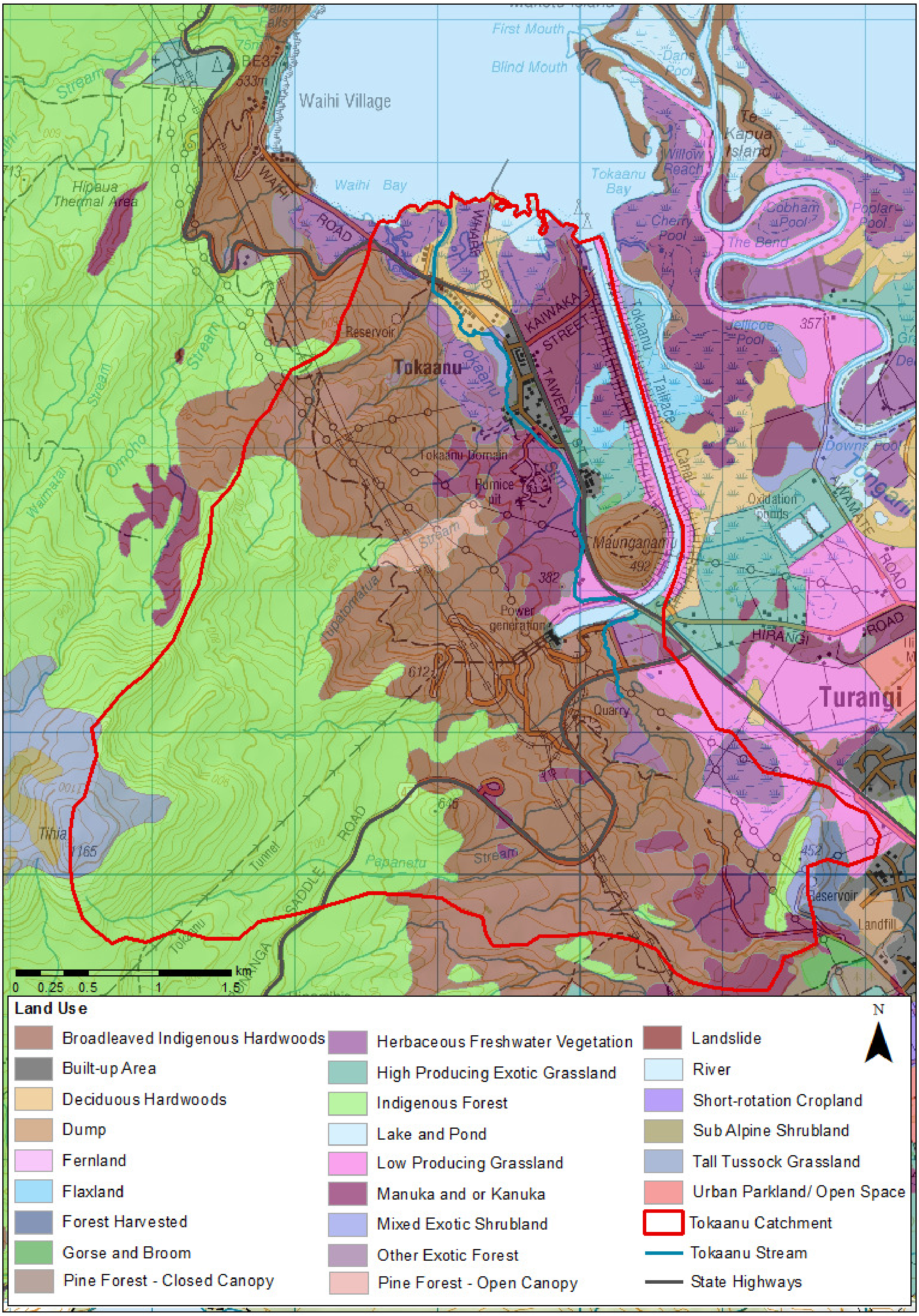

Figure 2.4: **Land use in the Tokaanu catchment.**

The Tokaanu flood plain has over time been modified by a range of human activities, intervention, and development. The flood plain has been 'separated' from the Tongariro Delta to the east by the construction of the Tokaanu Power Station tailrace. An aqueduct at the State Highway 41 Bridge over the tailrace now conveys a maximum of $2m^3/s$ from the upper catchment to the lower Tokaanu Stream. Any additional flow from the upper catchment is discharged directly into Lake Taupo via the power station tailrace. This diversion of a significant portion of the higher flows from the upper catchment mitigates the flood risk across the lower flood plain.

State Highway 41 (SH41) forms a slightly raised profile above the swampy land that covers the lower part of the flood plain. The highway crosses the stream approximately 500m upstream of Lake Taupo. The bridge over the stream acts as a constriction on flood flows in the stream, while the raised profile of the road acts as a barrier to the overland flow of flood water directly to the lake. The results of the hydraulic modelling discussed later in this report illustrate and quantify the effect of these landscape modifications on the flood hazard.

The Tokaanu catchment has a relatively steep rainfall gradient. The mean annual rainfall in the headwaters of the catchment, the area likely to produce the greatest runoff, is approximately 1700mm per year. Rainfall then decreases rapidly with altitude to be only approximately 1425mm per year at Lake Taupo (Figure 2.5).

Under normal flow conditions the sediment load of the river consists of sands and silts in suspension. This is transported through the lower reaches although some is deposited in those areas where vegetation clogs the channel. Large flood events can mobilise significant quantities of bed load within the steeper tributary streams. Most of this sediment is deposited at the break of slope just upstream of the confluence of these tributaries with Tokaanu Stream. These high energy events are the dominant channel forming process.

2.2 Study area

The greatest flood hazard within the Tokaanu catchment is between the stream and SH41, particularly from just upstream of Tokaanu Village to the road bridge, and towards Lake Taupo (Figure 2.6). The flood risk over the first 1km downstream of the tailrace is low because of the diversion of any flow above approximately $2m^3/s$, and the lack of major tributaries. Likewise the flood risk to land between the slopes to the west and the stream is low because of steeper gradients, and the lack of locations for the accumulation of water.

It is significant that much of the area prone to flooding from large flows in Tokaanu Stream is also subject to potential inundation as a result of high lake levels i.e. 357.8m. Any reduction in the elevation of the land as a result of ongoing tectonic deformation, or the settlement of the sediments forming Tongariro delta, is likely to exacerbate the risk for flooding from either high lake levels or river flows.

The focus of this study is therefore on the lower Tokaanu Stream, between the Tokaanu tailrace and Lake Taupo, including the area adjacent to Tokaanu Village (Figure 2.6).

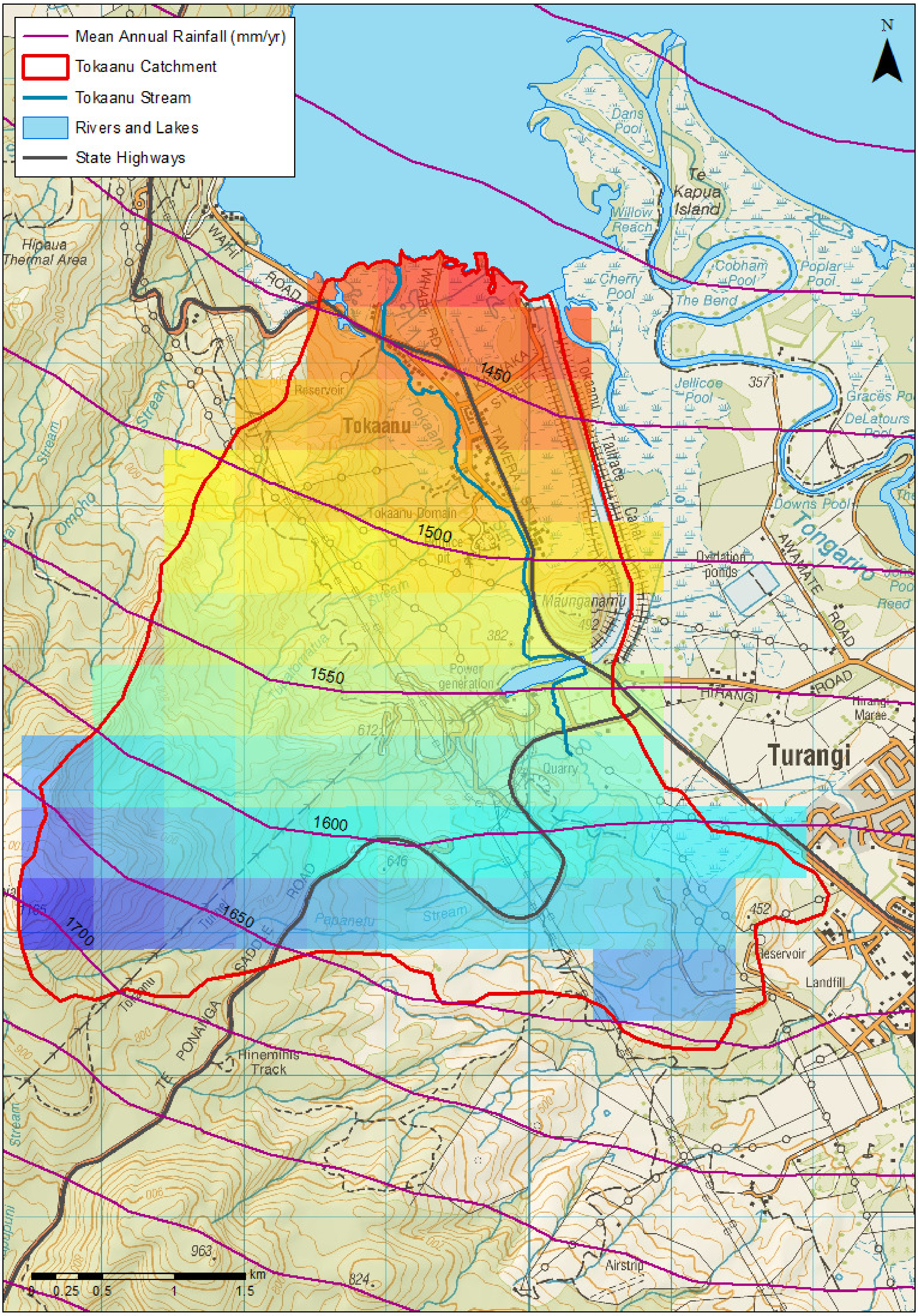

Figure 2.5: Mean annual rainfall (MAR) throughout the Tokaanu catchment.

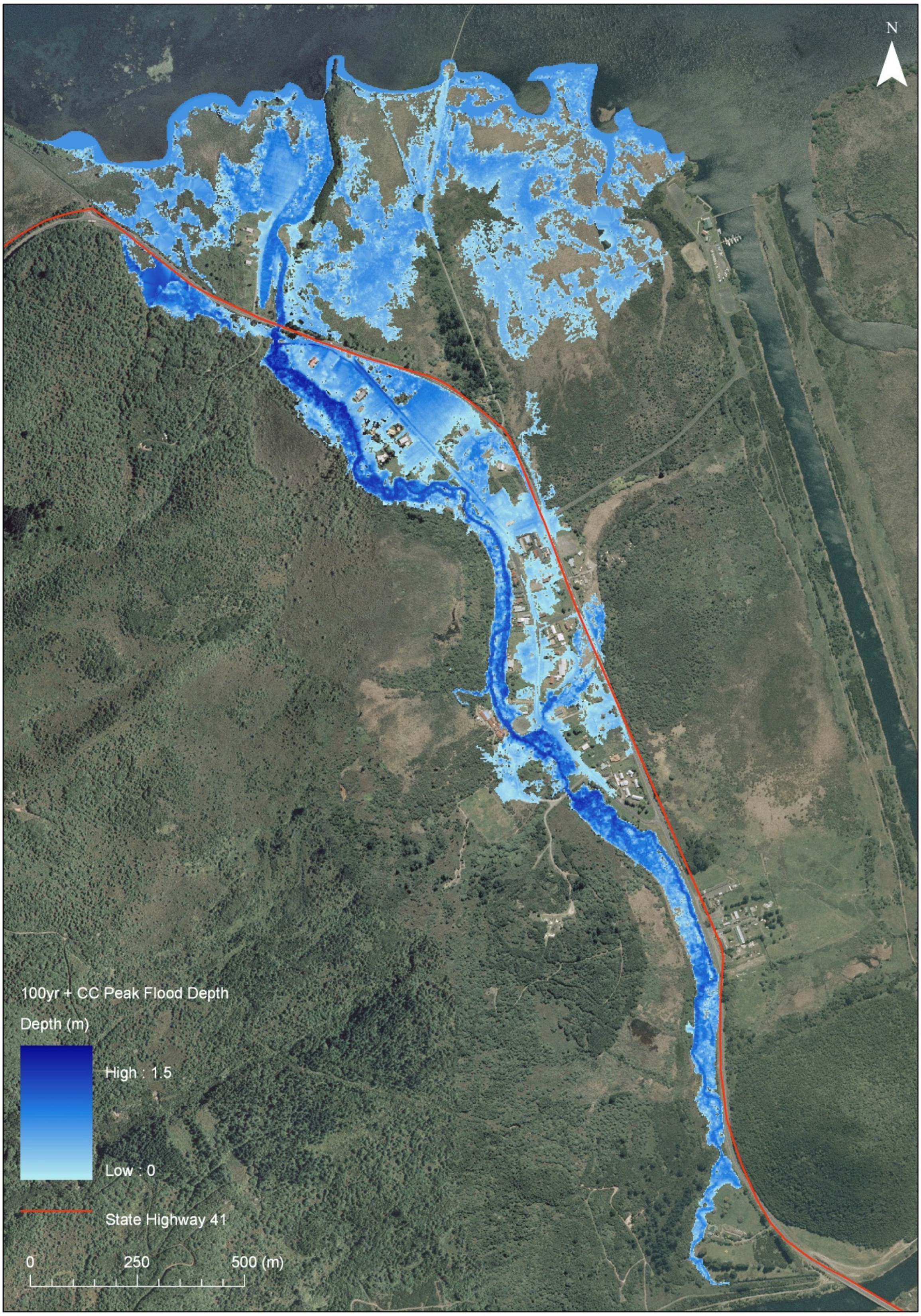

Figure 2.6: **Depth of inundation predicted by flooding of the Tokaanu Stream; assuming the 'worst case' scenario modelled i.e., 100-year peak flood flow increased to allow for predicted climate change to 2090 and a lake level of 357.5m.**

3 Flow regime of Tokaanu Stream

3.1 Available flow information

Flows have been recorded within Tokaanu Stream over two periods from two different locations (Table 3.1 & Figure 3.1). Both these records, however, cover different time periods and are of relatively short duration; the longest being just less than 5 years. This paucity of flow information acts as a considerable constraint on the ability to undertake reliable analysis of the frequency and magnitude of expected flood events. It also restricts the derivation of robust estimates of the magnitude, frequency, and characteristics of likely large flow events using site-specific flow data.

Table 3.1: Flow records from Tokaanu Stream.

Site	Start date	End date	Duration
Tokaanu at Power House	October 1976	July 1978	~22 months
Tokaanu at Township	December 1986	November 1991	~60 months

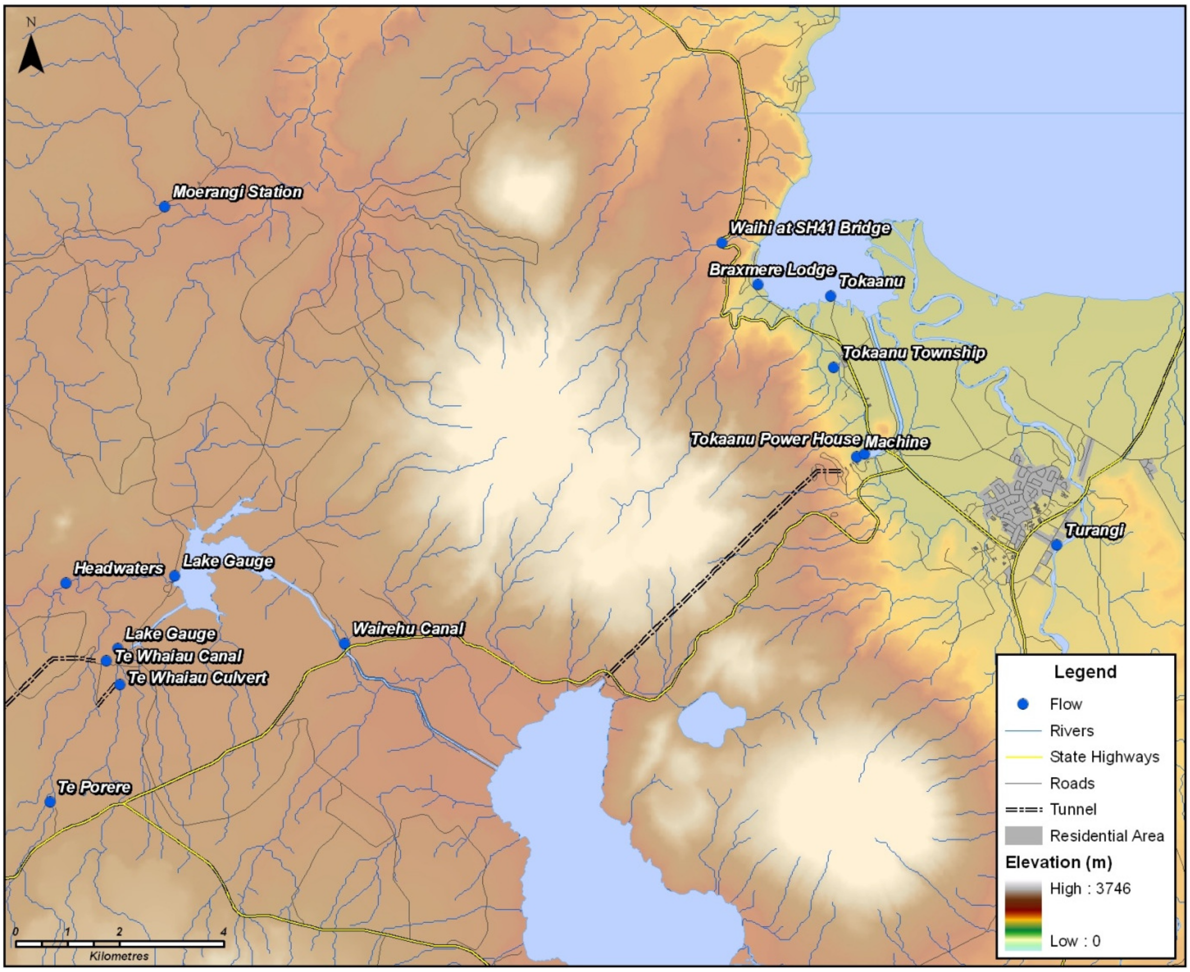

Figure 3.1: Water level and flow sites within Tokaanu Stream and the surrounding catchments.

The approximately 2-year flow record for the Tokaanu Stream at Power House is shown in Figure 3.2, and summarised in Table 3.2. This shows that flood events are randomly distributed throughout the year, but with a greater frequency of events during the winter period. It also appears that the baseflow between flood events increases during winter and then gradually falls during summer and autumn as expected. The flood events, which are interspersed with periods of lower flows, are of very short duration which is to be expected from a small headwater catchment such as Tokaanu Stream. The similarity between the mean and median flows, and the relatively high baseflow, suggest that a significant portion of the flow in Tokaanu Stream may be spring derived. This period of record does not contain any major flood events.

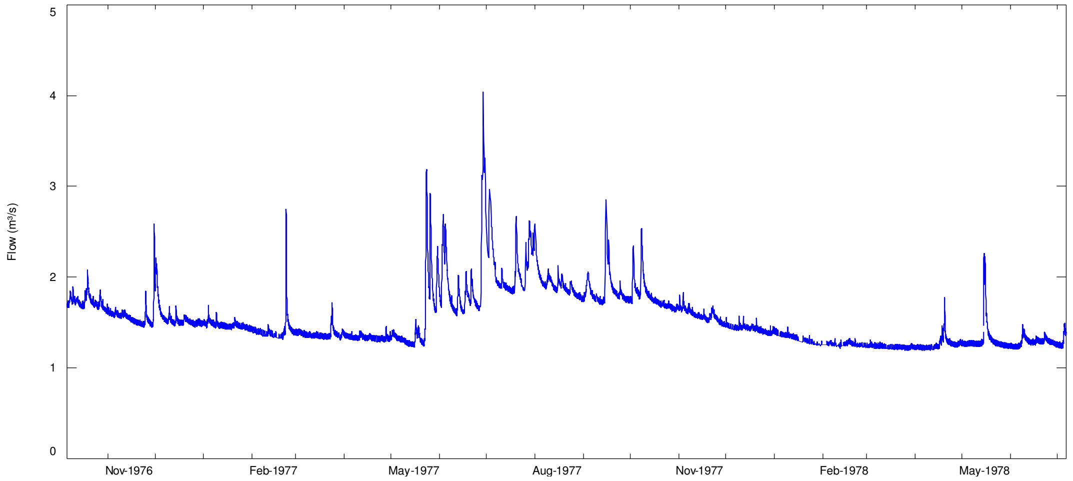

Figure 3.2: **Flow record from Tokaanu Stream at Power House (1976-1978).**

Table 3.2: **Summary statistics of the flow record from Tokaanu Stream at Power House (1976-1978) (m³/s).**

	Minimum	**Median**	**Maximum**	**Mean**	**Standard Deviation**
Tokaanu Stream @ Power House	1.19	1.45	4.04	1.54	0.32

The longer flow record for the Tokaanu Stream at Township shows the same characteristics as discussed above (Figure 3.3). The strong seasonality of the flow regime and the essentially random occurrence of discrete flood events are both apparent. As a result, the summary statistics from this longer period of record, although from a slightly more downstream site, are very similar to those obtained further upstream (Table 3.3).

Table 3.3: **Summary statistics of the flow record from Tokaanu Stream at Township (1986-1991) (m³/s).**

	Minimum	**Median**	**Maximum**	**Mean**	**Standard Deviation**
Tokaanu Stream @ Township	0.51	1.21	4.13	1.47	0.44

The significantly lower minimum flow appears to be related to some dubious data in the flow record. The greater difference between the median and mean flows reflects the influence of the larger number of flood events over this longer record. The largest flood recorded is only 4.13m³/s which is a relatively small event. The short flow record, the absence of any large flood event, and the fact that these data are now over 20-years old mean that they could not be used to determine robust estimates of the magnitude, frequency, and characteristics of design flood events.

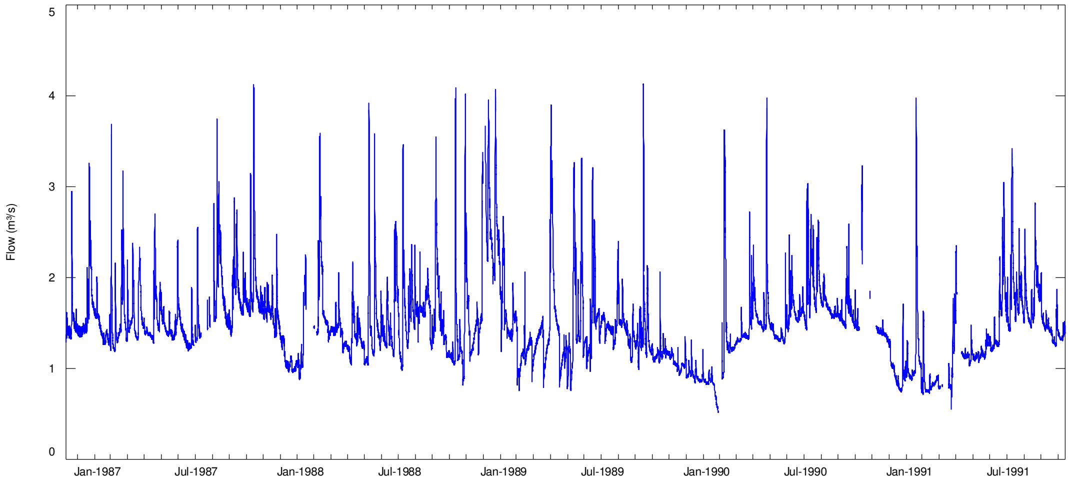

Figure 3.3: Flow record from Tokaanu Stream at Township (1986-1991).

3.2 Sub-catchments

The lack of reliable, locally-derived, flow information for Tokaanu Stream means that an alternative approach for determining the magnitude of various design floods is required. Two different approaches were adopted for this study; the rational method, and flow scaling from adjacent catchments.

There are four main sub-catchments below the Tokaanu tailrace aqueduct (Figure 3.4). These four sub-catchments contribute the majority of the ‘uncontrolled’ flow that reaches Lake Taupo. This is because the tailrace aqueduct allows only a maximum flow of approximately 2m³/s to enter Tokaanu Stream downstream of the tailrace. Any flow from the upstream catchment which is in excess of 2m³/s is discharged directly into the Tokaanu Power Station tailrace. These high flows therefore bypass the lower reaches of Tokaanu Stream. Since this flood risk assessment is focussed largely on Tokaanu Stream downstream of the tailrace, a flow of 2m³/s has been assumed immediately below the tailrace, and downstream to the first tributary (i.e., sub-catchment 4 in Figure 3.4).

It has also been assumed that the flows from each of the four sub-catchments enter the main stem of Tokaanu Stream at the same time. Such an approach is likely to be slightly conservative for two reasons. First, it is unlikely that a rainstorm event would remain static over all the sub-catchments for the duration of the flood. Second, the different sizes of the various sub-catchments mean that the time of concentration of each catchment is different i.e. the time it takes water to move from the furthest part of the sub-catchment to the confluence. Consequently, it is unlikely that the peak flows from each of the sub-catchments would occur concurrently. Therefore the magnitude of the combined flow during an actual flood would likely be less than assumed in this analysis. The results from the hydraulic modelling are therefore likely to be conservative i.e. predicting slightly higher water levels.

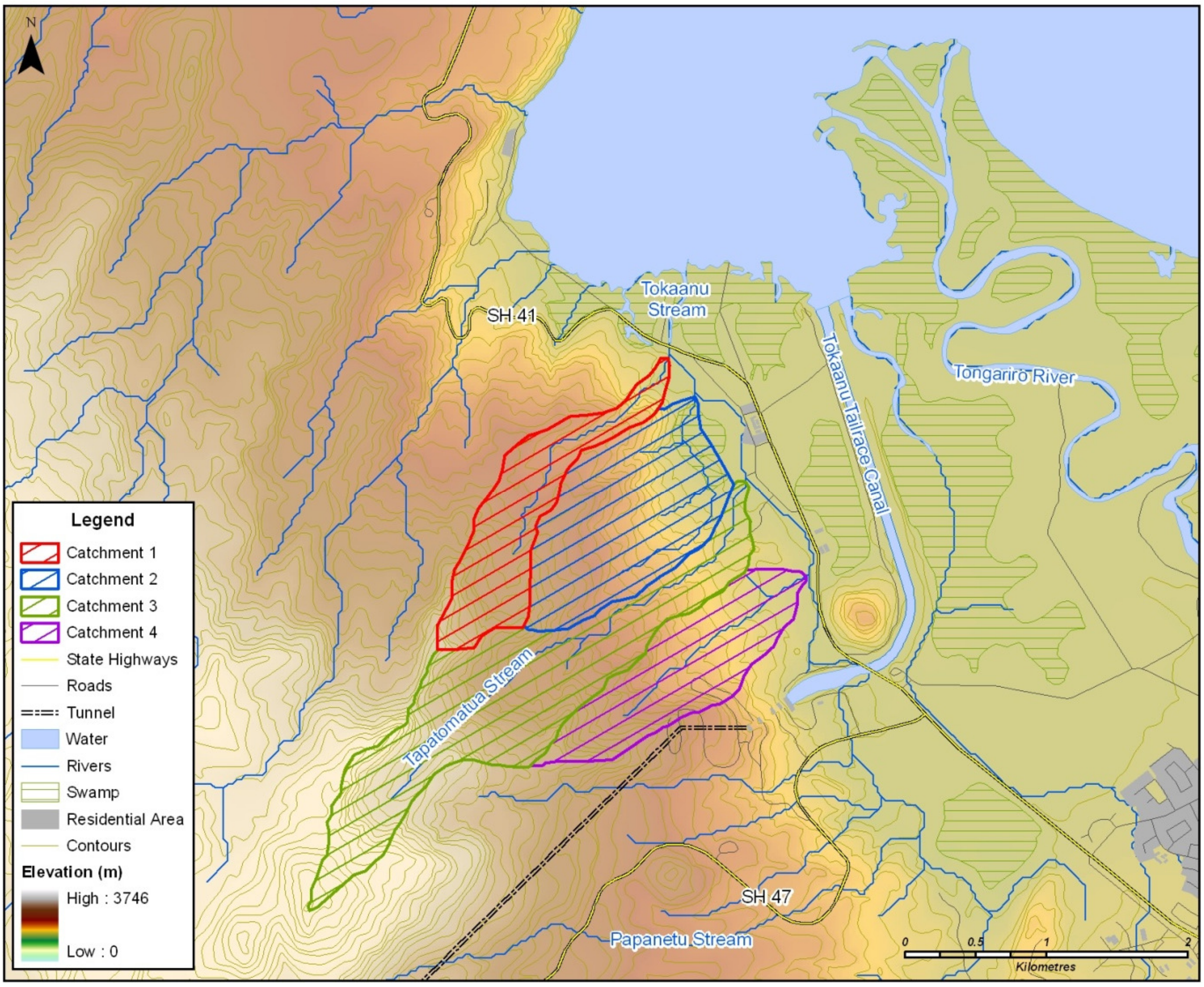

Figure 3.4: Location of the four main sub-catchments of the Tokaanu Stream downstream of the Tokaanu Power Station tailrace.

3.3 Rational method

The rational method is widely used around the world for flood estimation in small rural drainage basins, and is the most widely used method for urban drainage design. It is generally considered to be an approximate deterministic model representing the flood peak that results from a given rainfall, with the runoff coefficient being the ratio of the peak rate of runoff to the rainfall intensity.

The method is used to estimate the peak flow during a flood event of a given return period, assuming an average rainfall intensity over a critical duration i.e.

$$Q_T = C\, I_T\, A$$

where:

Q_T = estimate of the peak discharge during a flood event with an average recurrence interval (ARI), T

C = runoff coefficient; proportion of the rainfall that appears as surface runoff from the contributing drainage area

I_T = average rainfall intensity (mm/hr) for some recurrence interval, T, over a storm duration equal to T_c

A = contributing drainage area above the point of interest

T_c = time of concentration (TOC); the time it takes runoff to flow from the furthest part of the catchment to the point of interest

The runoff coefficient (C) represents the integrated effects of infiltration, evaporation, retention, flow routing, and interception; all of which affect the temporal distribution and peak rate of runoff.

There are four commonly used methods to derive the Time of Concentration (TOC) for a catchment; the Standard Method for Rural Catchments, the Ramser-Kirpich method, the Bransby-Williams method, and the US Soil Conservation method. When applied to the sub-catchments of the Tokaanu Stream these four different methods produced two distinct groups of values. The Ramser-Kirpich and the US Soil Conservation methods produced the same TOC, while the Bransby-Williams and the Standard Method for Rural Catchments gave similar but distinctly different values. To determine the most realistic TOC, the average flow velocity was derived using each value. The Ramser-Kirpich method provided the most realistic average velocity of 2.75m/s during a large flood event. Therefore, the TOC obtained using the Ramser-Kirpich method was used in the rational formula to estimate the peak discharges within the four sub-catchments with various return periods (Table 3.3).

Table 3.3: Peak flow estimates for various design storms obtained using the rational method (m^3/s).

	Sub-catchment 1	Sub-catchment 2	Sub-catchment 3	Sub-catchment 4
Area (km^2)	*0.91*	*1.43*	*2.05*	*1.03*
2-year ARI	4.2	6.6	6.5	4.7
5-year ARI	6.7	10.5	8.1	7.6
10-year ARI	7.9	12.4	9.2	8.9
20-year ARI	9.0	14.2	10.2	10.2
50-year ARI	11.5	18.1	14.4	13.0
100-year ARI	12.7	19.9	15.5	14.3

Despite using local rainfall information, industry best practice, and professional judgement it is considered that the peak flows determined using the rational method are unrealistically conservative i.e. the peak discharges are too high. It is possible that this is a result of difficulties in defining a runoff coefficient that reflects accurately the infiltration and runoff characteristics of the surficial materials within Tokaanu Stream.

3.4 Flow scaling

The lack of a long term flow record for Tokaanu Stream acts as a major constraint when defining robust estimates of the likely magnitude of various design storms. The rational formula also appears to produce values of peak discharge which are unrealistic. It was therefore considered appropriate to scale and translate flows from an adjacent catchment with a similar rainfall and runoff relationship, and a long flow record, to provide a surrogate record for Tokaanu Stream. Discussions with NIWA staff, who maintain a number of sites in the general vicinity, indicated that the site on the Whanganui River at Te Porere would be most representative.

The catchment upstream of the Whanganui at Te Porere flow site (28.2km²) is significantly larger than that of Tokaanu Stream downstream of the power station tail race (5.4km²). However, both sites are expected to be affected by similar rainfall patterns, and to have a similar rainfall-runoff relationship. The flow record from the Whanganui at Te Porere is very long (i.e. from 1966-2011) allowing robust estimates of the frequency and magnitudes of various design flood events. The flow record from the Whanganui at Te Porere is shown in Figure 3.5, and it is summarised in Table 3.4.

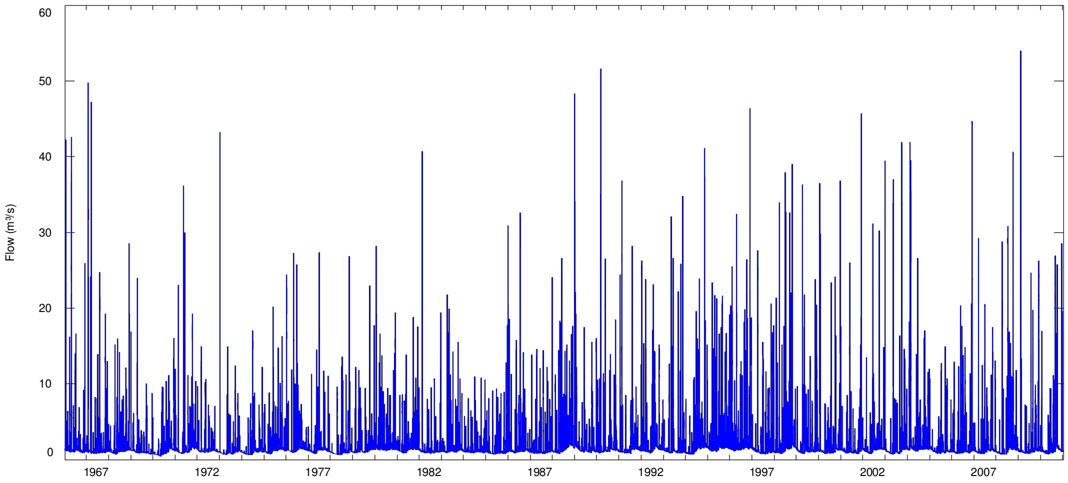

Figure 3.5: **Flow record from the Whanganui at Te Porere (1966-2011).**

Table 3.4: **Summary statistics of the flow record from the Whanganui at Te Porere (1966-2011) (m³/s).**

	Minimum	Median	Maximum	Mean	Standard Deviation
Whanganui @ Te Porere	0.51	1.16	53.98	1.38	1.21

A frequency analysis was completed on the Whanganui at Te Porere flow record to estimate the peak flows for storm events of specific return periods. The GEV statistical distribution provides the best fit to the annual maxima series obtained from the Whanganui at Te Porere flow data (Figure 3.6 & Table 3.5).

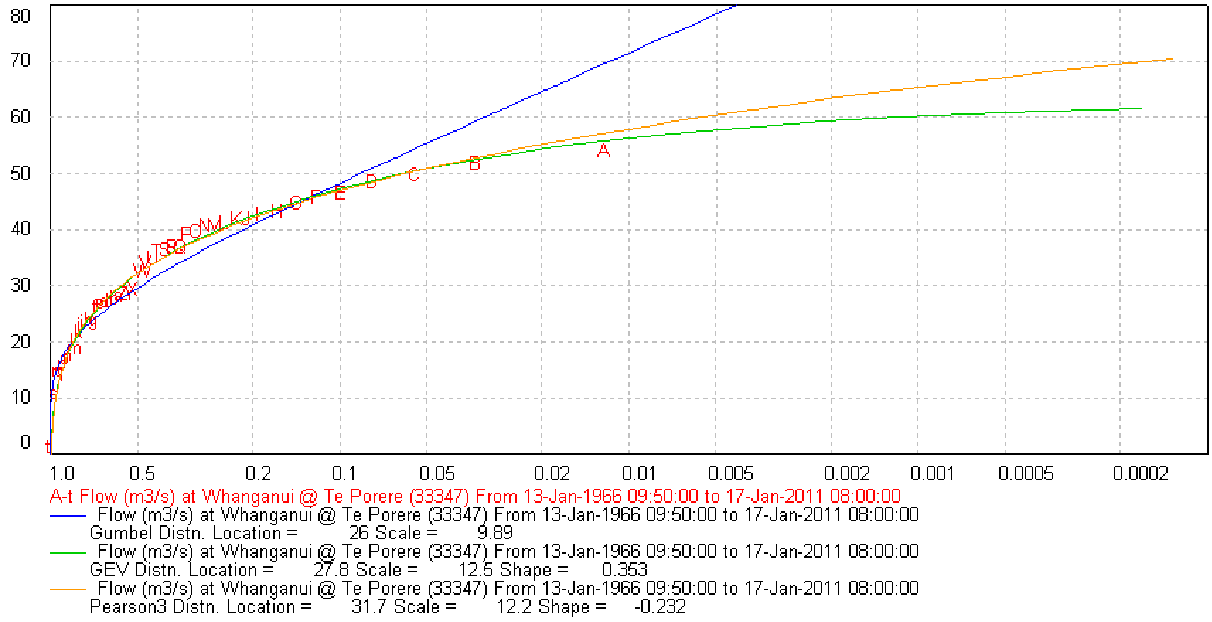

Figure 3.6: Frequency analysis of the Whanganui at Te Porere flow record.

Table 3.5: Peak discharge estimates derived from the Whanganui at Te Porere flow record assuming a GEV statistical distribution (m³/s).

	Whanganui at Te Porere
Distribution	*GEV*
2.33	34.3
5	42.4
10	47.2
20	50.8
50	54.3
100	56.3

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

The peak flow estimates from the Whanganui at Te Porere for various design events were therefore scaled using the ratio of the catchment areas to the power of 0.8 to provide estimates of the peak flow expected in each of the Tokaanu Stream sub-catchments (Table 3.6).

Table 3.6: Peak flows for various design storm events at the Whanganui at Te Porere and scaled to reflect expected flows in the various sub-catchments of Tokaanu Stream (m³/s).

ARI	Te Porere	Catchment 1	Catchment 2	Catchment 3	Catchment 4
Distribution	*GEV*	*Scaled*	*Scaled*	*Scaled*	*Scaled*
2.33	34.3	2.5	3.5	4.1	2.7
5	42.4	3.1	4.3	5.1	3.4
10	47.2	3.4	4.8	5.6	3.7
20	50.8	3.7	5.1	6.1	4.0
50	54.3	3.9	5.5	6.5	4.3
100	56.3	4.1	5.7	6.7	4.5

3.5 Comparison of flow estimates

The two methods used to derive peak flow estimates for the various design storms yielded quite different results. Those values derived using the rational method are significantly larger, up to three times greater, than those obtained by scaling the flow record from the Whanganui at Te Porere.

As discussed later, there is a short term flow record from the Waihi Stream at SH41 Bridge. Despite being a very short record an extreme flood event was 'captured'. This flood had a peak discharge of 34.4m³/s, and an estimated return period of approximately 100 years. Catchments which are similar in area and elevation, affected by the same rainstorm event, and with a similar rainfall-runoff relationship, would be expected to have similar flood discharges.

Sub-catchment 3 (Tupatomatua Stream) is approximately 20% of the size of the Waihi catchment. Thus, the peak discharge during this event would be expected to be approximately 20% of that recorded in the Waihi. Assuming that this was in fact a 100-year event, flow scaling of the Whanganui at Te Porere record provides a peak discharge of 19.5% of that at Waihi i.e. the modelled and recorded values are very similar. The rational method, however, estimates a flow of 45% of that measured in the Waihi i.e., over twice that expected based on the catchment areas.

This suggests that the peak flow estimates derived by scaling the Whanganui at Te Porere flows are likely to be realistic. The values derived using the rational method are significantly too high i.e., up to three times what could realistically be expected for the 100-year event.

3.6 Waihi Stream

There is a short term flow record from Waihi Stream at SH41 Bridge. The catchment is adjacent to Tokaanu Stream (Figure 3.7). The record is only about 3 years long and therefore it is not possible to obtain reliable or robust design flood estimates. The flow record does, however, contain an extremely large flood event which had an estimated return period of approximately 100 years (Figure 3.8).

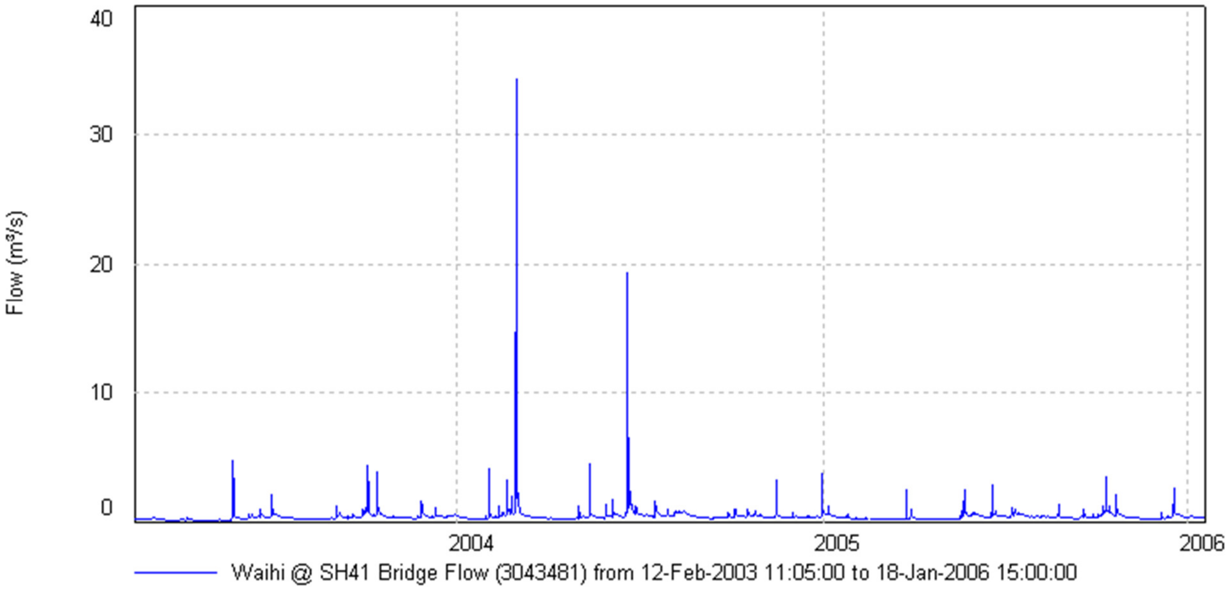

Figure 3.7: **Flow record for the Waihi Stream at SH41 Bridge.**

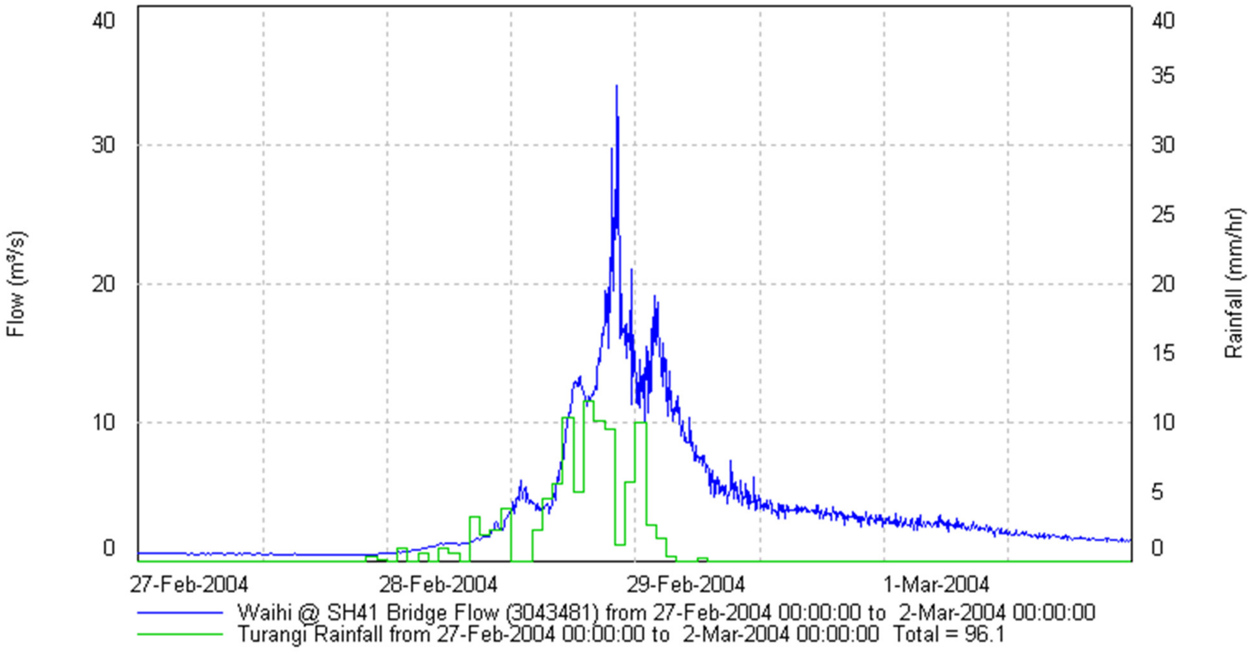

Figure 3.8: **Flood hydrograph of the largest flow on record at Waihi at SH41 Bridge.**

Since the Waihi catchment is adjacent to Tokaanu Stream it is expected to be affected by similar storm patterns, and to have a similar rainfall–runoff response. The flood hydrograph for this extreme event in Waihi Stream was therefore used as the type-hydrograph for various design flood scenarios affecting the sub-catchments of Tokaanu Stream. Consequently, this type-hydrograph was scaled to the peak discharge estimates for the design storms in the various sub-catchments of Tokaanu Stream. These flood hydrographs for the various sub-catchments were used as input to the MIKE21 hydraulic model.

Although the exact pattern of response of each of the sub-catchments would be slightly different, because of different physical characteristics, any uncertainty is likely to be within the limits of other sources of uncertainty within the hydraulic model.

3.7 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 the extremes are drawn randomly and independently from a single statistical distribution. Implicit in this assumption is that the same processes and relationships that existed in the past will continue to apply in the future. For example, the relationship between rainfall and runoff during particular events will be the same. However, should anything change this relationship e.g., climate or land use change, then stationarity may no longer apply. When this occurs, the reliability of the frequency analysis, and any derived design storm events, may be questioned.

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

3.8 Potential effects of land use change

Previous 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 3.7.

Table 3.7: 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 Tokaanu catchment, a possible land use change would be the conversion of all the indigenous forest to pasture. It must be recognised that such a land use change is extremely unlikely given the various constraints on clearing indigenous forest. At present only 1.3% of the Tokaanu catchment is under some kind of exotic forestry management. Given how little exotic forest there is within the catchment, any conversion to pasture would have little effect on runoff. If anything, a conversion from pasture to forestry would be more likely. This would cause a reduction in the flood peak rather than any increase.

3.9 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℃ by the 2040s and 0.6 and 5.6℃ by the 2090s (Figures 3.8a and 3.8b). These data are summarised in Table 3.8.

Table 3.8: Projected increases in mean annual temperature by 2040 and 2090 for the Lake Taupo catchment. (Ministry for the Environment, 2010).

2	2040 (℃)	2090(℃)
Lower limit	0.2	0.6
Average	0.9	2.1
Upper limit	2.4	5.6

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

The MfE methodology recommends percentage adjustments per degree of warming that should be applied to the high intensity rainfall totals to account for the effect of global warming. For example, a 12-hour duration 100-year return period rainfall will increase by 8 percent per degree of projected warming (highlighted in Table 3.9).

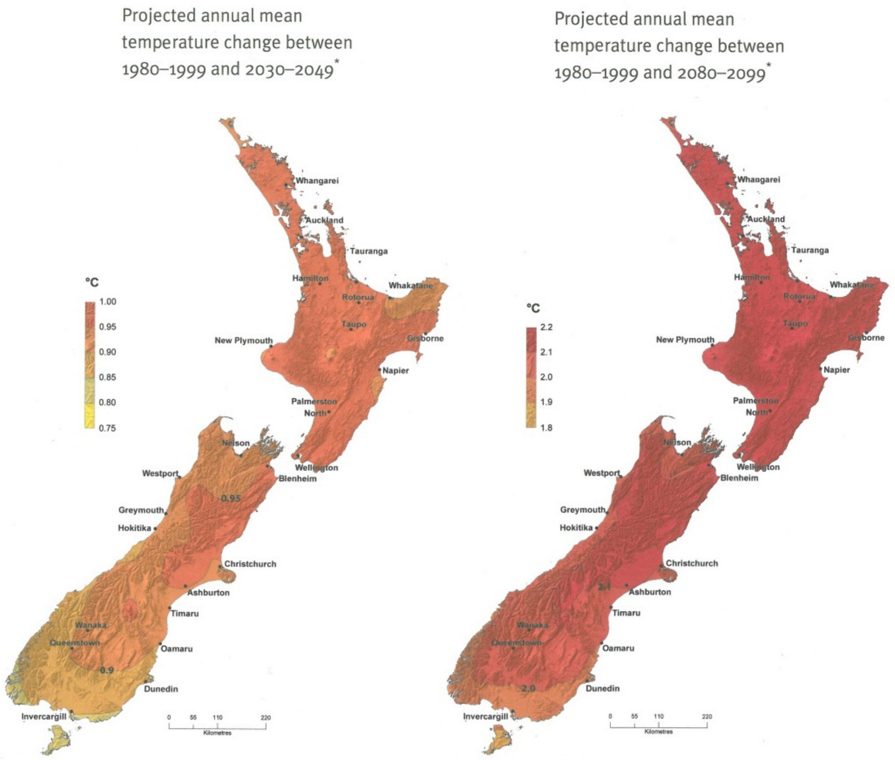

Figure 3.8a: **Predicted increases in mean annual temperature by 2040 and 2090 relative to 1990; average of 12 climate models for A1B emission scenario (Ministry for the Environment, 2010a).**

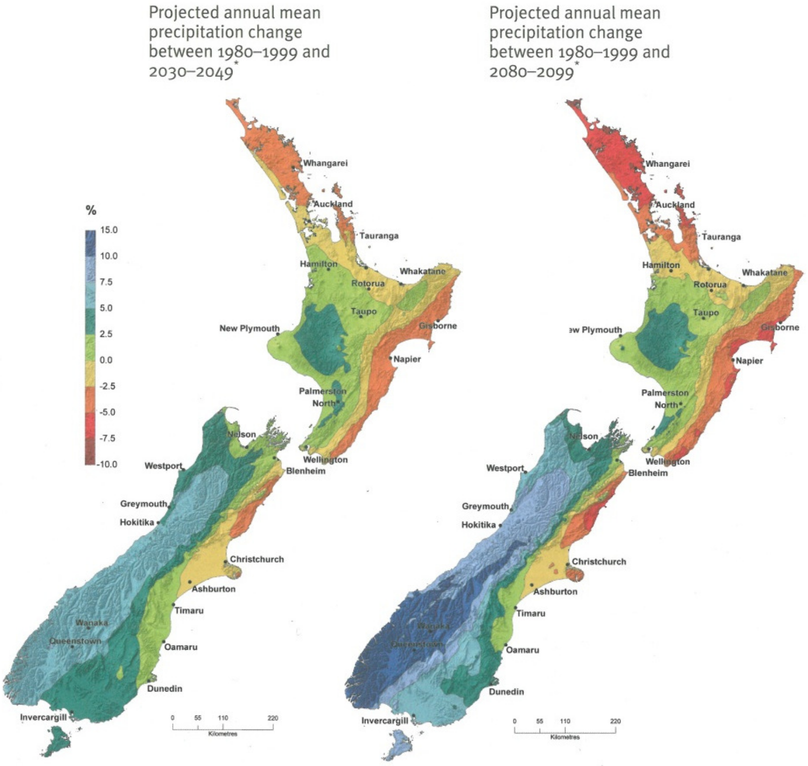

Figure 3.8b: **Predicted increases in rainfall by 2040 and 2090 relative to 1990; average of 12 climate models for A1B emission scenario (Ministry for the Environment, 2010a).**

Analysis of a range of flood events has shown that rainfall durations of from 6 to 12 hours are likely to pose the greatest flood risk in the Tokaanu catchment. Since the percentage increase in rainfall (per degree warming) decreases with increasing storm duration, and to take a conservative approach to flood risk, a critical storm duration of 12 hours was considered in this analysis.

Assuming temperature increases of between 0.2°C and 2.4°C (2040s) and 0.6°C and 5.6°C (2090s) for the respective scenarios, the 100-year return period rainfall will increase by a maximum of 19.2% by 2040 and 44.8% by the 2090s (Table 3.10). 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 3.9: 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 : Ministry for the Environment, 2010.

Table 3.10: Estimated percentage increase in 12-hour rainfall totals for the Tokaanu Stream as a result of global warming.

Return period	2040			2090		
	Lower limit (0.2°)	**Average (0.9°)**	**Upper limit (2.4°)**	**Lower limit (0.6°)**	**Average (2.1°)**	**Upper limit (5.6°)**
2.3	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 3.10 have been translated directly to percentage increases in flow.

Table 3.11 lists the increases in peak discharge as a result of current 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 3.10). It should be noted, however, that the predicted flood peaks by 2040 using the highest temperature increases are very similar to those by 2090 using the 'average' values. This is therefore considered to be a conservative approach. It allows predicted increases in flood peaks to be managed efficiently now. There is sufficient lead time by 2090 that, should the maximum predicted increase appear likely, further mitigation of the flood risk is possible.

The type-hydrograph obtained from Waihi Stream, and discussed in section 3.6, was therefore scaled to the peak discharge estimates of the various design storms listed in Table 3.11. The four hydrographs derived for the various sub-catchments, together with a hydrograph scaled to a peak discharge of $2m^3/s$ to represent flow from the catchment upstream of the power station tailrace, were used as input to the MIKE21 model. This $2m^3/s$ discharge from upstream of the tailrace was not scaled for the potential impact of climate change since this flow is constrained by the hydraulic design of the spillway structure and not the rainfall-runoff relationship. The MIKE21 model was then used to predict the likely extent and depth of flooding during various design flood scenarios.

As discussed already the various assumptions adopted when deriving the input hydrographs, together with the assumption of concurrent peak discharges in all tributaries, means that the results of the flooding modelling are likely to be conservative, but still realistic.

Table 3.11: Increased flood discharge for the Tokaanu Stream as a result of global warming, using average predicted temperature change for 2090.

Catchment Name	Return Period	Flood peak discharge	Flood peak discharge 2040 – highest temperature prediction (m^3/s)	Flood peak discharge 2090 – average temperature prediction (m^3/s)
Catchment 1	**2.33**	2.5	2.8	2.7
	5	3.1	3.5	3.5
	10	3.4	3.9	3.8
	20	3.7	4.3	4.3
	50	3.9	4.6	4.6
	100	4.1	4.9	4.8
Catchment 2	**2.33**	3.5	3.9	3.8
	5	4.3	4.9	4.8
	10	4.8	5.5	5.4
	20	5.1	6.0	5.9
	50	5.5	6.6	6.4
	100	5.7	6.8	6.7
Catchment 3	**2.33**	4.1	4.5	4.5
	5	5.1	5.8	5.7
	10	5.6	6.4	6.3
	20	6.1	7.2	7.0
	50	6.5	7.7	7.6
	100	6.7	8.0	7.8
Catchment 4	**2.33**	2.7	3.0	2.9
	5	3.4	3.8	3.8
	10	3.7	4.3	4.2
	20	4	4.7	4.6
	50	4.3	5.1	5.0
	100	4.5	5.4	5.3
Tailrace		2.0	2.0	2.0

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

4 Other factors that affect flooding

4.1 Sediment transport

Under normal flow conditions the sediment load of the Tokaanu Stream consists of sands and silts in suspension. Because this material is in suspension it is generally transported through the lower reaches of the river to the mouth, except when trapped by vegetation within the channel. The finest material is deposited in Lake Taupo. This sediment therefore has little effect on the flow capacity and the potential for flooding. Flood events, however, can mobilise significant quantities of bedload 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 when the channel gradient flattens and on the lower flood plain.

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 effects can either exacerbate or limit the flood extent, duration, and inundation depth they are difficult to build into flood hazard model. This is because they are essentially random occurrences in both time and place. Assuming that the river channel geometry and flow capacity are maintained and potentially enhanced by management practices, any adverse effects of sediment within the channel should be minimised.

4.2 Lake level

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

The risk of flooding and inundation adjacent to Tokaanu Stream 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. 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.

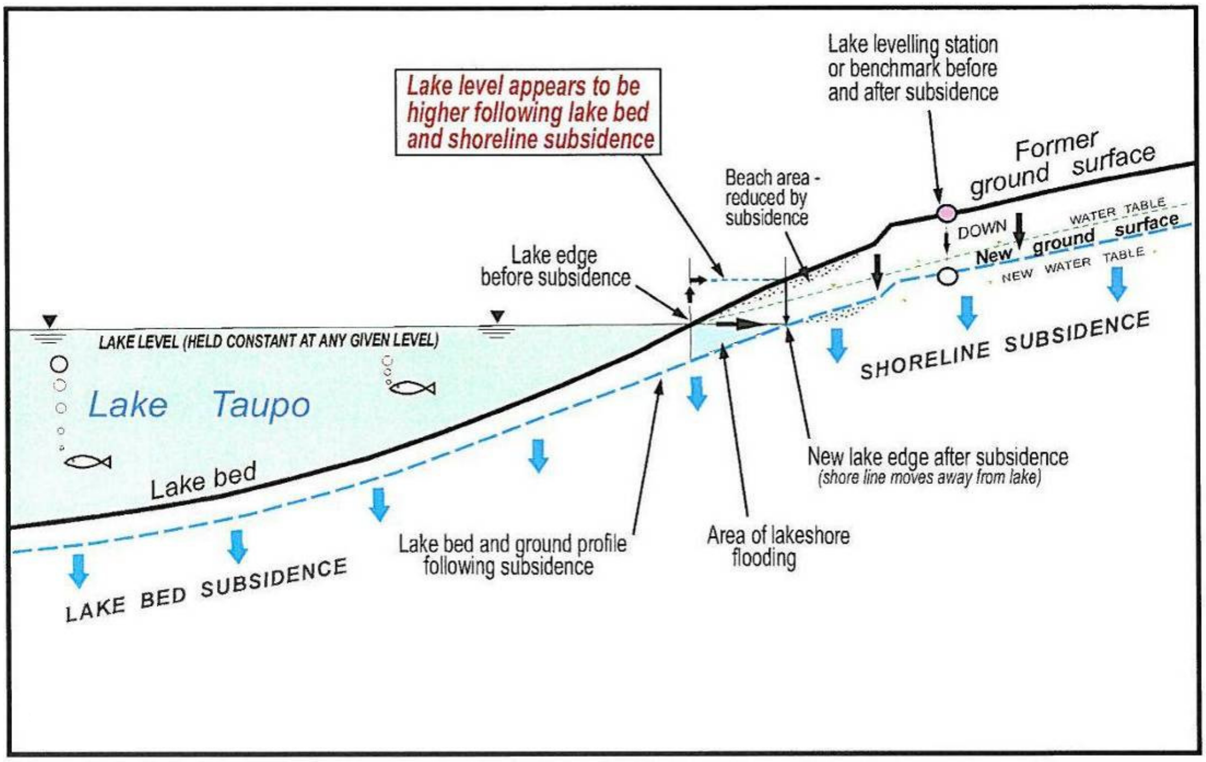

Figure 4.1: Effect of ground level subsidence on relative lake levels (Hancox, 2002).

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

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

Table 4.2: Ground deformation over various time periods (mm)

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

Based on this ground deformation model the area in the vicinity of the lower reaches of Tokaanu Stream is estimated to be subsiding at approximately 2.6mm/year. Because of its magnitude, and potential impact on water levels, this tectonic deformation needs to be built into projections of future lake and river levels, and consequently the flood hazard model. Over a 100-year period the lower Tokaanu Stream is likely to subside approximately 260mm. The effect of this on the flood risk is that lake levels will be relatively higher, and this, in combination with reduced channel slopes, may increase the extent, duration, and depth of flooding caused by large storm events.

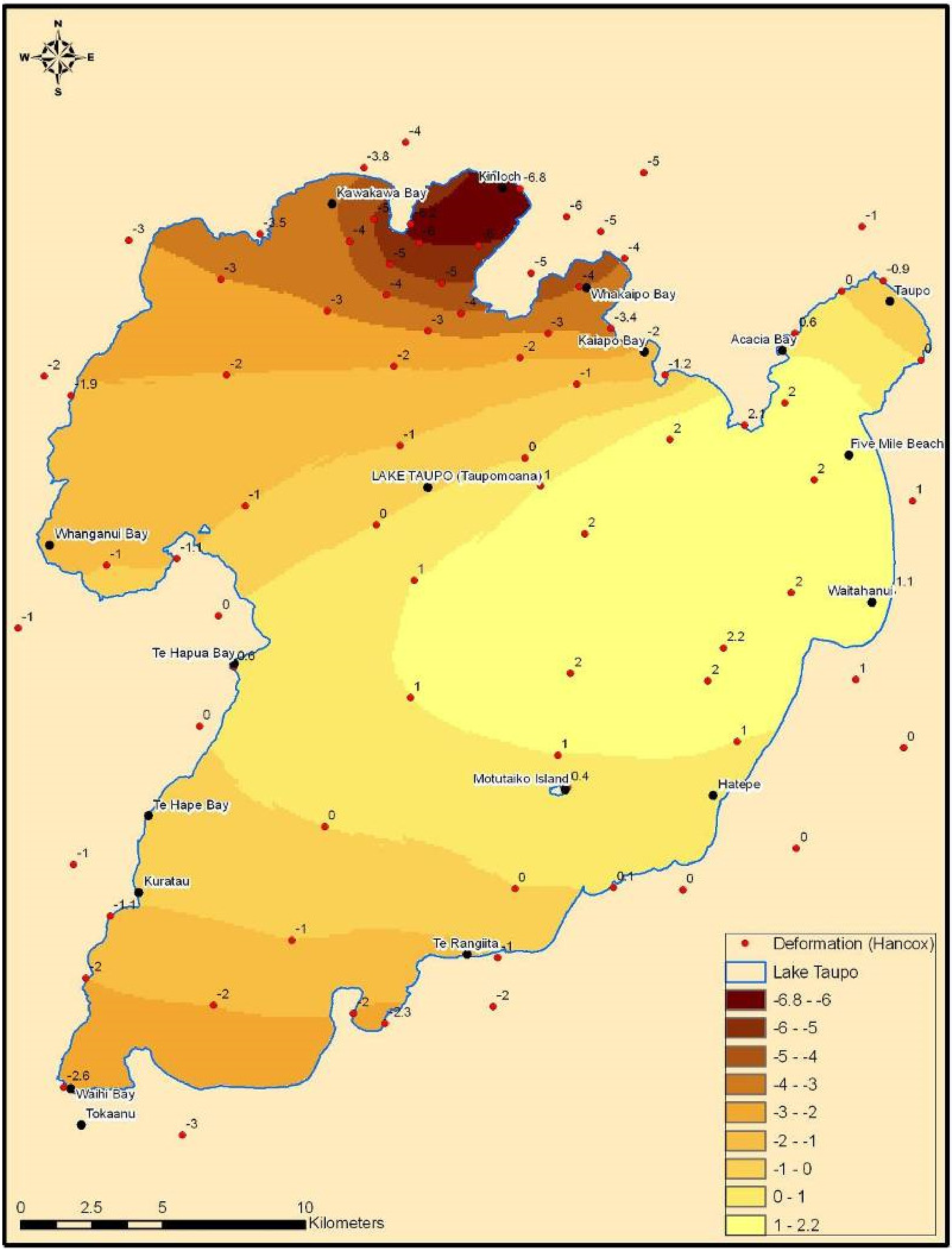

Figure 4.2: **Average rates (mm/yr) of ground deformation between 1979 and 2002 (After Hancox, 2002).**

4.4 Waves

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

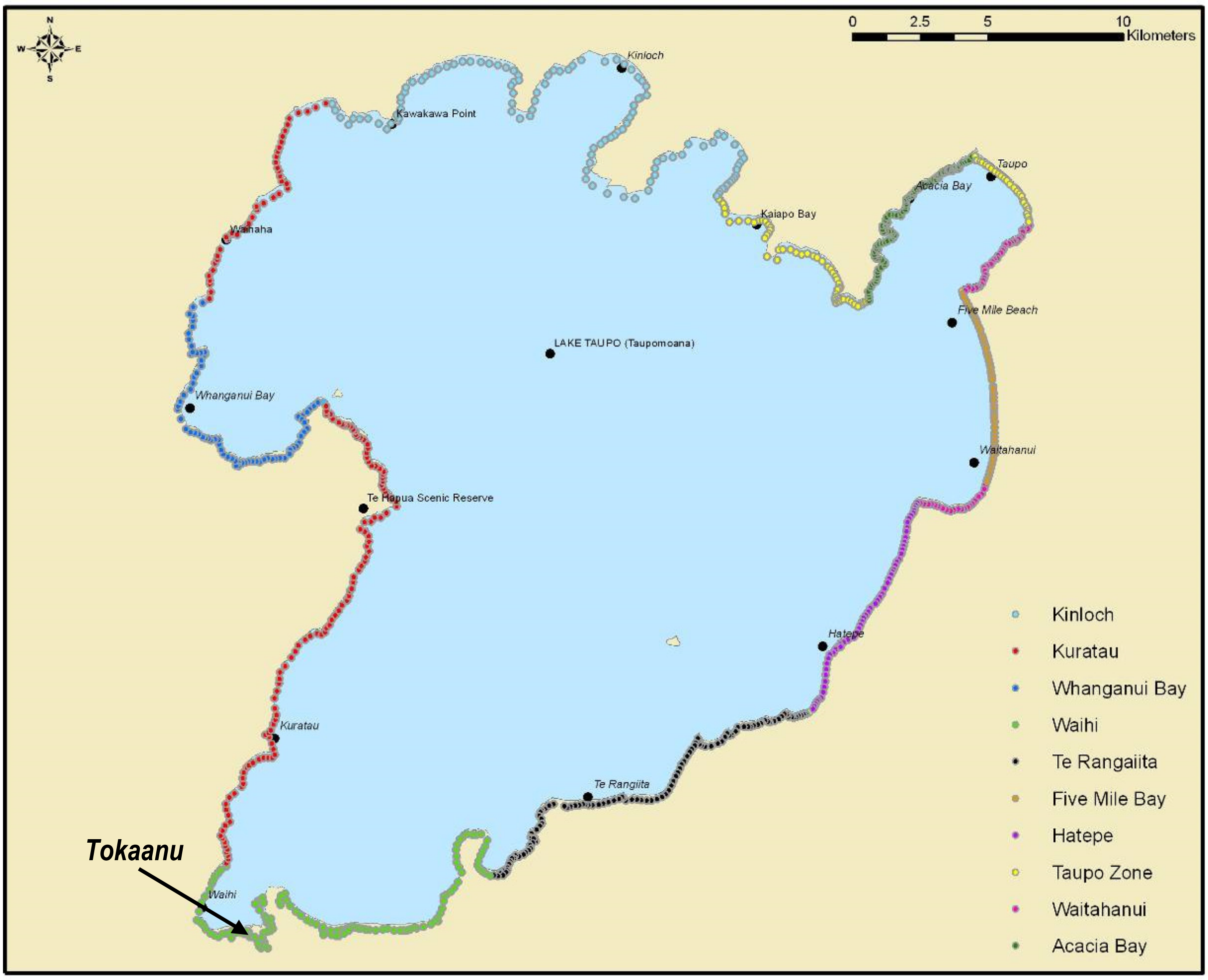

Figure 4.3: Wave run-up environments around the shore of Lake Taupo.

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

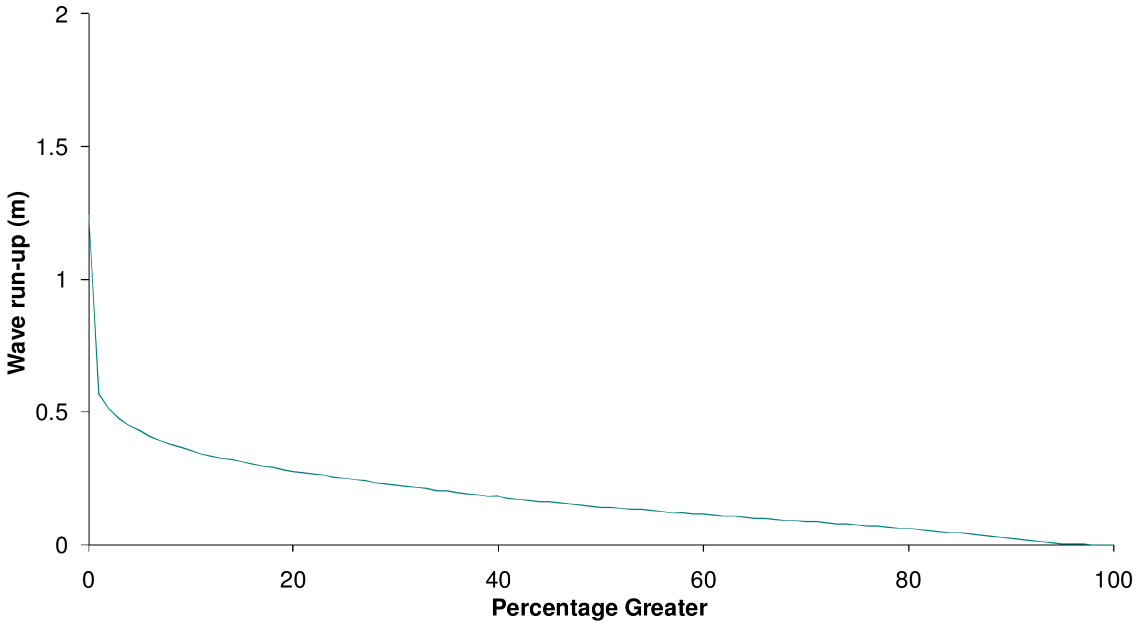

Figure 4.4: Frequency distribution of wave run-up in the Waihi wave environment.

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

Table 4.3: Summary of 2% exceedance wave run-up heights with different return periods for Waihi.

Best-fit Distribution	**PE3**
Return Period	*Height (m)*
2.33	0.74
5	0.85
10	0.94
20	1.03
50	1.14
100	1.22
200	1.28

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

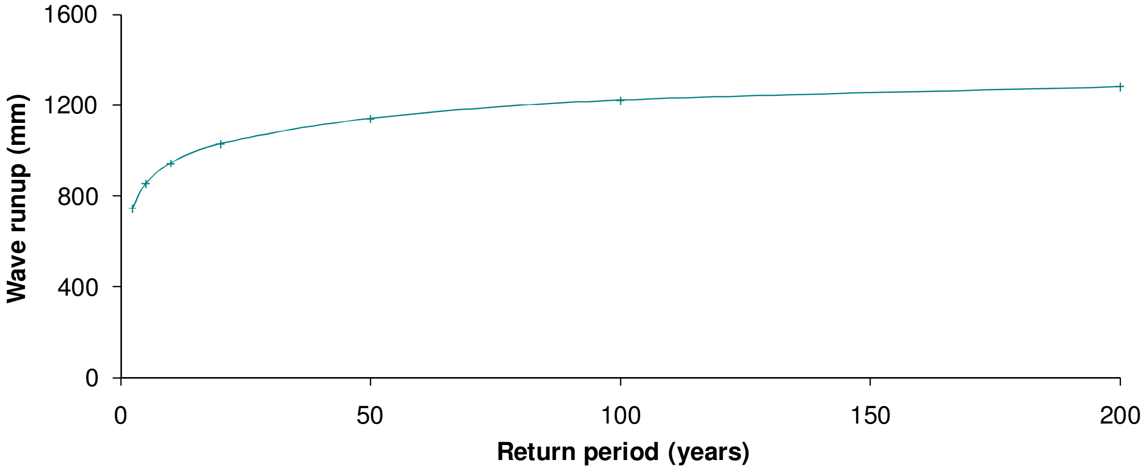

Figure 4.5 **Wave run-up for the Waihi wave environment at different return periods.**

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 (0.260m at Tokaanu). The static water level defined in this manner delineates areas where inundation to some degree is considered to be inevitable over a 100-year period, or with a likelihood of 1% each year.

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

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

5 Flood risk

The flood risk in the vicinity of the Tokaanu Stream is a combination of both lake-induced flooding, and overbank flows from the river. These two situations may not occur at the same time. The total area potentially affected by flooding, however, needs to be considered in any planning and management framework. The area likely to be affected by high lake levels is shown in Figure 5.1. Water levels will potentially be 260mm higher than shown if subsidence of the area continues at the present rate.

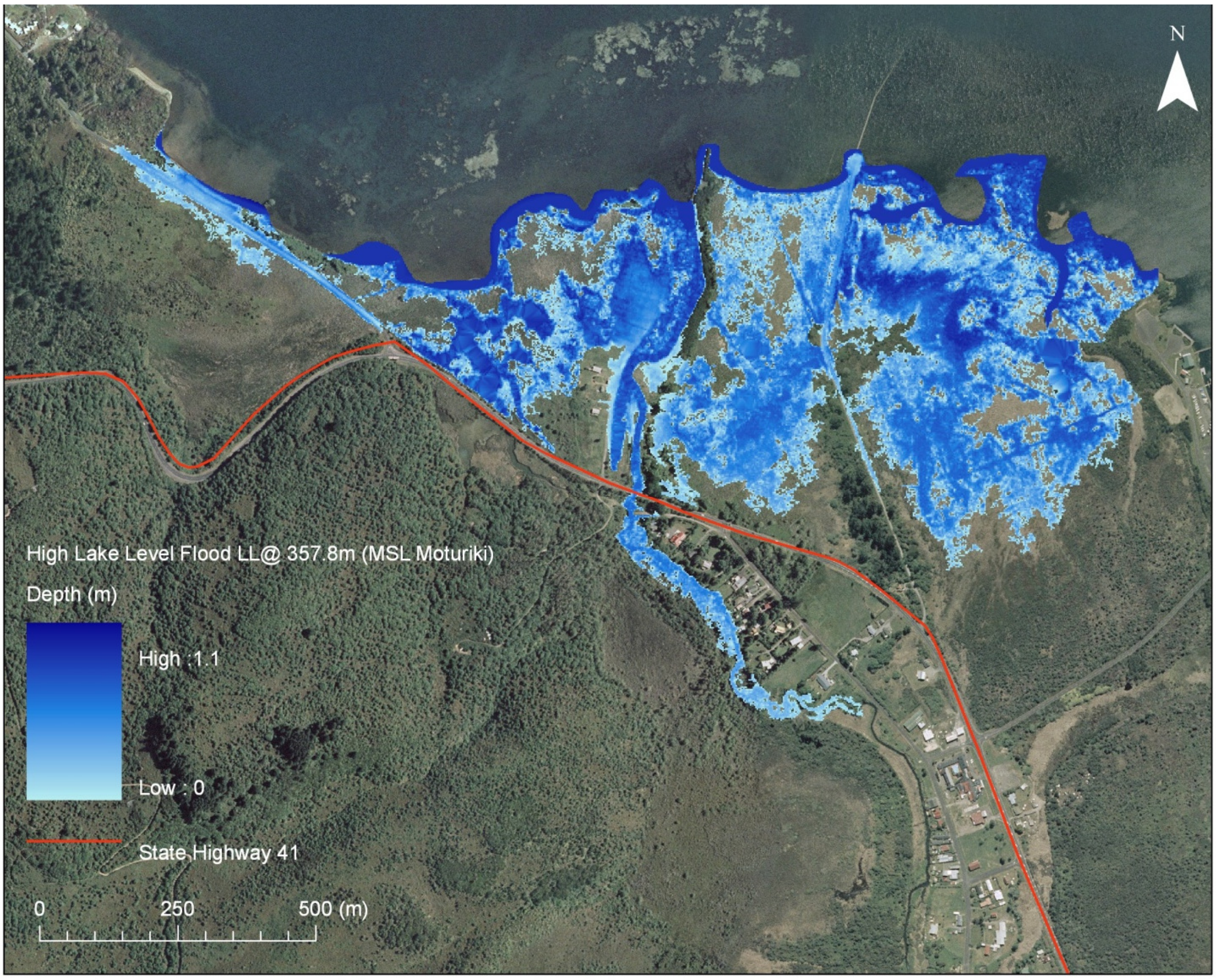

Figure 5.1: Area affected by a water level of 357.8m (MSL Moturiki). This does not include the potential effects of subsidence which could lower the ground by an additional 0.260m.

The majority of Tokaanu Village is located well above a potential lake level of 357.8m (MSL Moturiki) shown in Figure 5.1. Near the river mouth, and between SH41 and Lake Taupo, the same areas will be affected under either high lake levels or high river levels. This is partly because both of the flood risks are controlled largely by ground elevation; however, it also provides confidence in the results of the two distinct modelling exercises.

To assess the likely extent, depth, and velocity of a 100-year flood event in Tokaanu Stream, and the potential effects of predicted climate change on this flood event, a MIKE21 two-dimensional hydraulic model was developed for the area.

6 MIKE21 model

MIKE21 is a two-dimensional hydrodynamic modelling software package developed by DHI (formally the Danish Hydraulic Institute) which allows the user to accurately reflect the flood plain response to river channel overtopping.

6.1 Methodology

Using LiDAR topographic information a two-dimensional MIKE21 model was established. The model covers an area of approximately 1.33km^2. It extends 3.6km along the Tokaanu Stream downstream of the SH41 aqueduct, and includes all the low-lying area between the steep slopes draining Tihia and Lake Taupo (Figure 6.1).

Figure 6.1: MIKE21 approximate model extent.

While all the other flood studies of the various tributaries to Lake Taupo used MIKE FLOOD, MIKE21 was used to model the extent of flooding adjacent to Tokaanu Stream. This is because the channel of Tokaanu Stream is very small and shallow. Since the role of the channel during large flood events is relatively minor it was not necessary to model the channel separately from the wider floodplain.

When LiDAR information is processed, algorithms are used to adjust elevation values to remove or smooth out the effects of vegetation. Over heavily vegetated areas this is difficult and may lead to errors. Thus water levels in heavily vegetated areas should be analysed with caution.

LiDAR data does not contain information over water bodies such as lakes, rivers and ponds. In this model, the volume of the channel of Tokaanu Stream below the water surface when the LiDAR was captured was ignored. Surveyed cross-section data were not available. Given that the width and volume of water in the stream during low flows when the LiDAR was likely to have been captured are very small relative to those during the extreme events considered in this study, this assumption is reasonable. Any error caused by this assumption is likely to be small when compared to the inherent uncertainty of other inputs to the hydraulic model.

The MIKE21 model was then used to estimate the extent and characteristics of the 100-year average recurrence interval (ARI) flood event adjusted for the effect of predicted climate change to 2090.

Consideration was given to modelling the flow through the specific design characteristics of the SH41 Bridge over Tokaanu Stream. However, investigation of the preliminary model results showed that flood levels remain well below the soffit of the bridge. Also, the pier arrangement (one narrow pier in the centre of the stream) is such that no undue flow energy losses would occur which require special treatment of the bridge within the hydraulic model. Losses resulting from contraction and expansion of flow through a narrow opening are accounted for by default when taking a two-dimensional modelling approach. Other small bridges are not likely to require special treatment as they are within a highly vegetated main channel which is modelled with a relatively high resistance factor.

In this analysis it was assumed that there are no culverts under SH41 that pass water from Tokaanu Village to the north-eastern side of the highway. It was assumed that any such culverts would have a minor effect on flood inundation. The inclusion of minor conveyance features such as culverts was also deemed outside the scope of this broader reconnaissance-scale flood investigation.

Flow inputs to the model were distributed as source discharges onto multiple cells for each of the 5 sub-catchments. This flow was ‘added’ just upslope of where the sub-catchments meet Tokaanu Stream. Some analysis was carried out to determine whether the flood extent was sensitive to the exact placement of these flow sources. It was found that the placement of flow inputs did not have any significant impact on the flood modelling results. A constant 100-year ARI lake level was implemented as the downstream water level boundary.

An extensive series of sensitivity analyses were carried out on key hydraulic parameters. These tests allow assessment of the potential effects of any errors on calculating flood levels and extents. This is vitally important given that there are no available field calibration data for the model.

6.2 Sensitivity analysis

A sensitivity analysis using the 100-year ARI flood event plus the effect of climate change, was carried out on several of the hydrodynamic modelling parameters, as well as the input data. This was to assess the likely effect of any error in the various data sources, and consequently the confidence that can be placed in the model results. Inputs were varied by amounts consistent with the accuracy that might be expected when modelling a catchment of this nature. These ranges were based on experience gained from flood assessments in other Lake Taupo catchments.

The analysis confirmed that over the range of values tested no parameter was particularly sensitive. Manning's n had some impact, but produced variations in peak flood level of only 5cm. This is not significant when compared to other uncertainties in the modelling. This is not surprising considering that the flood plain in this area is an extension of the Tongariro delta and consists of relatively flat and low-lying land.

Increasing the peak discharge from Sub-catchment 1 (the catchment closest to the SH41 Bridge) significantly from 4.6m^3/s to 9.2m^3/s only resulted in an increase in flood levels of 0.07m in front of the SH41 Bridge. This demonstrates the dominant effect that the SH41 Bridge and raised vertical profile of SH41 have on flood levels. The bridge provides a constriction in the stream while the road acts as a barrier to the lateral movement of flood water.

The sensitivity analysis also showed that increasing the lake level by 0.3m had negligible impact on flood levels upstream of the SH41 Bridge. This is discussed in greater detail later.

Considering the inherent uncertainty relating to the input data, together with the lack of calibration data, the sensitivity analysis showed that the model produces sensible and realistic results. The model does not react in an over-sensitive manner to small changes to the inputs. The model can therefore be relied on to give a good indication of potential flood hazard in the lower Tokaanu catchment.

6.3 Effect of lake level on flooding

Figure 6.2 shows a sketch of the longitudinal water surface profile along a river which flows into a lake. This is commonly referred to as the 'backwater profile' (Henderson, 1966). Beyond a certain distance upstream, the backwater profile for a given river discharge (flow) is governed by the size, shape, slope and frictional characteristics of the river channel.

Toward the lake at the downstream end of the reach, the backwater profile has a concave upwards shape which transitions asymptotically to the horizontal lake level surface. The downstream lake level in fact acts as a hydraulic control on the backwater profile so that river levels, for a given discharge, are influenced also by the lake level for a certain distance upstream of the lake depending on the river channel slope.

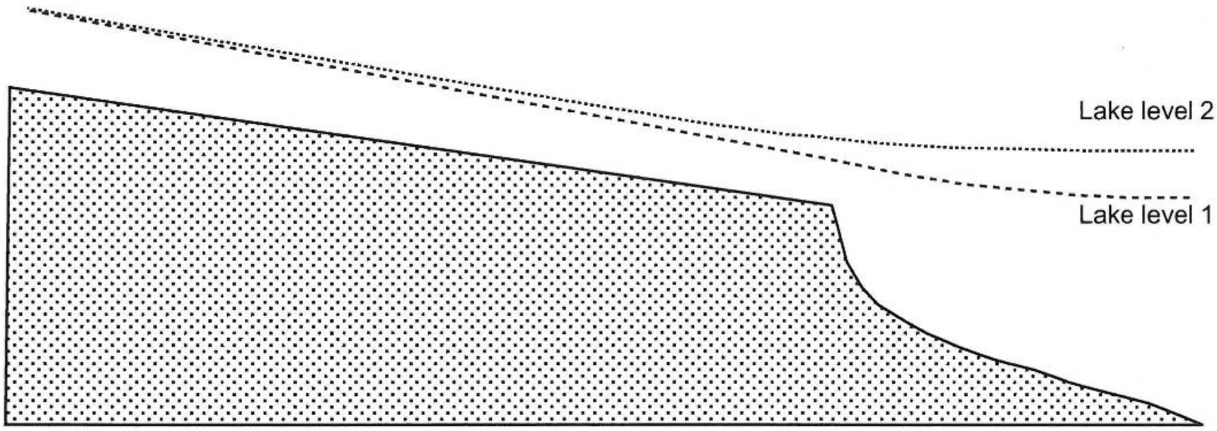

Figure 6.2 Backwater profiles for river flow discharging into a lake (constant discharge).

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

Figure 6.3 shows the predicted backwater profile along the Tokaanu Stream for the 100-year ARI event, including the potential effect of climate change. The backwater profile is based on the 100-year ARI lake level estimated to be RL 357.5m. The shape of the backwater profile is slightly different from that shown in Figure 6.2 in that it is faintly concave downwards towards the mouth of the river, before the profile flattens as it reaches the lake at chainage 1640. This is quite significant as it indicates that the influence of the size, shape, slope and frictional characteristics of the river channel on the backwater profile is much more dominant than the influence of the lake level towards the mouth of the river.

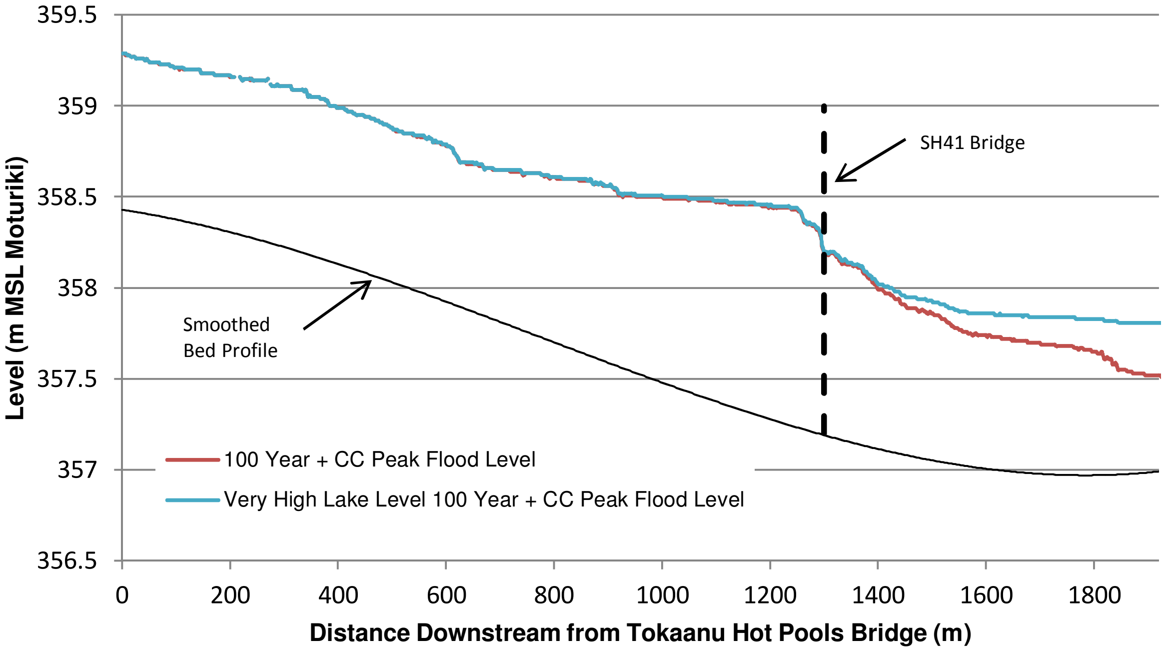

Figure 6.3 **Backwater profiles simulated for the 100-year ARI event plus climate change showing the effect of increasing the downstream boundary water level (i.e. lake level) by 0.3m.**

Sensitivity tests were carried out with the model for the simulated 100-year ARI event, plus the effects of climate change, and with the downstream lake level raised arbitrarily by 0.3m. The results confirm that the backwater profile only changes noticeably with varying lake levels over the lower 550 metres of Tokaanu Stream. For example, 300 metres upstream of the river mouth (at 1600m in Figure 6.2) a 300mm difference in lake level causes a shift in the backwater profile of less than 120mm. This effect is likely to be well within the range of the other uncertainty within the hydraulic model.

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

6.4 Description of scenarios modelled

Only one major flood hazard scenario was simulated using the MIKE21 model. The scenario considered the 100-year ARI flood event, adjusted to include the predicted increase in discharge resulting from climate change. Because of the inherent uncertainties regarding the hydrologic inputs, caused by the lack of a long term high resolution flow record for Tokaanu Stream, this scenario was seen as a useful benchmark for flood hazard classification and long-term flood risk management. Should calibration data become available in the future, the model could quickly be 're-tuned' for any other scenario.

For the downstream boundary condition, the 100-year ARI lake level was used. The combination of the two 100-year ARI scenarios will result in a conservative estimate of flood extent and depth in some areas. Overall, however, such a scenario provides a good estimate of the likely 100-year ARI flood near the mouth of the river. The reasoning for this argument is discussed more fully in McConchie *et al*. (2008).

Table 6.1 summarises the boundary conditions used in the flood prediction scenarios simulated using the MIKE21 model.

Table 6.1: Summary of 100 year ARI adjusted for predicted future climate change MIKE21 model boundaries.

Boundary Type	Boundary	Peak discharge (m^3/s)
Inflow hydrograph with a 100-year flood peak discharge adjusted for the effects of climate change to 2090 (m^3/s)	**Sub-catchment 1**	4.8
	Sub-catchment 2	6.7
	Sub-catchment 3	7.8
	Sub-catchment 4	5.3
	Downstream of tailrace	2.0
Downstream boundary: Lake level (m MSL Moturiki)	**Lake Taupo Water Level**	357.5

6.5 Flood inundation maps

Figure 6.4 shows the maximum extent of inundation predicted when simulating the 100-year ARI flood event with its peak discharge increased to allow for the predicted effect of climate change. It is apparent that under the extreme scenario modelled significant areas of Tokaanu Village would potentially be affected by flood waters. These areas are principally where flood waters are constrained between Tokaanu Stream and the embankment formed by SH41. In general, however, the depth of potential inundation is shallow except where secondary flow paths become active.

Figure 6.5 shows the flooding in the vicinity of Tokaanu Village in more detail. While some properties would potentially be affected, the depth of flood waters is generally shallow. The re-activation of secondary flow paths is also apparent, together with the effect of SH41 in restricting the lateral flow of flood waters towards Lake Taupo. The effect of the constrictions formed by bridges over Tokaanu Stream is also obvious with consequential increases in both water depth and velocity.

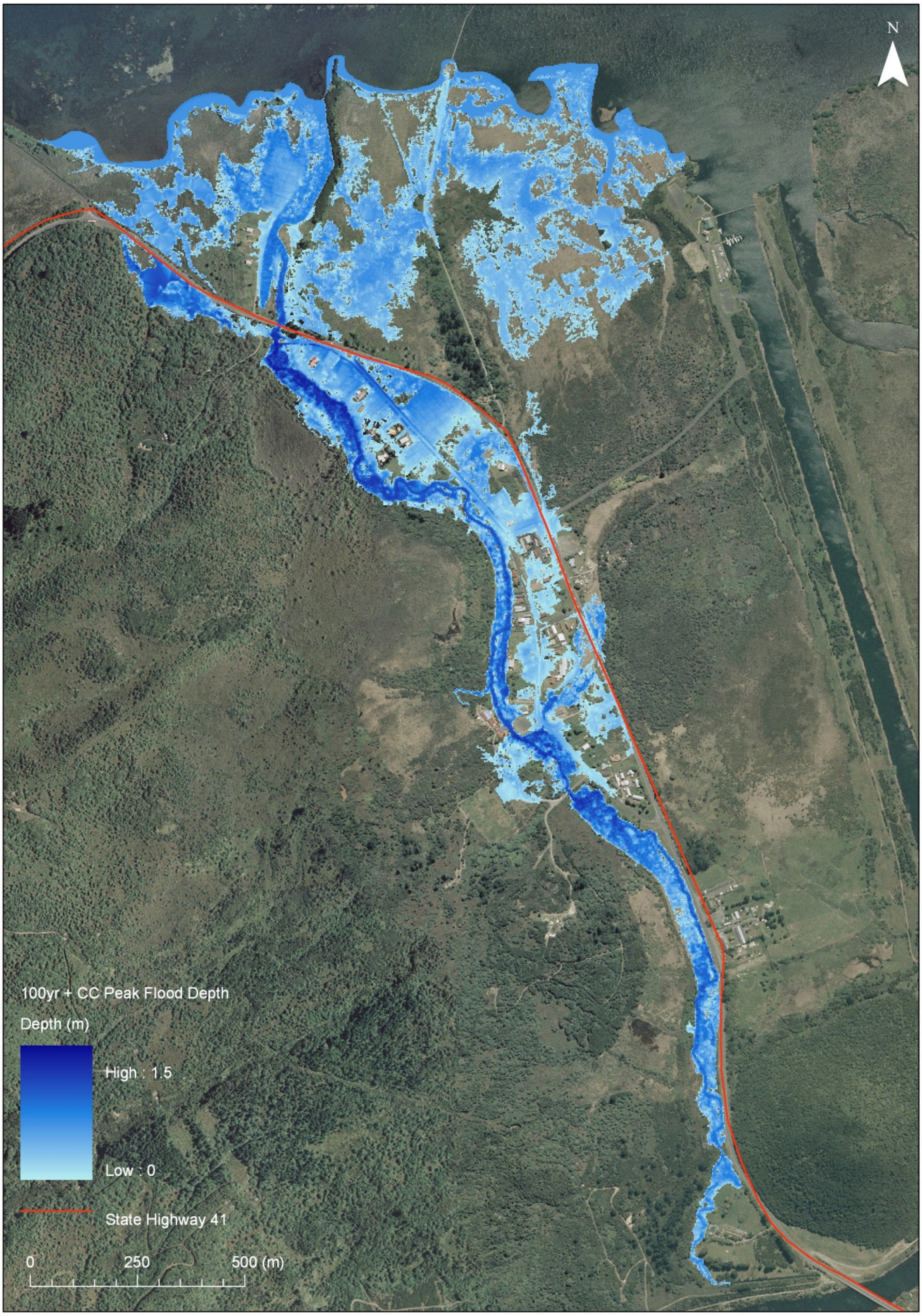

Figure 6.4: **Depth and extent of inundation predicted for Tokaanu Stream; assuming a 'worst case' scenario i.e., 100-year flood event increased to allow for the predicted effects of climate change and a lake level of 357.5m.**

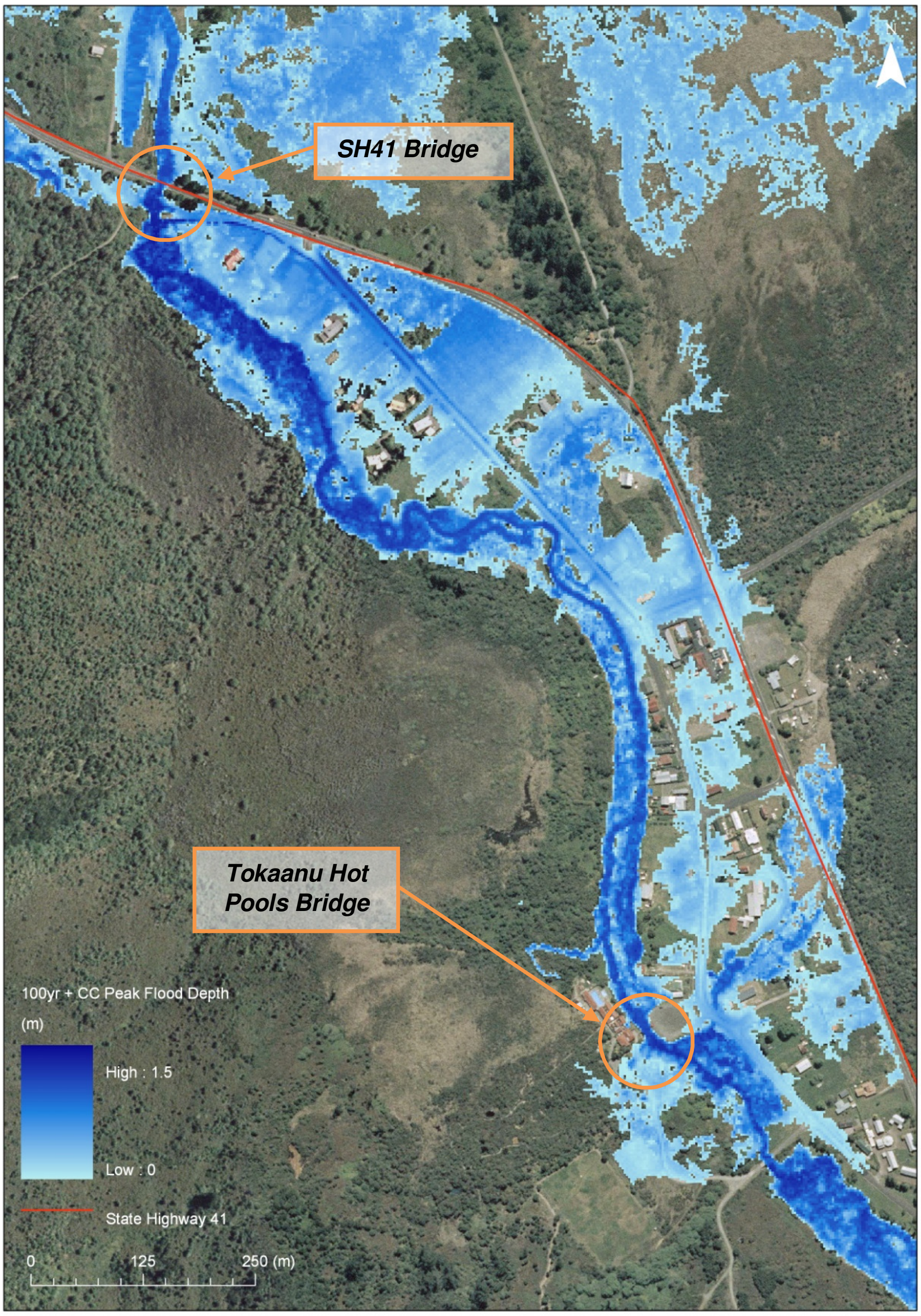

Figure 6.5: **Detail showing the depth of inundation around Tokaanu Village and the effect of bridges which constrict flow, increasing both the depth and velocity of flood waters.**

The accuracy of the model should be considered when analysing areas potentially at risk from flooding. The horizontal resolution of the data used in the model is 2.5m. Therefore, when considering the horizontal flood extent a ±2.5m margin of error should be allowed. The vertical accuracy of the flood levels should also consider the accuracy of the LiDAR data which is typically ±0.15m. This vertical error may be significantly greater in areas where correction for vegetation has been required (LiDAR cannot penetrate vegetation and water surfaces).

6.6 Maximum velocity maps

Figure 6.5 shows the maximum flow velocity for the 100-year ARI event increased to allow for the predicted effects of climate change to 2090. Higher flow velocities are generally restricted to the main channel. Some higher velocities, approximately 1.1m/s, were simulated through the SH41 Bridge. In this area the flow is confined by the narrow channel and consequently speeds up.

7 River flood hazard classification

7.1 Introduction

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

7.2 Significance to people and property

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

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

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

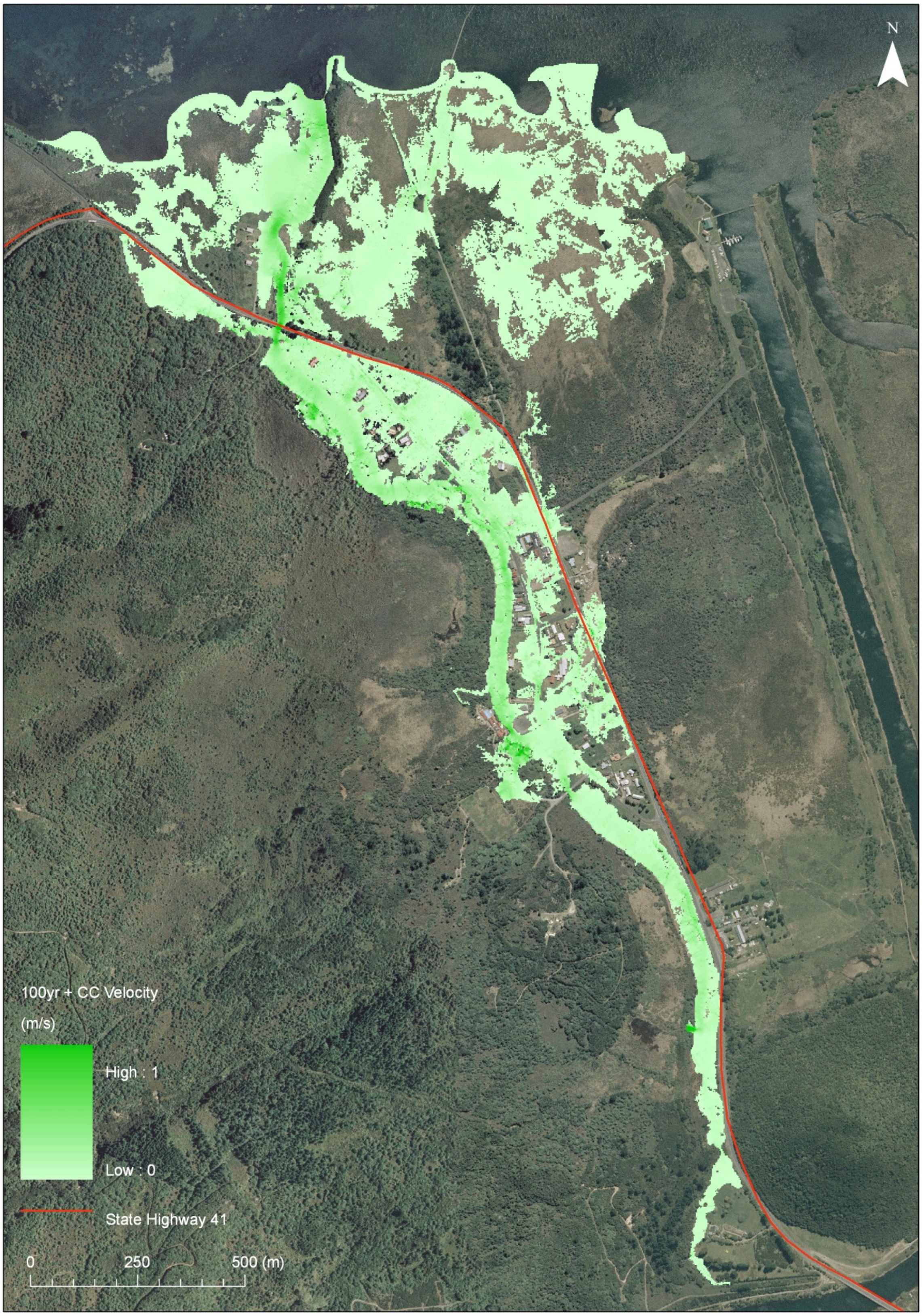

Figure 6.5: **Flow velocity of flood waters in Tokaanu Stream; assuming a 'worst case' scenario i.e., 100-year flood event increased to allow for the predicted effects of climate change and a lake level of 357.5m.**

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

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

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

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

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

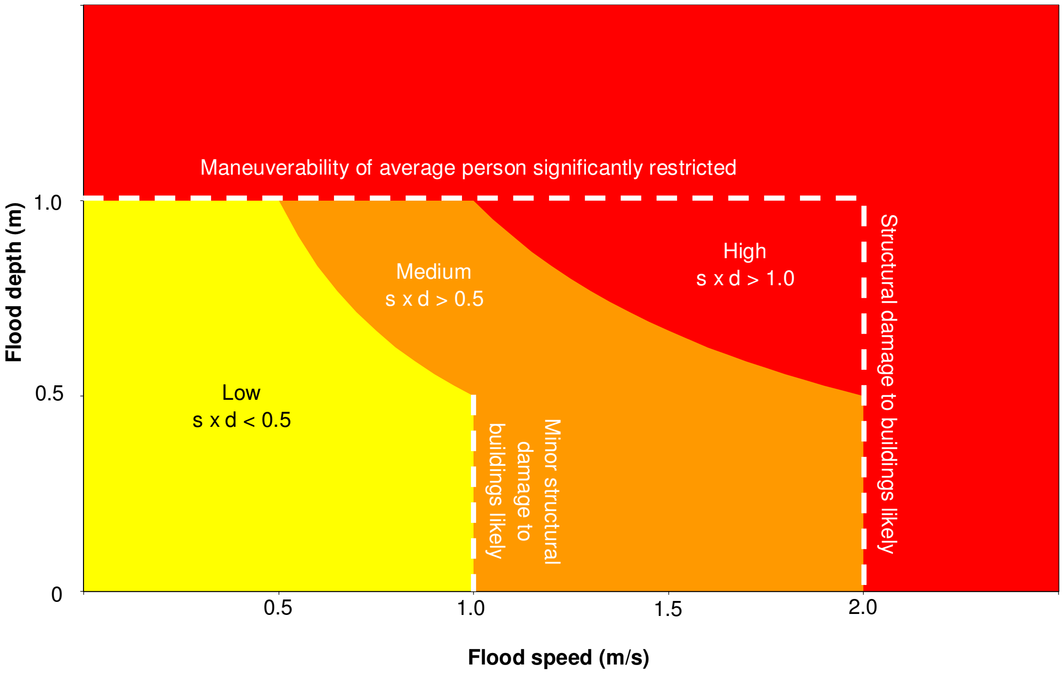

Figure 7.1: River flood hazard classification matrix (Environment Waikato, 2008b).

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

- Land that is surrounded by flooding that is classified as a ‘high’ flood hazard.
- Instances where floodwaters are directed by flood defences, including formal spillways.

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

7.3 Flood hazard assessment

The analysis of flood water levels highlights the fact that the extent and depth of flooding of Tokaanu Stream are relatively insensitive to the level of Lake Taupo. Therefore the flood hazard posed by Tokaanu Stream 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 depth and extent of inundation during this extreme scenario are shown in Figure 6.3 and the velocity of the flood waters in Figure 6.5.

Multiplying these two risks (i.e., that from the depth of water and that from the flow velocity) together provides the combined measure of the flood hazard (Figure 7.2). Note that in this flood study, flood hazard is calculated from the product of maximum velocity and depth at each point. The definition of hazard as the product of the maximum depth and velocity is a simplification of reality as the peak velocity may not always coincide with peak depth.

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

Figure 7.2 shows that a significant portion of Tokaanu Village is likely to be at risk from flooding during the simulated 100-year ARI flood event. However, in general the flood risk is low as a result of the maximum water depth being less than 1m around the majority of properties and the maximum flow velocity being less than 1m/s across the flood plain. Greater depths of inundation and higher velocities are only experienced within the main channel of the Tokaanu Stream.

Therefore while a large portion of the township is likely to experience flooding, and the cost of flooding and inconvenience may still be high, the actual risks to life and property are not great as the dwellings lie within a ‘Low” flood risk category.

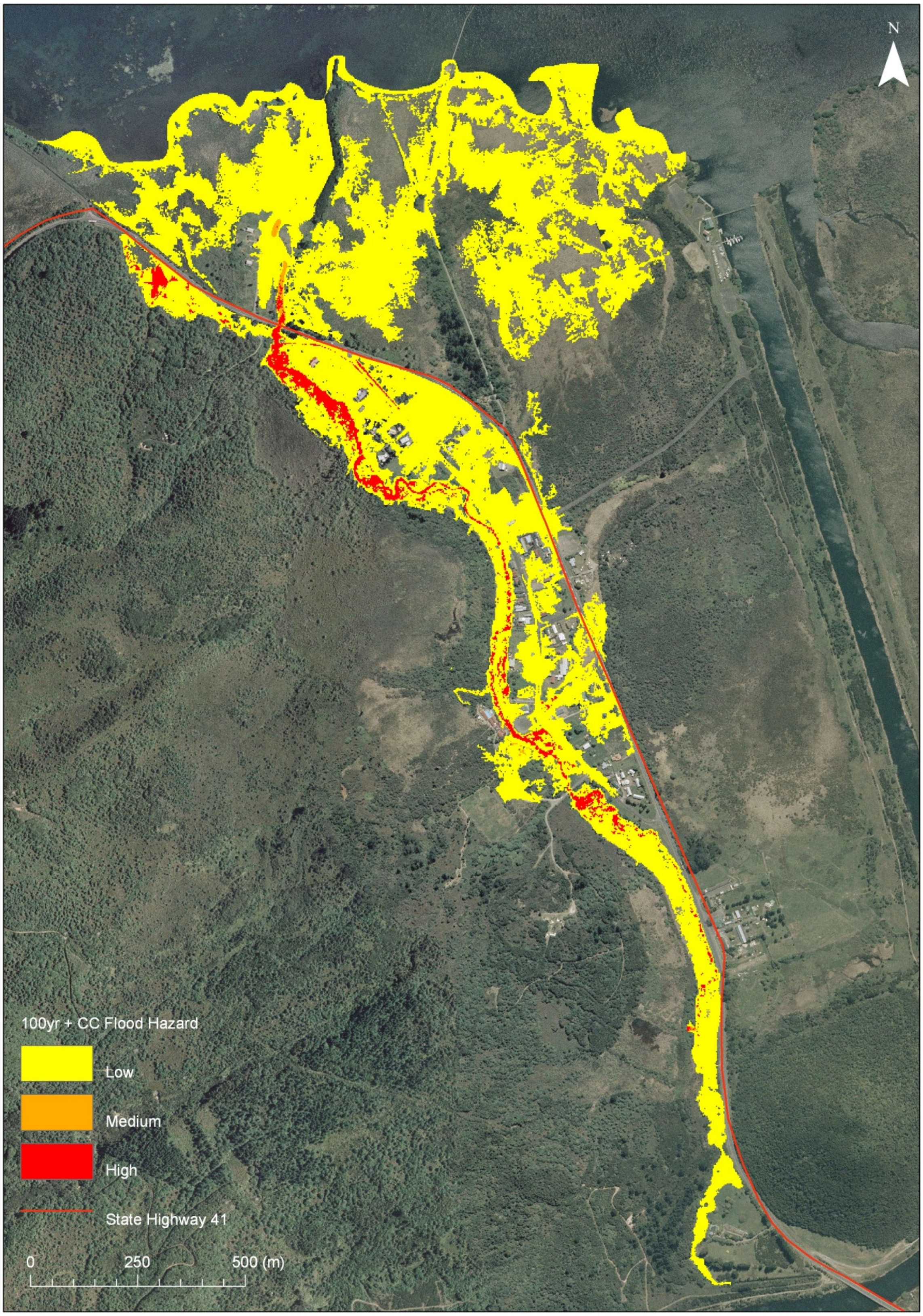

Figure 7.2: **Flood hazard classification adjacent to Tokaanu Stream during the 100-year flood adjusted for the predicted effects of climate change. Lake level assumed to be at 357.5m.**

7.4 Summary

A MIKE21 hydraulic model was established for the lower 3.6km of Tokaanu Stream. The model was created to represent the velocity, extent, and depth of flood water within the river channel and on the flood plain as accurately as possible. The model allows the potential impact of flood flows to be quantified. Now that the model has been established, it can quickly be re-tuned to explore any scenario; including climate change, channel works, flood protection options etc.

The topography of the channel and flood plain is based on LiDAR data. No information was available with which to calibrate the model. The best estimates when selecting model parameters therefore had to be based on expert advice. A comprehensive set of sensitivity analyses was undertaken and showed that the model results are likely to be realistic.

The model was then used to simulate the likely extent, depth and velocity of a 100-year flood event, adjusted for the predicted effects of climate change to 2090.

Flood waters that break out of the main channel occupy much of the low-lying area between the river and SH41. There are several areas along the stream where the channel narrows, restricting flow and causing water levels to rise upstream. This water consequently breaks out of the river and flows over the adjacent land. These areas include the SH41 Bridge, and the bridge crossing from the Tokaanu Hot Pools carpark on Mangaroa Road to the Hotpool building.

The flood maps show that water that accumulates upstream of the SH41 bridge breaks out on the right bank of the stream. SH41 in this area acts as a barrier restricting water from flowing across the alluvial fan towards Lake Taupo. Water levels back up in this region elevating flood levels around the surrounding dwellings.

8 Conclusion

Flooding of Tokaanu Stream during extreme events represents a significant potential risk. The natural processes that affect channel morphology and natural flood paths have been affected by human development on the flood plain. These developments include the construction of the Tokaanu Power Station Tailrace, SH41, a number of bridges, and housing development.

Flood modelling identified that while much of the low-lying area adjacent to the river is potentially at risk from flooding, the actual flood hazard is relatively low because of shallow water depths and low flow velocities.

The SH41 Bridge over the Tokaanu Stream constricts flows, raising flood levels in that portion of Tokaanu Village upstream of the bridge. Furthermore, the raised foundation of SH41 acts as a barrier to overland flood flow from the stream. This causes further backing up of flood water within Tokaanu Village. The potential effect of allowing the passage of flood waters from one side of SH41 to the other on reducing the potential flood risk from Tokaanu Stream is worth future consideration in flood management.

The Tokaanu Stream flood corridor contains high levels of dense vegetation, particularly within the stream channel. The feasibility of clearing or reducing this vegetation to reduce flow resistance and therefore increase channel conveyance is also worth further investigation.

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

8.1 The river flood hazard

Any flood risk assessment of Tokaanu Stream is constrained by the lack of a long term reliable flow record. Analysis of those data which do exist indicate a relatively consistent pattern of response. Rainstorms leading to significant flood events are usually of 3-12 hours duration. The resulting floods typically have one major peak, and the body of the flood lasts for less than 24 hours.

Analysis of the flow records from adjacent catchments with similar rainfall-runoff response allows realistic estimates of the likely frequency and magnitude of flood events. Various design floods can therefore be derived for each of the sub-catchments which contribute flow to Tokaanu Stream. These flood discharges can be adjusted for the predicted effects of climate change out to 2090 (Table 8.1).

Modelling of an extreme flood scenario (Table 8.1) shows that the river would breach the main channel upstream of the SH41 Bridge, pond behind the embankment formed by SH41, and inundate a significant portion of Tokaanu Village.

However, when both the depth and velocity of flood water are considered together, the majority of the area potentially inundated will be subject to a relatively low flood hazard. The risks to life and property are generally low. The highest flood hazard is within the active river channel.

Table 8.1: Estimated peak flood discharges during the 100-year event in the sub-catchments of Tokaanu Stream. The potential effect of predicted climate change on this event are also shown.

Catchment Name	100 Year ARI Flood peak discharge	Flood peak discharge 2040 – highest temperature prediction (m^3/s)	Flood peak discharge 2090 – average temperature prediction (m^3/s)
Sub-catchment 1	4.1	4.9	4.8
Sub-catchment 2	5.7	6.8	6.7
Sub-catchment 3	6.7	8.0	7.8
Sub-catchment 4	4.5	5.4	5.3
Tailrace	2.0	2.0	2.0

8.2 The combined flood hazard

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

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

8.3 Area affected

The combined flood hazard resulting from both high lake and river levels depends on the topography of the land as well as the water levels. Therefore, the water levels were overlaid on a LiDAR-derived terrain model to determine the location of flooding, and depth of inundation.

8.4 Uncertainty

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

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

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

With respect to Tokaanu Stream, the magnitude of the design flood hydrographs had to be 'modelled' rather than extrapolated from an appropriate annual maxima series. There are essentially no useful in-stream flow measurements or annual flood maxima from Tokaanu Stream.

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

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

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

The regional flood frequency indices are currently being revised and updated to include all information collected since the original report (i.e. since 1985). Once these new indices are available it would be appropriate to undertake a revision of the design flood estimates for Tokaanu Stream. This would add to the robustness and consistency of design flood estimates when flood information has to be translated and scaled from adjacent catchments.

9 References

Environment Waikato. 2005: *Invitation to tender: Taupo District Flood Hazard Study*. Waikato Regional Council, River and Catchment Services, Contract RCS 2005/6-15.

Environment Waikato. 2006: The effect of land use change on the flood hydrology of pumice catchments. Environment Waikato Technical Report 2006/35.

Environment Waikato. 2008a: Natural hazards variation to the Thames-Coromandel District Plan – proposed river flood hazard methodology for notification. Environment Waikato Technical Report April 2008 (Doc # 1197854).

Environment Waikato. 2008b: Karaka Stream river flood hazard assessment. Environment Waikato Technical Report April 2008 (Doc # 11301821).

Hamilton, D. 2001: Waikato Project Watershed Contributor – Hydrology background technical paper. Unpublished report prepared for Environment Waikato, May 2001.

Hancox, G.T. 2002: *Statement of Evidence of Graham Trendell Hancox*, representing Mighty River Power during the Taupo/Waikato resource consent application to Environment Waikato.

Henderson, F.M.1966: *Open channel flow.* MacMillan, New York, 522p.

McConchie, J.A.; Freestone, H.J.; Knight, J.R.; Morrow, F.J. 2008: Taupo District Flood Hazard Study: Stage 1 – Lake Taupo Foreshore. Report prepared for Environment Waikato and Taupo District Council, Opus International Consultants Ltd, Wellington.76p.

McKerchar, A.I. and Pearson, C.P. 1989. Flood Frequency in New Zealand. Christchurch, New Zealand: Hydrology Centre, Division of Water Sciences, Department of Scientific and Industrial Research.

Ministry for the Environment, 2008: Climate Change Effects and Impacts Assessment: A guidance manual for local government in New Zealand, 2nd edition.

Ministry for the Environment, 2010. Tools for estimating the effects of climate change on flood flow: A guidance manual for local government in New Zealand.

Ministry for the Environment, 2010a: Preparing for future flooding. A guide for local government in New Zealand.

10 Glossary

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

Inundate – to cover usually dry land with flood waters.

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

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

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

Risk – The possibility of suffering harm or hurt.

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

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


OPUS