Taupo District Flood Hazard Study

HINEMAIAIA RIVER

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

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Executive Summary

A flood hazard assessment of the Hinemaiaia River 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 a flood. Any particular flood event is a function of both the flow in the river and lake conditions at the time the flood peak reaches the mouth of the river. Lake conditions are a function of the static water level, and over the longer term any ground deformation.

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 repeated in detail here. This report focuses on the extent and depth of flooding caused predominantly by large flows in the Hinemaiaia River.

Flows in the Hinemaiaia River have been monitored at various locations since 1976. Combination, correlation, and translation of these separate records allowed a 35-year flow series to be derived. This extended record was used to provide robust estimates of the magnitude and frequency of large flood events within the Hinemaiaia catchment. The large floods of 2000 and 2001 had return periods of just greater than 50 years. This seems reasonable and confirms the validity of the hydrological inputs to the hydraulic modelling.

Analysis of a series of flood hydrographs indicates a consistent pattern of runoff response to large rainstorm events within the Hinemaiaia catchment. Rainstorm durations leading to significant flood events are usually 12-24 hours in duration. The resulting floods typically have one major peak, often with a secondary peak 24 or more hours later. Water levels rise and fall rapidly, with the main body of the flood lasting up to 48 hours. This consistent pattern of response allowed a type-hydrograph to be defined which could be scaled to the magnitude of various design flood events. The design hydrographs were also scaled to allow for the predicted impact of climate change.

While the conversion of all exotic plantations in the catchment to pasture could lead to a 25% increase in peak discharge during the 100-year event, such a land use change is not considered likely. Consequently, the design floods were not adjusted to allow for land use conversion. This could be done at some stage in the future if considered necessary.

The small size and limited storage volume of the reservoirs associated with the Hinemaiaia hydro scheme, especially relative to large floods, mean that they have little effect on the peak of flood hydrographs. They do, however, appear to attenuate the flood duration slightly. The effect of these reservoirs on flood hydrology was therefore not considered within the hydraulic modelling.

A range of extreme flood scenarios were analysed using a MIKE FLOOD hydraulic model of the lower Hinemaiaia catchment. The lack of specific information relating to inundation during major flood events made it difficult to calibrate the hydraulic model using empirical data. The MIKE FLOOD model can, however, be further calibrated when such information becomes available.

To recognise the various constraints on the flood hazard assessment, a conservative approach was taken. Consequently, the flood extents and depths of inundation predicted 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.

Flood water levels were overlaid on a high resolution digital terrain model (DTM) to identify those areas which would be inundated by a particular combination of factors, and the depth of water. As well as illustrating the overall effect of particular parameter combinations, the risk from flooding at specific sites down to 5.0m resolution was analysed.

Flooding in the Hinemaiaia River is a persistent and ongoing process. The flood plain in the lower valley shows that flooding is not new, and is a natural occurrence. 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 to the Hatepe settlement relatively low. The majority of the settlement would be unaffected by flooding, even under the extreme scenarios modelled. Those small areas which could be potentially affected are subject to a low flood hazard because of shallow water depths and low flow velocities.

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

The lack of calibration and validation data for the flood model is a major constraint. Priority therefore needs to be given to recording water levels and flood extents during any large event which affects the Hinemaiaia 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.

Following the release of updated regional flood estimation parameters the design flows for the Hinemaiaia catchment 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 Hinemaiaia 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 to 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 ground deformation, and the topography and geology of the surrounding area. Major tributaries to the lake also pose a flood risk which can be exacerbated when high lake levels impede flood drainage. Environment Waikato and the Taupo District Council are therefore investigating the combined flood risk 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 the Hinemaiaia River, downstream of the SH1 Bridge. This area is essentially the flood plain of the Hinemaiaia River.

The flood risk was assessed using detailed hydrometric analysis and a 1- and 2-dimensional coupled computational hydraulic model. Various scenarios were modelled, including the potential effects of the latest predictions of climate change out 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 hazard across the flood plain was quantified.

2 Hinemaiaia catchment

2.1 Catchment description

The Hinemaiaia River flows north-west from the Kaimanawa Ranges, discharging onto the eastern shore of Lake Taupo at Hatepe, approximately halfway between Taupo and Turangi. The catchment is 163.7km² in area and contains two reservoirs and three power stations on the 22km main stem of the Hinemaiaia River (Figure 2.1).

Figure 2.1: Hinemaiaia River catchment.

The highest part of the catchment in the Kaimanawa Ranges, which receives the greatest and most intense rainfall, is eroded into greywacke bedrock. Quaternary breccias, older than the Taupo breccias, can be found at lower elevations and along the main valleys (Figure 2.2). Pumiceous lapilli overlies relatively small areas of the northern and eastern parts of the catchment. The majority of the catchment is mantled with Kaharoa and Taupo ashes (44.9%), and Taupo and Kaharoa breccias and pumiceous alluvium (28.5%). These rocks are composed of minerals and broken fragments of rock cemented together or reshaped by water and deposited along the river valley. Patches of ashes older than Taupo ash overlie the greywacke in the upper catchment and can also be found along the stable ridges in the mid-catchment (16.8%). All these materials are derived from volcanic activity associated with the Taupo Volcanic Zone which extends from Mt Ruapehu in the south to White Island in the Bay of Plenty.

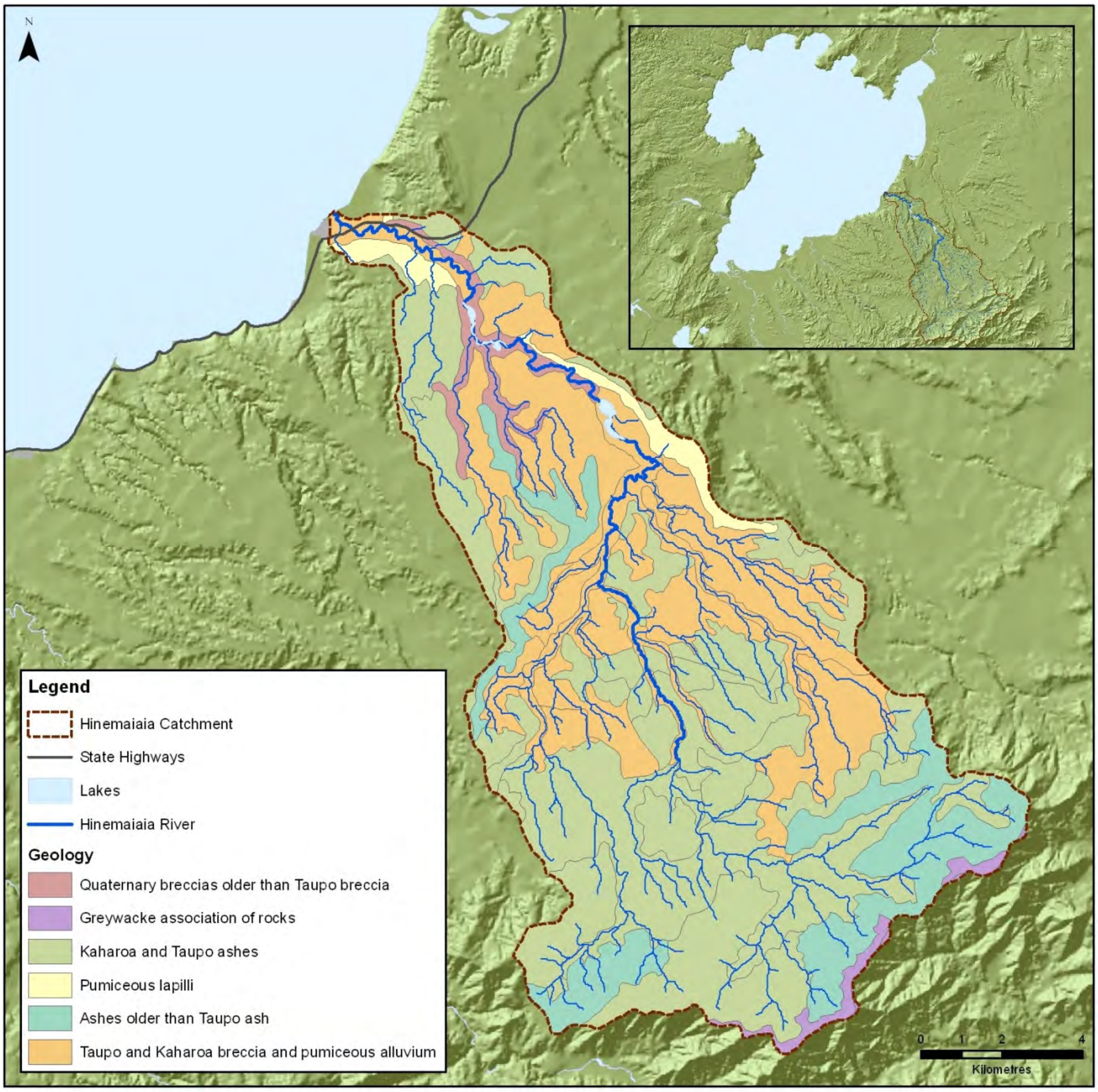


Figure 2.2: Geology of the Hinemaiaia catchment.

The slopes of the upper catchment are mantled with humose orthic podzols and podzolic orthic pumice soils (Figure 2.3). Podzol soils often occur in areas of high rainfall and have low fertility, low base saturation, and are strongly acidic. The pumice soils, however, have a low clay content and are mostly gravelly soils or pumice sand. The pumice soils are the dominant soil type in the Hinemaiaia catchment (72.9%); with the podzolic orthic pumice soils covering the greatest area (50.9%). Immature orthic pumice soils cover nearly 10% of the catchment. They have low soil strength, high macroporosity, are deep rooting, and have low strength when disturbed. The typic recent fluvial soil derived from alluvial sediments is weakly developed, showing limited signs of soil-forming processes. This soil has high natural fertility, with high base saturation, and covers 3% of the catchment. The Hinemaiaia catchment also has a small amount of typic orthic allophanic soil (0.8%).

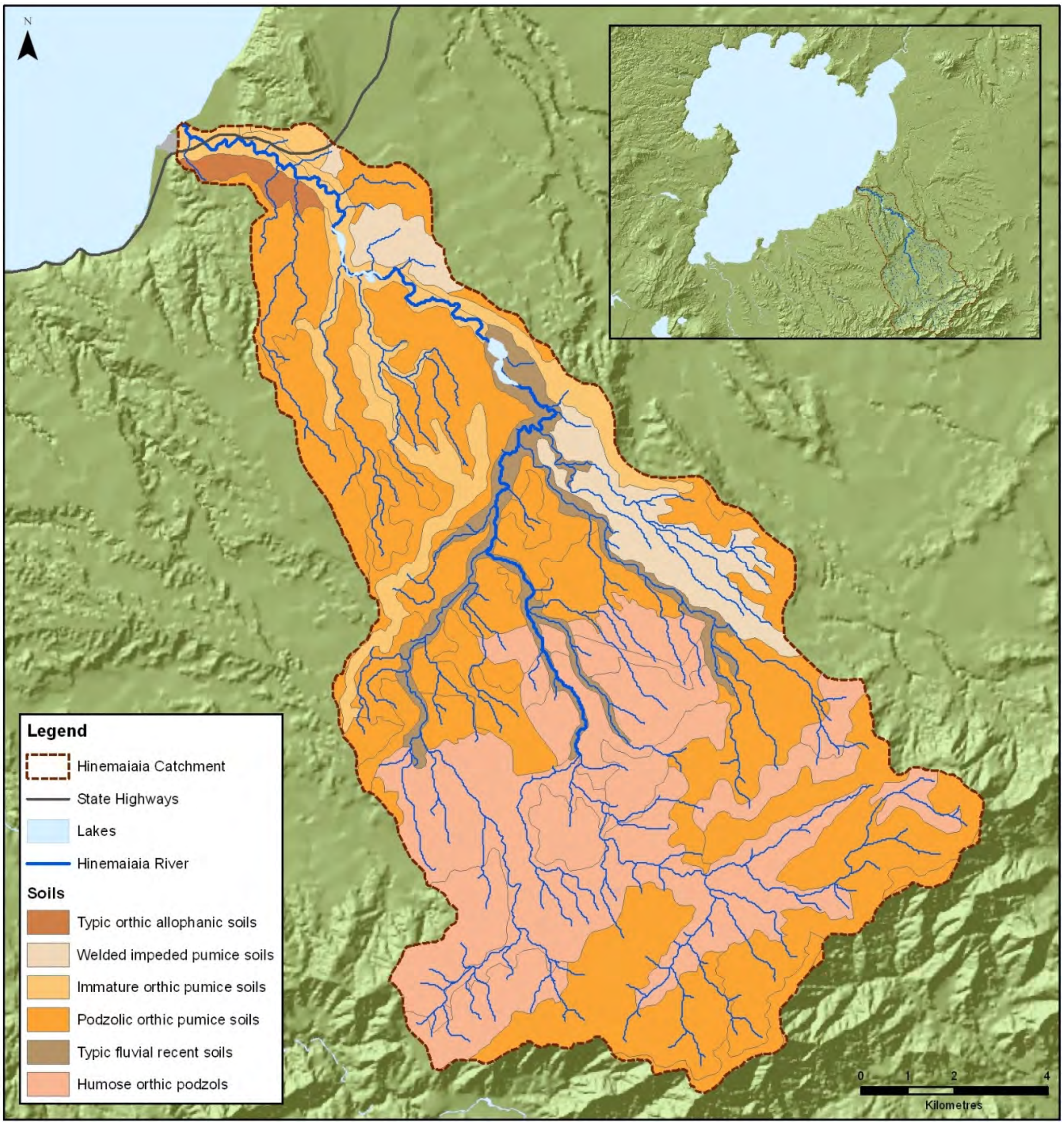


Figure 2.3: **Soils of the Hinemaiaia catchment.**

Erosion is common in the upper catchment because of the fractured greywacke, soft unconsolidated nature of the volcanic deposits, steep slopes (Figure 2.4), and high rainfall. This erosion provides a large volume of material that is available to be transported downslope and into the river system. The steep terrain and confined channel of the upper catchment allows the river to transport most of this sediment downstream. The two reservoirs in the lower catchment reduce the energy of the river and as a result its ability to transport sediment. Consequently, a considerable volume of material is deposited in these reservoirs. This loss of sediment may be responsible for the channel instability and degradation which is apparent over the lower reaches of the Hinemaiaia River. Changes to the river channel can be caused by both natural and anthropogenic processes. Floods, eruptions, tectonic uplift, river works, and land use change can all change the sediment supply to the river, and consequently its channel form and stability.

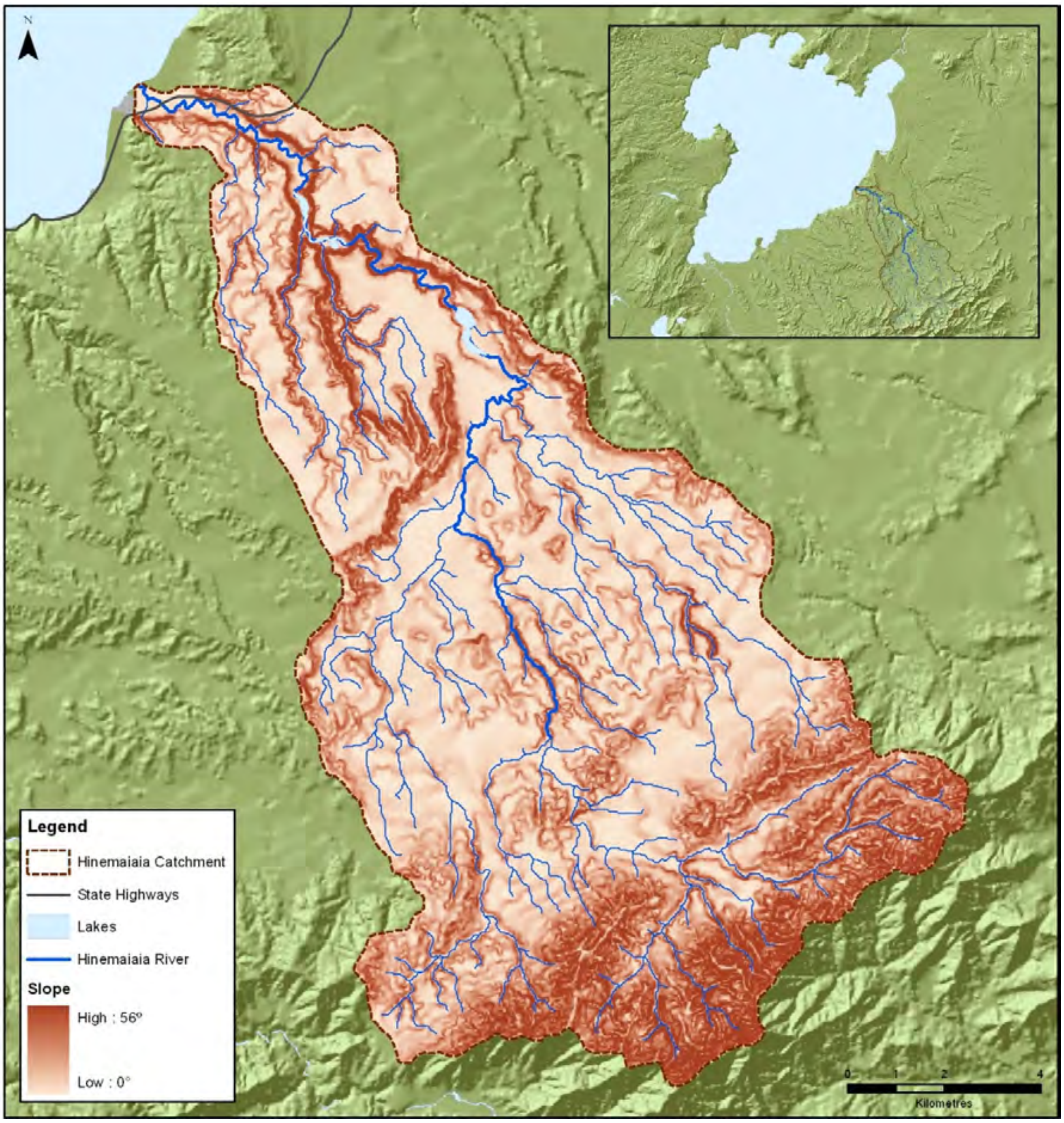


Figure 2.4: **Steeper slopes dominate the upper and mid catchment.**

The Hinemaiaia catchment has a steep rainfall gradient. The mean annual rainfall in the headwaters, the area likely to produce the greatest runoff, reaches 2150mm. Rainfall then decreases rapidly with altitude to be only 1125mm at Lake Taupo (Figure 2.5). Those areas which experience the highest annual rainfalls are also likely to experience the greatest rainfall intensities. Runoff from these areas therefore has a critical affect on the flood magnitude and risk in the lower catchment.

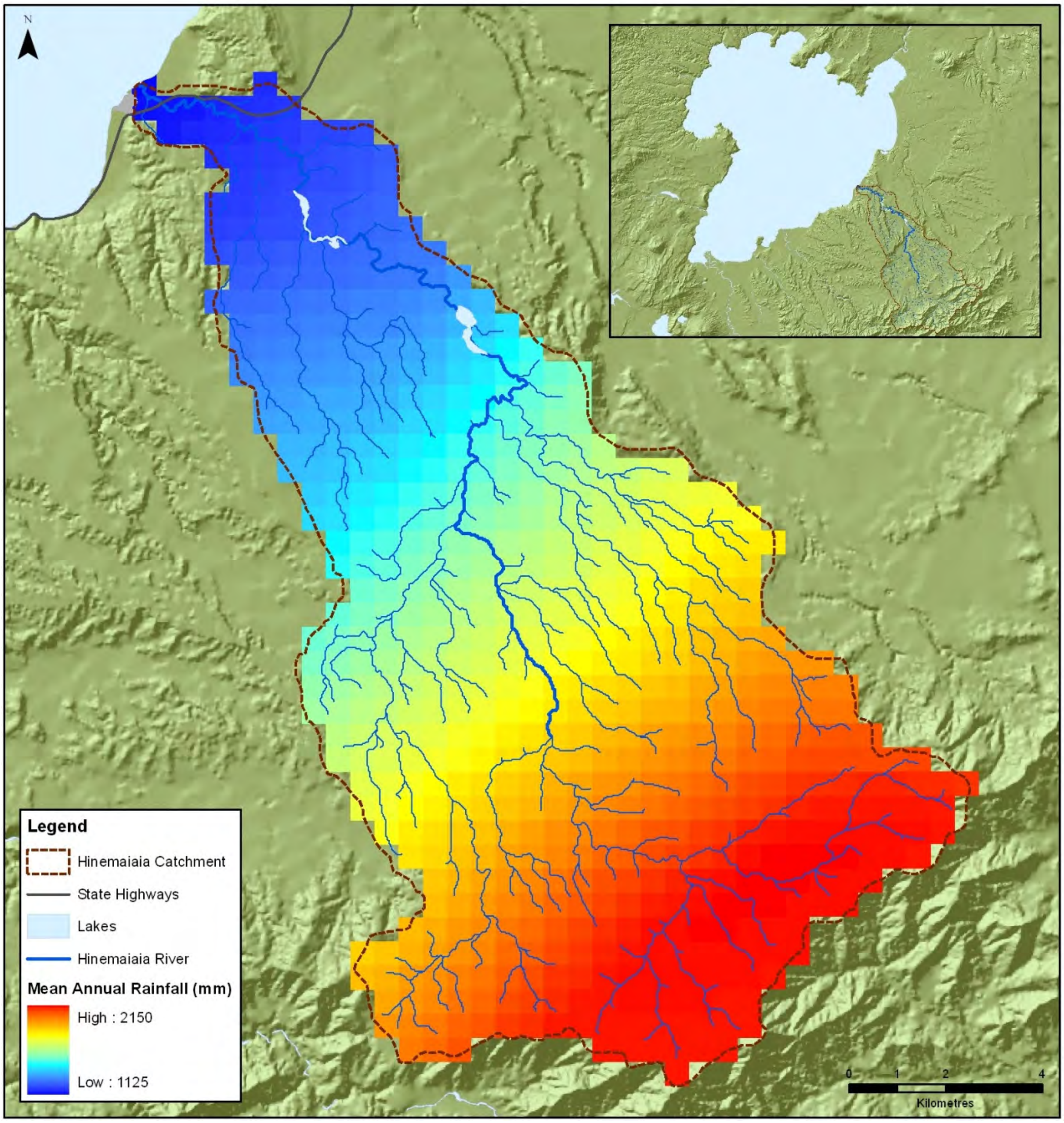


Figure 2.5: Mean Annual Rainfall (MAR) in the Hinemaiaia catchment.

Much of the Hinemaiaia catchment is under some form of forest or scrub cover (99.04%). This includes indidgenous forest which is the largest single land use in this catchment

(80.7%). Plantation forest of predominantly *Pinus radiata*, with either an open or closed canopy depending on age, covers another 14.2% of the catchment (Figure 2.6). The effect of the extensive forest cover throughout the catchment is to reduce erosion and to attenuate small to moderate flood events. The attenuation of flood events is further enhanced by the various porous materials discussed earlier which underlie the forest.

Land use within the catchment is summarised in Table 2.1.

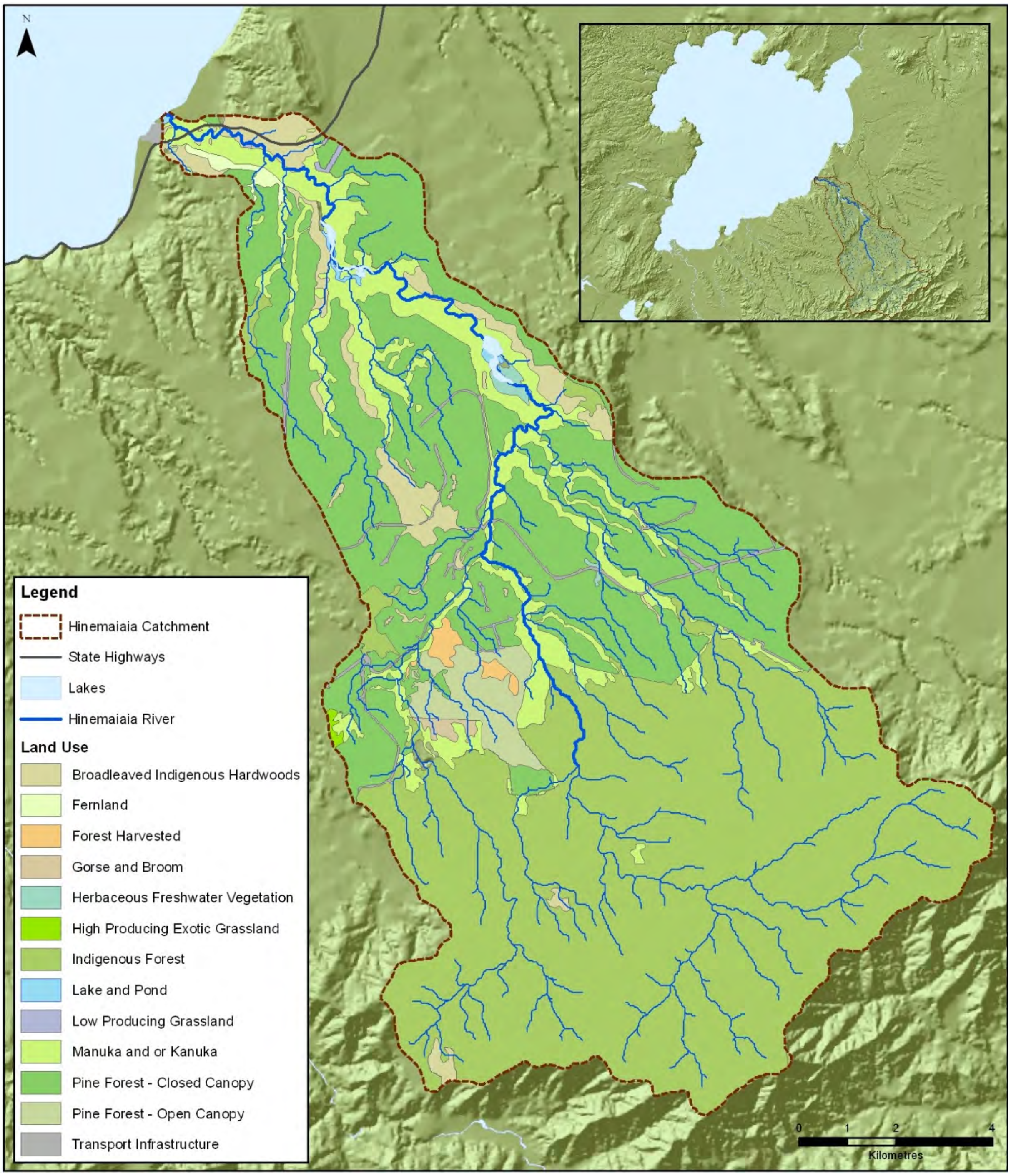


Figure 2.6: Vegetation cover within the Hinemaiaia catchment.

Table 2.1: Major land uses within the Hinemaiaia catchment.

Land use	Percentage
Broadleaved Indigenous Hardwoods	2.3
Indigenous Forest	80.7
Lake and Pond	0.2
Manuka and/or Kanuka	2.1
Pine Forest – Closed Canopy	13.8
Pine Forest – Open Canopy	0.4
Transport Infrastructure	0.2

2.2 Study area

The greatest flood hazard within the Hinemaiaia catchment exists in the lower valley, and particularly on the flood plain downstream of the SH1 Bridge. Further upstream the river is relatively incised and this reduces the potential for the banks to be overtopped even during major flood events. Below the SH1 Bridge the river flows between relatively low banks composed of easily erodible material, material which has been previously deposited by the river. This is also the area with the greatest capital investment, and density of people and infrastructure.

While the focus of this flood study is the area downstream of the SH1 Bridge, the coupled hydraulic flood model considered the lower 6.1km of the Hinemaiaia River. This was to account for overbank flows, flood storage, and flow attenuation upstream of the SH1 Bridge (Figure 2.7).

Figure 2.7: Extent of the coupled hydraulic model of the lower Hinemaiaia.

3 Flow regime of the Hinemaiaia Stream

3.1 Available flow data

Flows in the Hinemaiaia River have been monitored at various locations and over various time periods since 1976 (Figure 3.1 & Table 3.1). Some of these sites are upstream of the reservoirs used for power generation, while others are below the most downstream dam.

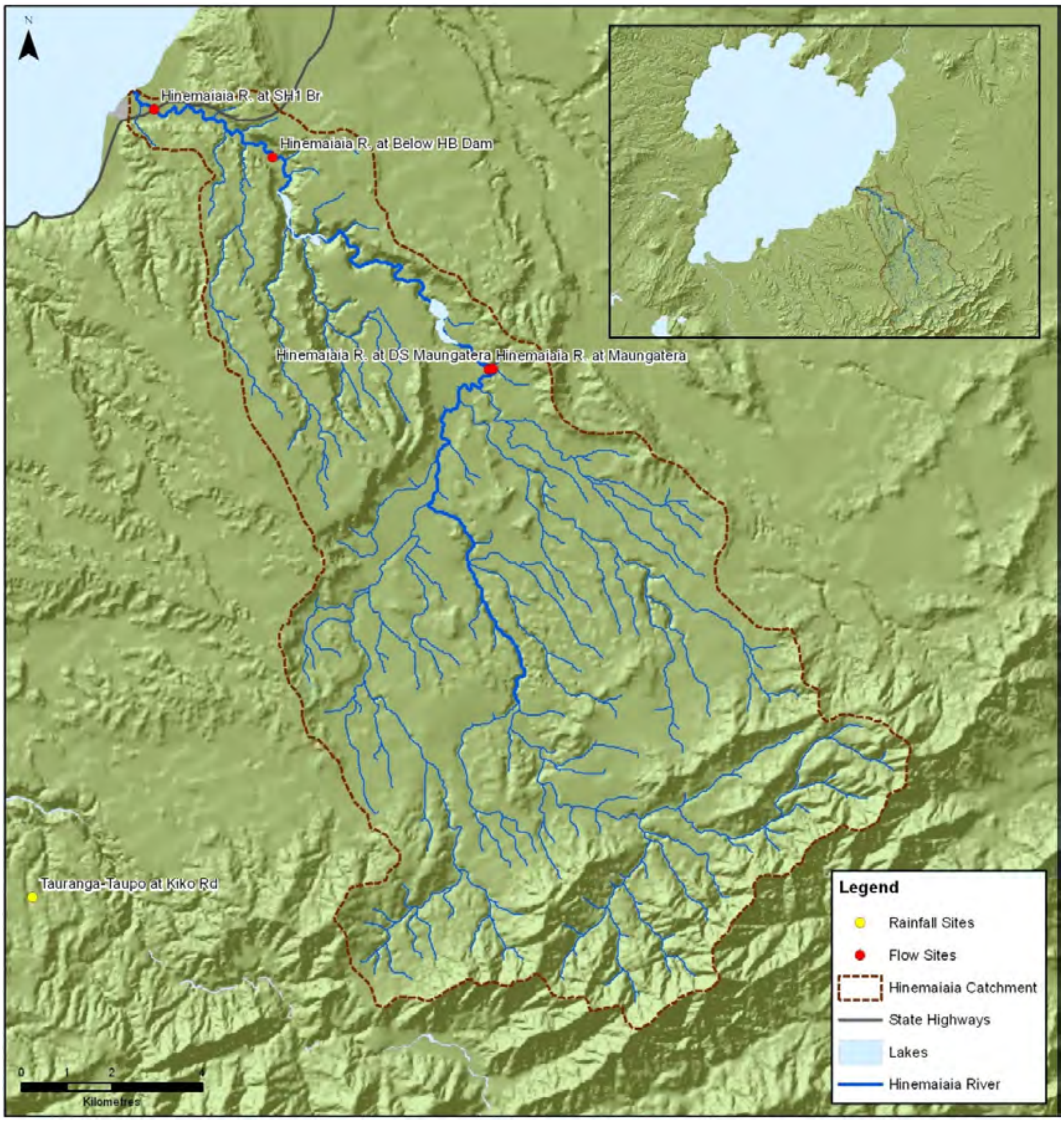


Figure 3.1: Flow and rainfall monitoring sites.

The current flow monitoring site, Hinemaiaia River below HB Dam, has been used since June 2000. This flow record now provides approximately 10 years of data from a constant location. The relatively short duration of this record, however, acts as a constraint to deriving robust estimates of the magnitude and frequency of more extreme flood events i.e. events with an average recurrence interval of more than 20 years (i.e. 5%AEP).

Table 3.1: Flow stations in the Hinemaiaia.

Name	Authority	Area (km²)	Start date	End date	Reference
Hinemaiaia at Below HB Dam	NIWA	153	19-Jun-2000	2-May-2011	U18:748556
Hinemaiaia at DS Maungatera	EW	127	29-Apr-1981	12-Apr-1987	U18:796509
Hinemaiaia at Maungatera	EW	127	13-Apr-1987	21-May-2003	U18:796509
Hinemaiaia at SH1 Br	EW	165	15-Mar-1976	29-Sep-1980	U18:722566

While a monitoring site was previously maintained at the SH1 Bridge, this site was discontinued in September 1980 and only provides approximately 4 years of flow data.

A robust flood hazard assessment requires a long term flow record from which reliable estimates of the magnitude and frequency of large flood events can be derived. Since there is no single long-term flow record available for the Hinemaiaia, the records from a number of different stations were joined together to create a reliable long term synthetic flow record.

The flow records from the Hinemaiaia at Maungatera and Hinemaiaia at Below HB Dam were correlated using three years of overlapping data (2000-2003). The daily average flows were used to avoid the variable lag caused by the time required for water to flow downstream from Maungatera. There is a high degee of correlation between the flows at the two sites with 94% of the variation in flows at Below HB Dam being explained by variation in the flows upstream at Maungatera.

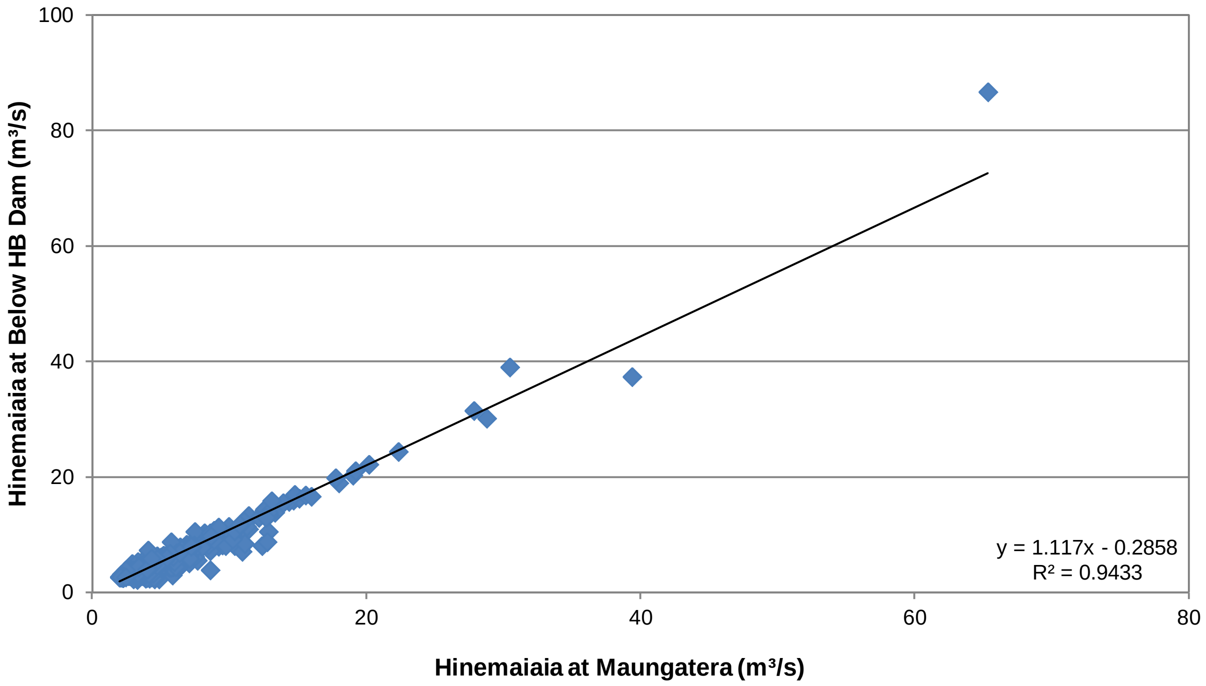


Figure 3.2: Correlation between mean daily flows at Maungatera and Below HB Dam.

The Hinemaiaia at Maungatera and at DS Maungatera records have no overlapping period. However, because the sites are very close together, and because Environment Waikato (EW) consider these to be the 'same site', the two records were merged. This produces a flow record for the Hinemaiaia at Maungatera extending from 1981 to 2003.

Using this extended record, flows were scaled downstream to Below HB Dam using the regression model defined in Figure 3.2. This produces a combined record, including both synthetic and measured flow data, for the Hinemaiaia below both reservoirs which commences in 1981 (Figure 3.3).

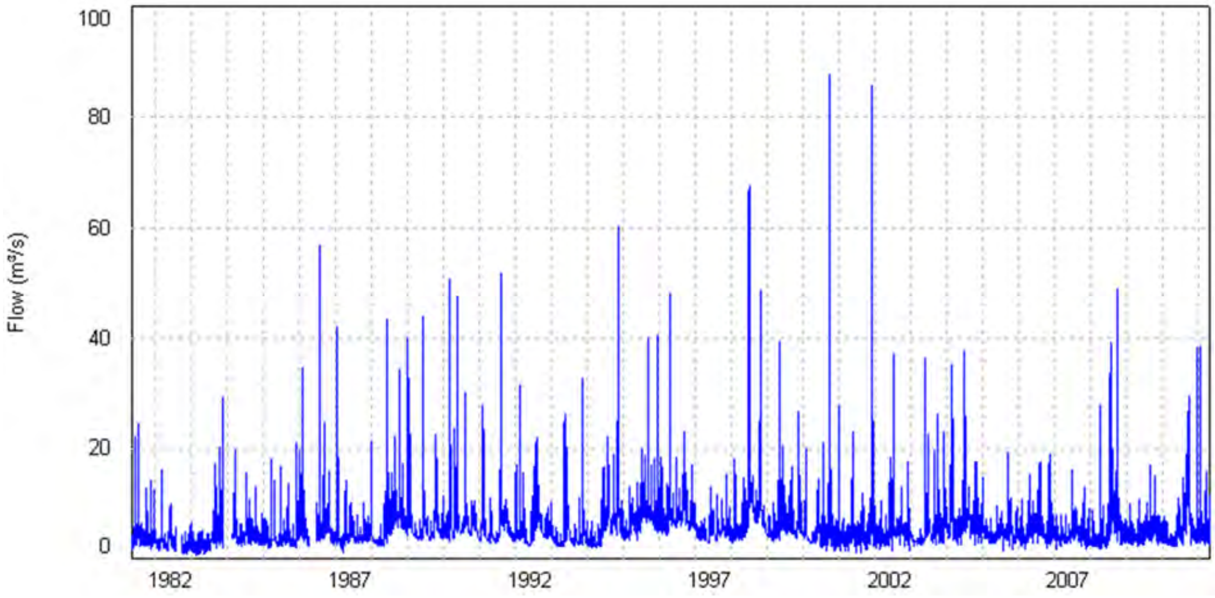


Figure 3.3: Synthetic flow record for the Hinemaiaia River (m³/s).

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 series 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, long records also increase the chance of violating the basic rule of stationarity because they have the potential to be affected by land use, climate, or other changes in the catchment.

Inspection of Figure 3.3 shows no distinctive change in the flow regime caused by the merging of the synthetic and measured data. This combined flow regime also shows no evidence of trends or cycles, other than an annual pattern of greater flows during winter. This record contains a complete record of all major flood events since 1981. This combined flow record therefore provides the basis for robust frequency analysis, allowing reliable estimates of the magnitude and frequency of various design events.

3.3 Flow characteristics

Overall the combined flow record for the Hinemaiaia River appears to be of high quality (Figure 3.3). The summary of flow statistics (Table 3.2 & Figure 3.4) shows that the Hinemaiaia 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 20% higher than the median. It is also signficant that the lowest flow recorded is less than 1% of the largest flood. This illustrates the difficulty in managing the flood risk of a catchment with a highly variable flow regime such as the Hinemaiaia. Table 3.3 lists the largest flood event each year since 1981.

Table 3.2: Summary flow statistics for the Hinemaiaia (m^3/s) April 1981-May 2011.

Site	Minimum	Mean	Median	Maximum	Standard deviation	Coefficient of variation
Hinemaiaia	0.81	5.43	4.54	87.52	3.42	0.63

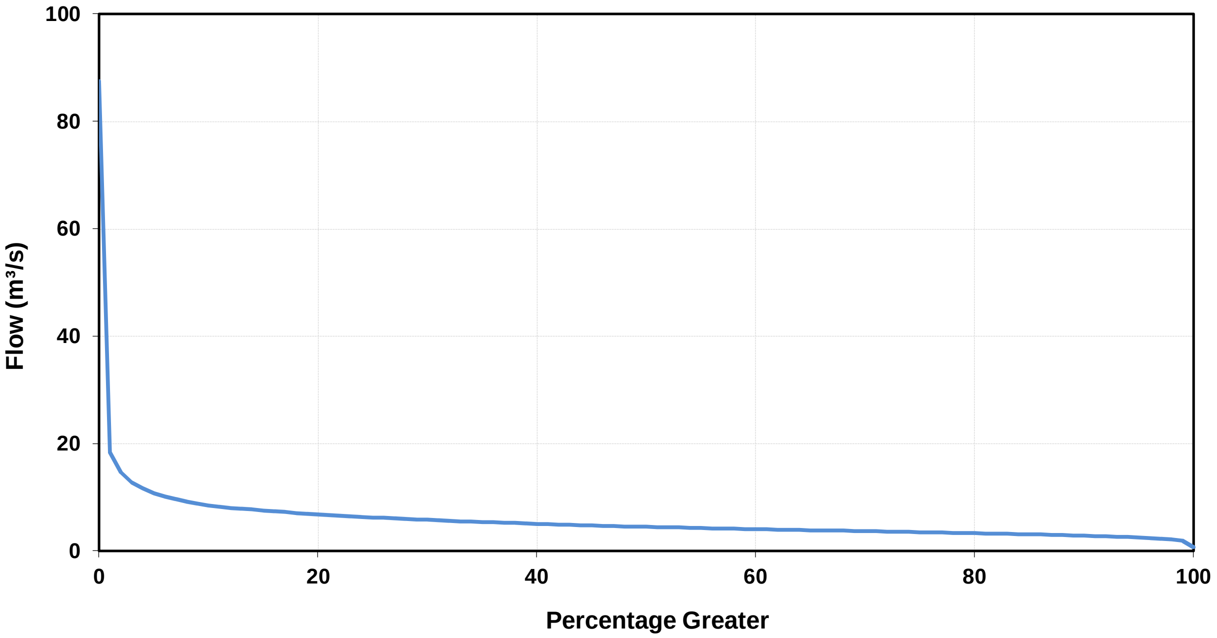


Figure 3.4: Flow distribution within the Hinemaiaia.

Table 3.3: Annual flood maxima for the Hinemaiaia (1981-2011).

Rank	Year	Flow (m^3/s)	Rank	Year	Flow (m^3/s)	Rank	Year	Flow (m^3/s)
1	2000	87.5	**12**	1987	42.2	**23**	1981	24.5
2	2001	85.7	**13**	1995	40.6	**24**	1985	20.9
3	1998	67.6	**14**	1999	39.6	**25**	1984	19.6
4	1994	60.1	***15***	*2011*	*38.6*	**26**	2005	19.2
5	1986	57.0	**16**	2010	38.3	**27**	2006	19.2
6	1991	51.8	**17**	2004	37.8	**28**	2009	17.0
7	1990	50.8	**18**	2002	37.4	**29**	2007	16.1
8	2008	48.8	**19**	2003	36.3	**30**	1982	16.1
9	1996	48.2	**20**	1993	32.7	**31**	1997	15.4
10	1989	43.9	**21**	1992	31.5			
11	1988	43.2	**22**	1983	29.3			

Note: 2011 is an incomplete year

The size of the largest flood in any year is highly variable. For example, the largest flood recorded (i.e. 87.5m³/s) is over five times larger than the smallest flood (i.e. 15.4m³/s). Also, the size of the annual flood appears to vary randomly over the length of record. This provides additional confidence in the accuracy and robustness of merging and scaling the various flow records to produce the continuous flow series used in the frequency analysis.

The largest flood in the Hinemaiaia was recorded in 2000, although the 2001 flood was only 2m³/s smaller. Since no rainfall data are available for the 2000 event, Figure 3.5 shows the flood hydrograph and associated rainfall for the second largest event i.e., the flood of 7 December 2001.

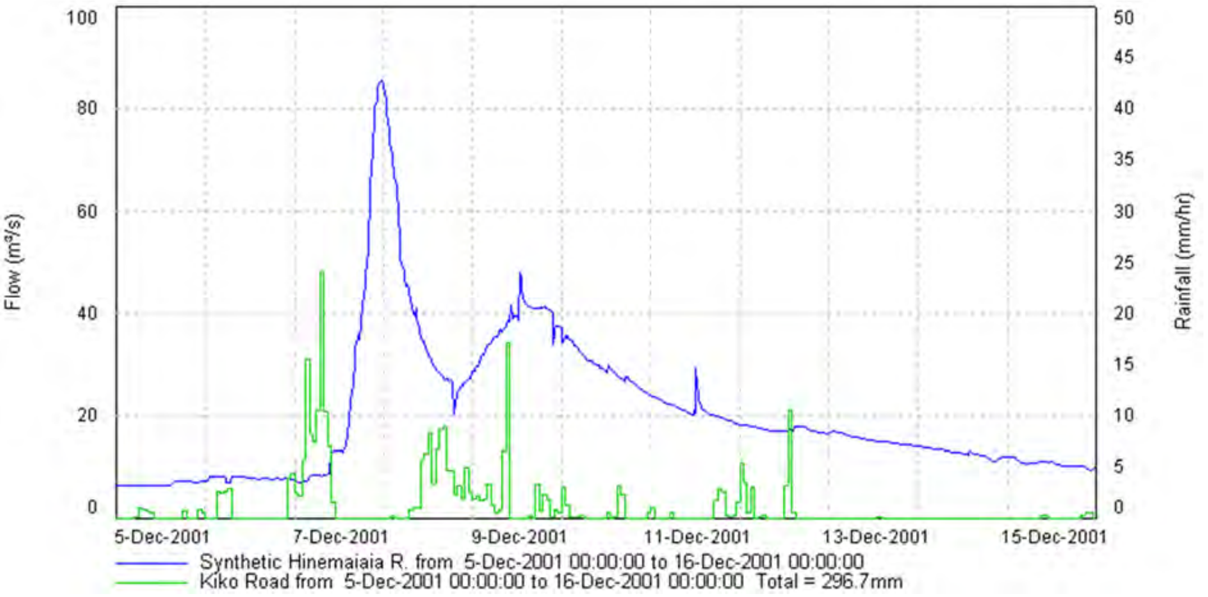


Figure 3.5: Flood hydrograph of the second largest event on record in the Hinemaiaia.

This hydrograph highlights a number of features of flood events in the Hinemaiaia catchment. In general, it takes rainfall events of approximately 12 hours duration to generate a significant flood. The floods tend to both arrive and dissipate rapidly. High intensity rainfall events tend to produce sharp, short duration flood peaks, while longer duration events 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.

Despite the variability of specific storms, there is a high degree of similarity in flood response (Figure 3.6). The four largest floods on record i.e. those of 2000, 2001, 1998, and 1994 all have very similar shapes and characteristics. It is also significant that three of these events show a sustained but more attenuated rise in discharge after the principal flood peak has passed. It is likely that this secondary peak is a function of the storage reservoirs upstream and their effect on attenuating catchment runoff processes.

Analysis of this series of flood hydrographs indicates a consistent pattern of runoff response to large rainstorm events within the Hinemaiaia catchment. Rainstorm durations leading to significant flood events are usually 12-24 hours in duration. The resulting floods typically have one major peak, often with a secondary peak 24 or more hours later. Water levels rise and fall rapidly with the main body of the flood lasting for up to 48 hours.

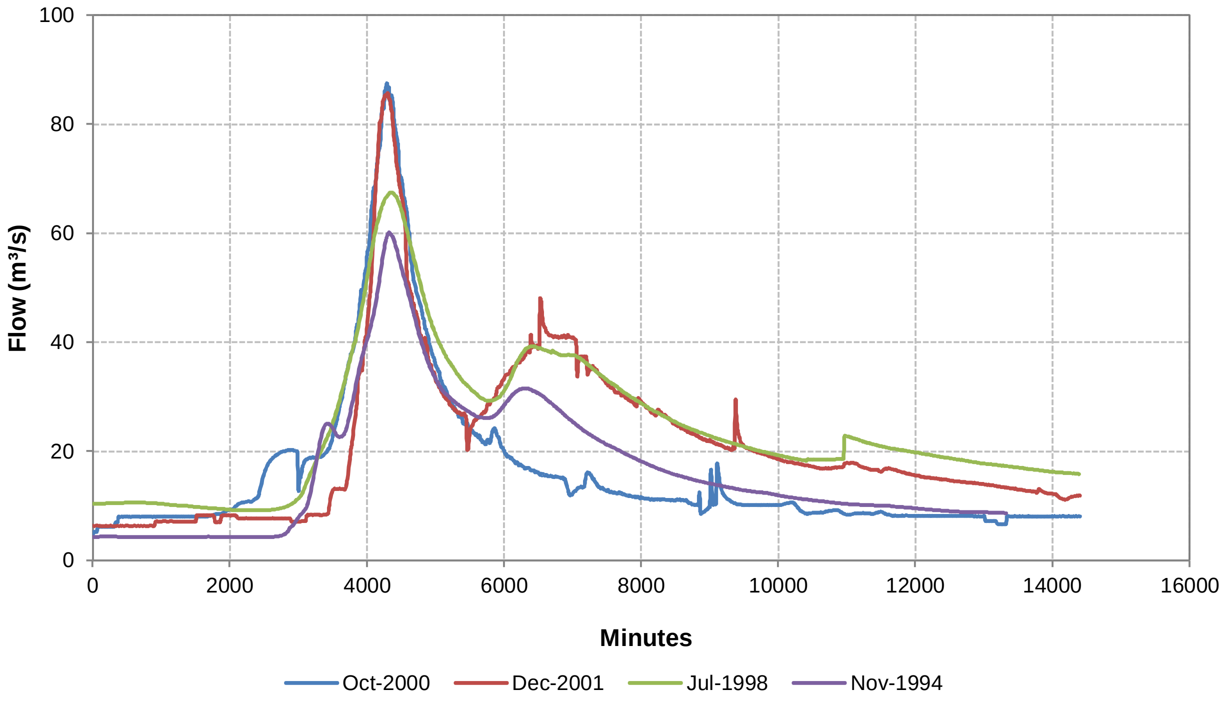


Figure 3.6: **Comparison of the four largest floods on record i.e., 2000 (largest) to 1994 (smallest).**

The consistent nature of these large flood events indicates that the use of a single type-hydrograph to model future flood scenarios is valid. It is likely that any future large flood event will have very similar characteristics to those recorded in the past. The flood hydrograph from the 2001 event was used as the type-hydrograph for scaling the flows used in the hydraulic modelling as, although it has the same general shape, it has a 'cleaner' rising limb i.e., there was no rainfall over the days preceding the major flood event.

3.4 Effect of Hinemaiaia hydro scheme

The Hinemaiaia River contains a small hydro electric scheme which consists of two reservoirs and three power stations (Figure 3.7). The scheme provides an annual output of 30Gwh, or close to 10% of the power requirements of Taupo.

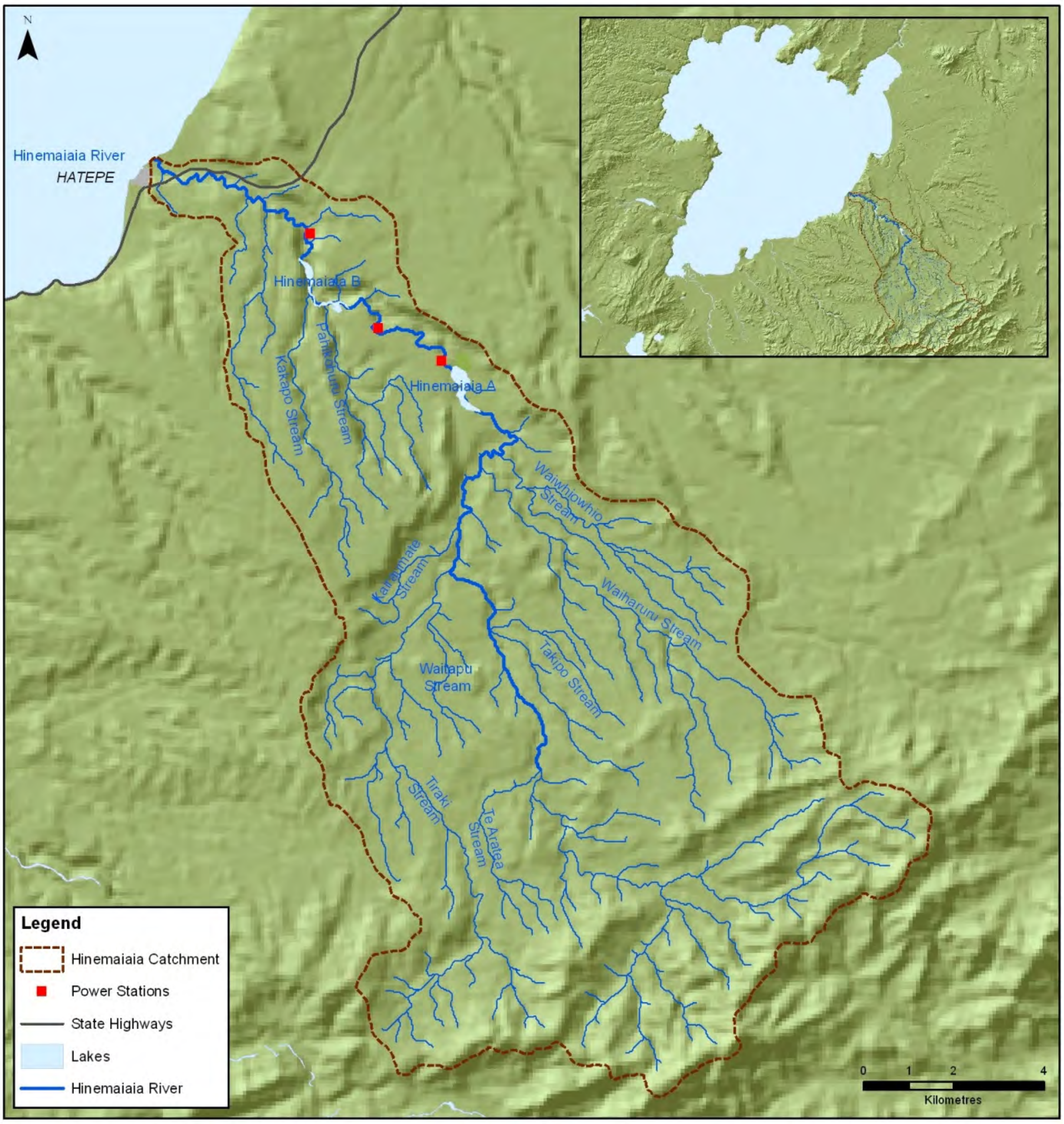


Figure 3.7: Hinemaiaia hydro scheme reservoirs and power stations.

The two reservoirs are relatively shallow (average depth 1.2m for Hinemaiaia A) and have areas of only 33ha and 12.1ha. Consequently these reservoirs have relatively little water storage potential. For example, Hinemaiaia A has only 16.6 hours storage and Hinemaiaia B 7 hours storage at mean flow (e.g., approximately 5m³/s). The mean flow is less than 6% of the peak flow during the largest recorded flood, and even less relative to the various scenarios modelled. These power stations therefore function largely as 'run of the river' schemes. It is likely that these reservoirs would not be empty prior to a large flood and this further restricts their potential impact on peak flow downstream in the Hinemaiaia River.

The small size and limited storage volume of the reservoirs associated with the Hinemaiaia hydro development, especially relative to large floods, therefore mean that they have little effect on peak flows; although they may affect the overall pattern of storm runoff. The effect of these reservoirs on flood hydrology was therefore not considered further within the hydraulic modelling.

3.5 Flood frequency analysis

A frequency analysis was undertaken using the entire length of flow record derived for the Hinemaiaia River. A series of the maximum flood event recorded each month was used rather than just the largest event each year. This approach samples 12 times the number of events than just using the annual flood maxima. It is therefore more likely to reflect the actual distribution of flood events, especially if the floods vary significantly over the record. It should be noted that, while this approach overcomes the 'loss' of multiple large floods in a single year, it still misses multiple large flood events if they occur in a single month. The flood frequency analysis provides estimates of the flood magnitudes for events with various return periods. A Pearson 3 statistical distribution provides the best fit to the data series (Figure 3.8). The results of this analysis are contained in Table 3.4.

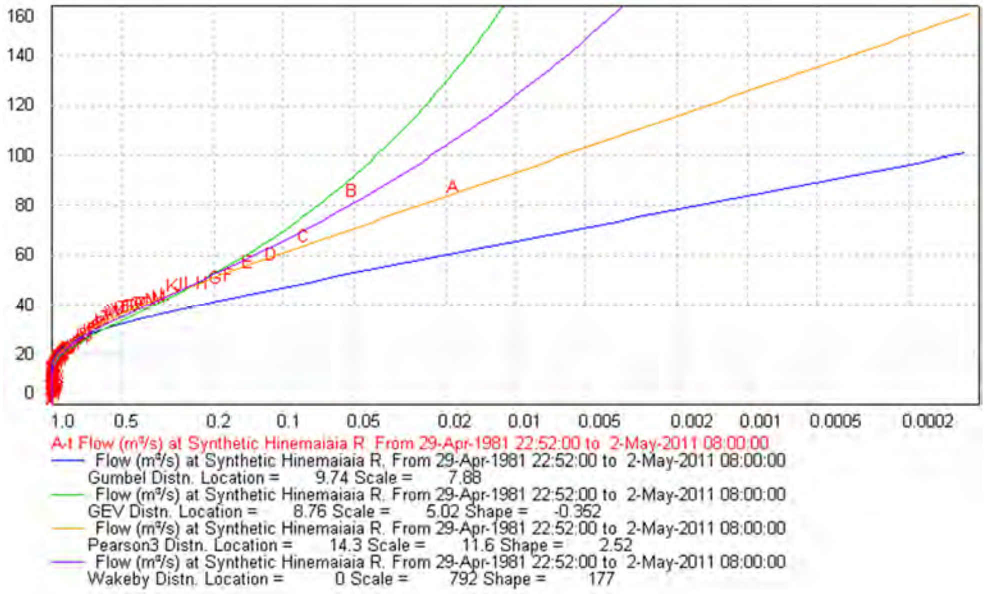


Figure 3.8: Flood frequency analysis of the Hinemaiaia River.

Based on this analysis it would appear that the large flood events of 2000 and 2001 had return periods of just greater than 50 years. This would seem reasonable and confirms the validity of the hydrological inputs to the hydraulic modelling.

Table 3.4: Flood estimates for the synthetic record of the Hinemaiaia River (assuming a Pearson 3 distribution).

Return Period (ARI)	Hinemaiaia River 1981-2011 (m^3/s)
2.33 (annual)	38.9
5	50.9
10	61.0
20	70.8
50	83.6
100	93.2
200	102.2
500	115.8

3.6 Potential effects of land use change

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

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

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

Given the current land use distribution and land management within the Hinemaiaia catchment, a possible extreme land use change would be the conversion of all exotic forests to pasture. As discussed, 14.2% of the catchment is currently under exotic forestry. This is equivalent to approximately 23km² which could potentially be converted to some form of pasture management. It must, however, be recognised that such a scenario is extremely unlikely given the various physical and management constraints on land use within the catchment.

If all this land was converted to pasture, and if the effects on the peak discharge during flood events were as predicted in Table 3.5, then the peak discharge during a 100-year event could increase by about 23m³/s (i.e. 25%).

Since this scenario is highly unlikely, and given the other sources of uncertainty in the hydraulic modelling, a possible increase in the flood magnitude caused by land use change was not considered further. However, should such a land use change be considered the model could easily be 're-tuned' to quantify the effects of increased in peak discharge on the flood risk to the lower Hinemaiaia valley.

3.7 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 (Figures 3.9a and 3.9b). These data are summarised in Table 3.6.

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

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

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

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 3.7).

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

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

Source: Ministry for the Environment, 2010.

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

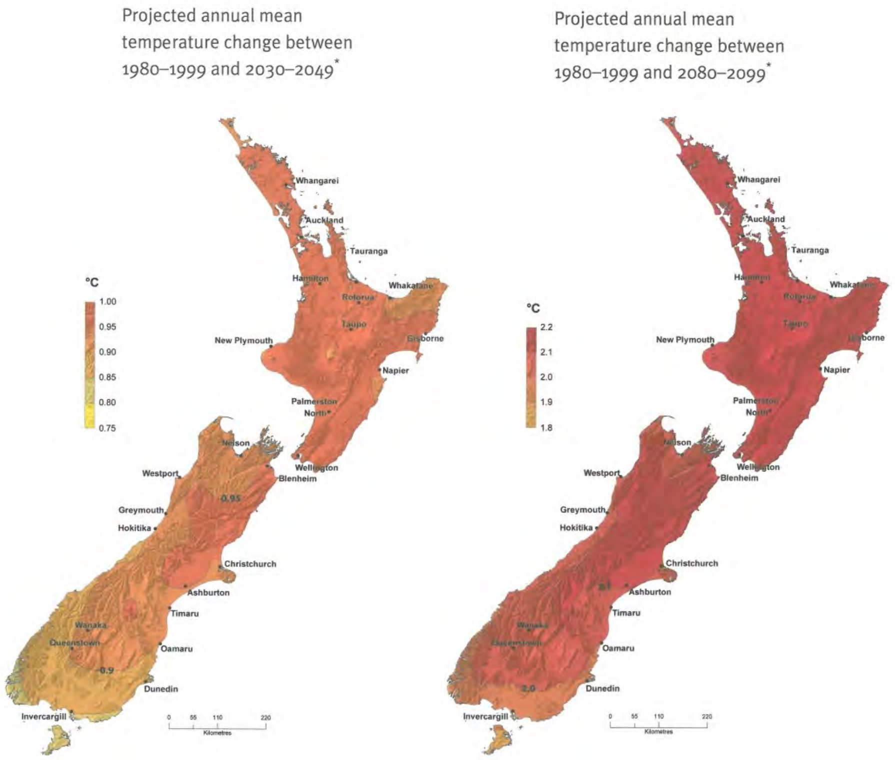
Assuming temperature increases of between 0.2°C and 2.4°C (2040s) and 0.6°C and 5.6°C (2090s) for the respective scenarios, the 100-year return period rainfall will increase by a maximum of 19.2% by 2040 and 44.8% by the 2090s (Table 3.8). This is based on the upper limits of the various global warming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

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

Table 3.8: Estimated percentage increase in 24-hour rainfall totals for the Hinemaiaia 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**

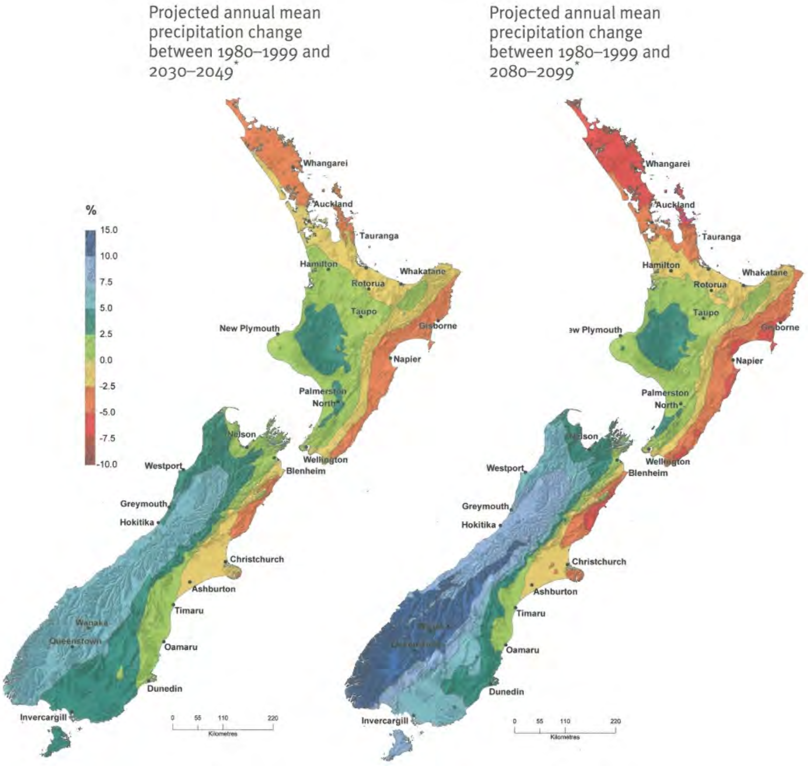
Note: Guidelines for the effect of climate change on rainfall do not extend beyond 100 years.



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

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

Figure 3.9a: **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).**



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

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

Figure 3.9b: **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).**

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

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

Return Period	Flood peak discharge estimated from the synthetic record	Flood peak discharge 2040 – highest temperature prediction (m^3/s)	Flood peak discharge 2090 – average temperature prediction (m^3/s)
2.33 (annual)	38.9	42.9	42.4
5	50.9	57.5	56.7
10	61	70.2	69.1
20	70.8	83.0	81.5
50	83.6	99.7	97.6
100	93.2	111.1	108.9

4 Other factors that affect flooding

4.1 Sediment transport

Under normal flow conditions the sediment load of the Hinemaiaia 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. 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 floods 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 deposited within the various reservoirs associated with the Hinemaiaia hydro power developments. Only the finest material moves downstream past the reservoirs to be deposited within Lake Taupo.

It is likely that the sediment trap formed by the reservoirs has resulted in sediment 'starvation' throughout the lower reaches of the Hinemaiaia. This is most likely responsible, at least in part, for the bank erosion and bed degradation particularly below the SH1 Bridge.

From a flood hazard perspective is it likely that the overall effect of changes to sediment routing through the Hinemaiaia has resulted in a slight reduction in the flood risk. Changes to the channel geometry are likely to have increased the conveyance capacity of the Hinemaiaia reducing the likelihood and magnitude of overbank flows. The reduced channel gradients immediately upstream of Lake Taupo, caused by lowered bed levels further upstream, may have slightly increased the flood risk in this area.

4.2 Lake level

The extent and depth of inundation caused by flooding of the Hinemaiaia River is partly controlled by the water level in Lake Taupo. Higher lake levels can exacerbate flooding while lower 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).

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

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

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

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

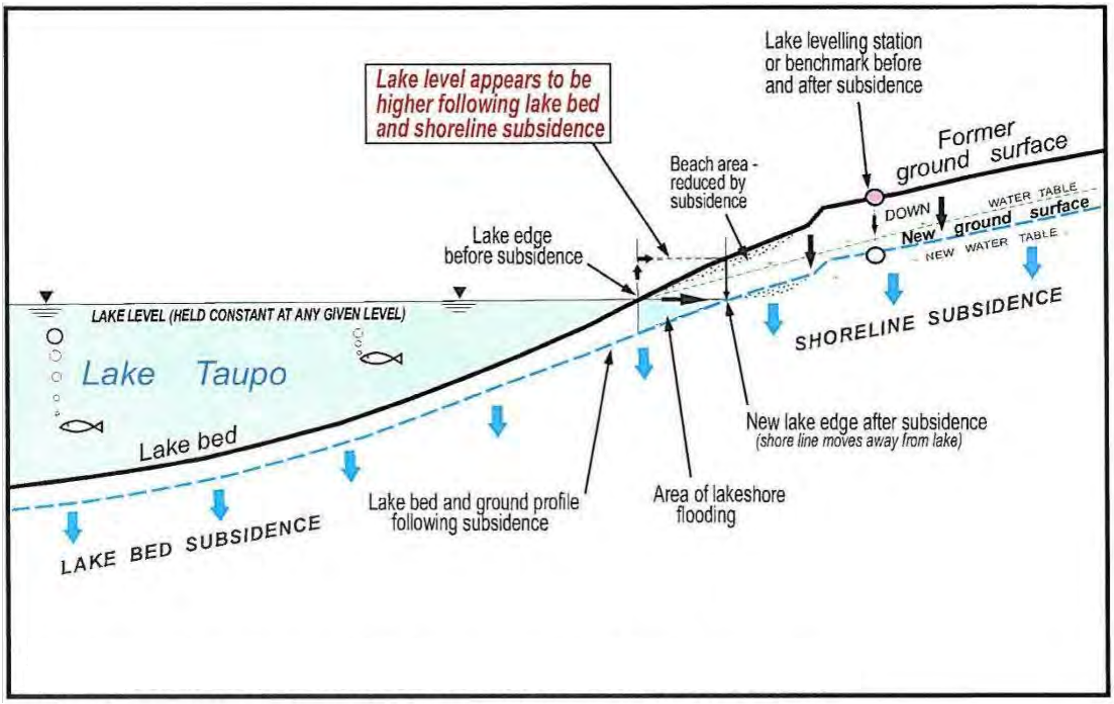


Figure 4.1: **Effect of ground level subsidence on relative lake levels (Hancox, 2002).**

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

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

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

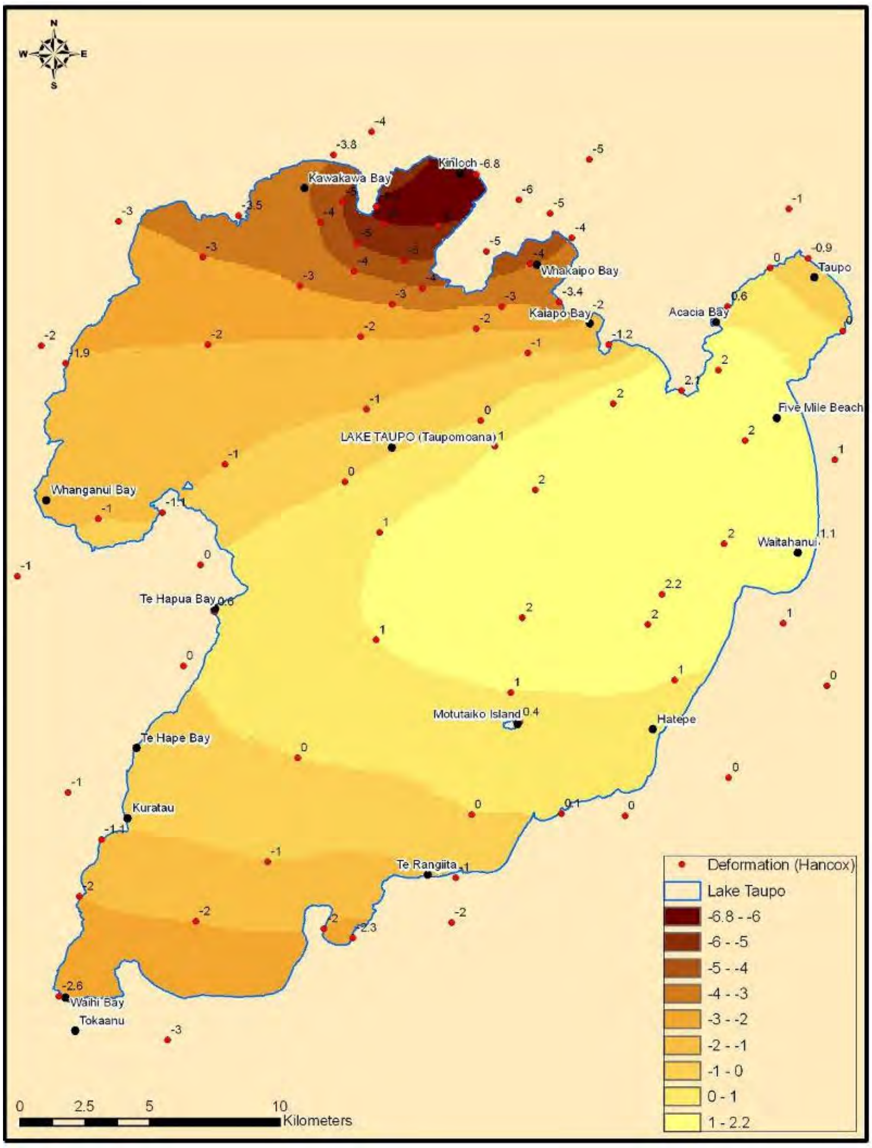


Figure 4.2: Average rates (mm/yr) of tectonic deformation between 1979 and 2002 (After Hancox, 2002).

Based on the ground deformation model the area in the vicinity of the lower Hinemaiaia would appear to be very stable relative to the overall movement of the ground surrounding Lake Taupo. Because of this stability of the ground surface, and the possibility of the area actually rising slightly, the effects of deformation were not considered further in relation to the flood risk posed by the Hinemaiaia.

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 the wave environment and their likely effects in the vicinity of Hatepe is contained in McConchie *et al.,* (2008). The Hinemaiaia River discharges into the Hatepe wave environment (Figure 4.3).

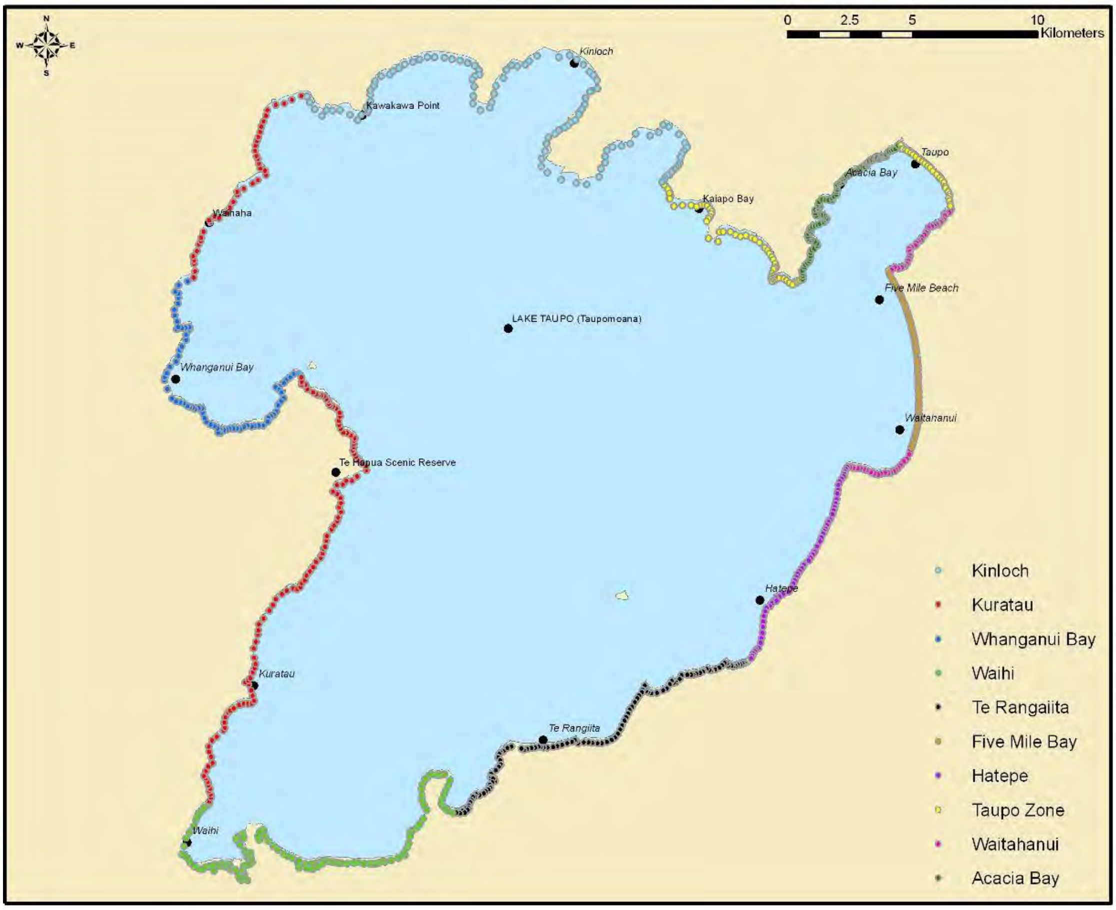


Figure 4.3: **Wave run-up environments around the shore of Lake Taupo.**

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

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

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

	Hatepe
Distribution	*GEV*
Return Period	
2.33	1.18
5	1.25
10	1.30
20	1.33
50	1.36
100	1.37
200	1.38

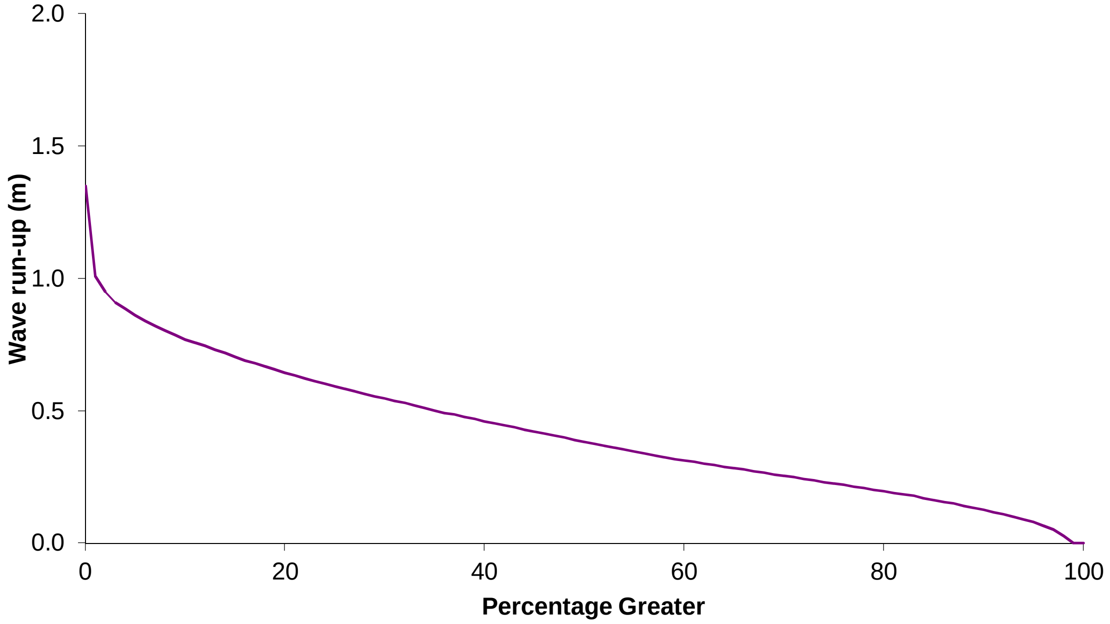


Figure 4.4: **Frequency distribution of wave run-up in the Hatepe wave environment.**

Figure 4.5 shows how the magnitude of the wave run-up changes with increasing return period (i.e. ARI). While the 'average' wave run-up at Hatepe is large relative to other areas around Lake Taupo, run-up does not vary significantly with the return period. That is, the wave environment is very uniform. The most rapid increase in wave run-up occurs out to a return period of 10 years; however, there is little change in wave run-up over longer return periods.

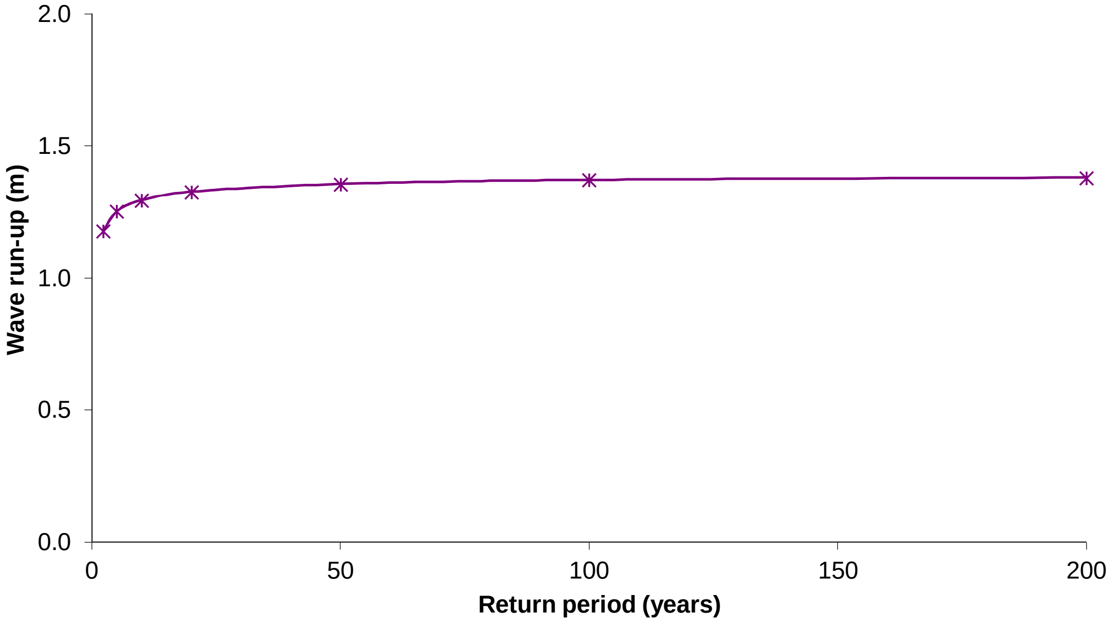


Figure 4.5: **Variation in wave run-up for Hatepe with different return periods.**

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 ground deformation. With respect to Hatepe and the vicinity of the Hinemaiaia River the potential effect of ground deformation can be ignored as this area is relatively stable. This area may actually be rising slightly over the longer term. The static water level defined in this manner delineates areas where inundation to some degree is considered to be inevitable over a 100-year period, or with a likelihood of 1% each year (i.e. 1%AEP).

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

Some areas in the vicinity of Hatepe and along the shoreline of Lake Taupo are likely to be affected by flooding over the next 100 years as a result of high lake levels. This risk is likely to be exacerbated by the relatively large waves which affect this area. 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 Hinemaiaia River is a combination of both lake-induced flooding, and overbank flows from the river. While both situations may not occur at the same time, the total area potentially affected by flooding must be considered in any planning and management framework. The area affected by high lake levels is shown in Figure 5.1.

The settlement of Hatepe is well above that area likely to be affected by high lake levels. Flooding caused by high lake levels is generally confined to the river channel and immediately adjacent areas. These areas are the same which are likely to be affected by river flooding. This is partly because both flood risks are controlled largely by ground elevation; however, it also provides confidence in the results of the two distinct modelling exercises.

The extent of the area at risk from flooding shown in Figure 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 MIKE FLOOD 1- and 2-dimensional coupled hydraulic model was developed for the area.

Figure 5.1: Area potentially flooded by higher lake levels over the next 100 years.

6 MIKE FLOOD hydraulic model

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

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

6.1 Methodology

Using LiDAR topographic information a two-dimensional MIKE21 model was established. The model covers an area of approximately 2.8km^2 and extends 6.1km down the Hinemaiaia River from below the HB dam to Lake Taupo. The model's general extent is shown in Figure 2.7 while all the flood maps in Section 7 cover the entire model.

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

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

No surveyed cross-sections were available for use in the hydraulic model. Therefore, cross-sections were extracted from a high resolution 1.0m DTM, and then checked carefully against the un-interpolated LiDAR data. These cross-sections were then implemented in the one-dimensional portion of the hydraulic model.

Also using LiDAR topographic information, a two-dimensional MIKE21 model was established of the flood plain using a 5.0m resolution grid. The MIKE11 and MIKE 21 components were then dynamically coupled together using MIKE FLOOD. Model parameters were estimated using expert professional advice, and knowledge obtained from previously calibrated hydraulic models of other rivers draining to Lake Taupo.

The digital terrain models (DTMs) were derived from LiDAR information captured during 2009. The models could not be adjusted to reflect the river and its flood plain prior to the flood event of October 2000 because of a lack of available data prior to this event. The 2009 channel and flood plain configuration were therefore used for:

- The qualitative calibration undertaken based on the 2000 flood event; and
- To assess the flood risk arising from a 100-year average recurrence interval (ARI) flood, both with and without the effects of predicted climate change.

6.2 Sensitivity analysis

A sensitivity analysis was carried out on the input data and several hydrodynamic modelling parameters using the 100-year ARI event, adjusted to include the potential effects of climate change. This was to assess the magnitudes and consequences of any errors in the various model inputs, 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 such as Hinemaiaia. These ranges of values were based on experience gained from flood assessments in other Lake Taupo catchments.

The sensitivity analysis confirmed that over the ranges tested, the model is most sensitive to changes in Manning's n. However, no parameter had a significant effect on predicted flood levels. This finding is consistent with the steeply sloping and relatively confined, nature of the Hinemaiaia. The nature and characteristics of the stream and its hydrologic regime also suggest that channel geometry is the most important hydraulic control.

The sensitivity analysis also showed that the effect of increasing the water level in the lake by 0.3m was only noticeable over the first 300m of the river upstream of its mouth. Beyond this lake level has a negligible impact on the water levels resulting from a 100-year ARI flood event, even when adjusted for the potential effects of climate change.

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

6.3 Model calibration – October 2000 flood event

Calibration of the hydraulic was constrained by the lack of observed water levels and extents during previous large flood events; particularly events which have occurred under the existing channel and flood plain configuration.

Some limited observations of water levels during specific floods are available from residents at Hatepe; particularly for the 2000 flood event. However, because of the lack of a detailed DTM of the channel and flood plain during this event, and the lack of detailed water level information, the calibration could only be to a qualitative level. Various flood scenarios involving different peak discharges and lake water levels were explored and the results also reviewed by local residents.

The results were shown to be reasonable, however, slightly conservative. That is, the predicted water levels would appear to be up to 0.5m higher than observed at some locations. This is likely to be at least partly a result of the channel and floodplain configuration not reflecting accurately the situation in 2000. It may also be a function of the 5.0m resolution model grid. The Hinemaiai River system is dynamic, changing over the longer term as well as during any large flood event. These changes are impossible to model and therefore some residual uncertainty will exist in any model results.

It is considered that the results while potentially conservative are appropriate for a reconnaissance-scale flood assessment. As and when more detailed information regarding water levels and flood extents become available, the model could be re-calibrated to reduce the level of uncertainty.

7 Flood prediction

7.1 Scenarios modelled

The MIKE FLOOD model was used to simulate the flood response to a 100-year ARI event including the effects of climate change. Because of inherent uncertainties regarding the hydrologic flow record, this scenario is considered a useful benchmark for flood hazard classification, and long-term flood risk management. Table 7.1 summarises the boundary conditions used in each of the flood prediction scenarios simulated using the calibrated MIKE FLOOD model.

Table 7.1: Description of flood prediction scenarios.

Scenario	**Boundary Conditions**	
	Hinemaiaia River Flow (m^3/s)	**Lake Taupo Level (m)**
100-year flood event predicted from instrumental record	99	357.5
100-year flood event predicted from instrumental record adjusted for the predicted effects of climate change in 2090	115	357.5

The differences between the results from modelling these two scenarios, the 100-year ARI event both with and without climate change, are generally small. The flood extents under both scenarios are almost identical, at least at the scale of the DTM i.e. ±5.0m. There is a slight increase in the depth of flooding under the more extreme scenario as expected. However, this difference in water levels between the two scenarios reduces to zero towards the lake because of the dominating backwater effect of Lake Taupo.

An illustration of this effect of the water level in Lake Taupo on flooding is shown in Figure 7.1. This sketch shows the longitudinal water surface along a river which flows into a lake and 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. Towards 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.

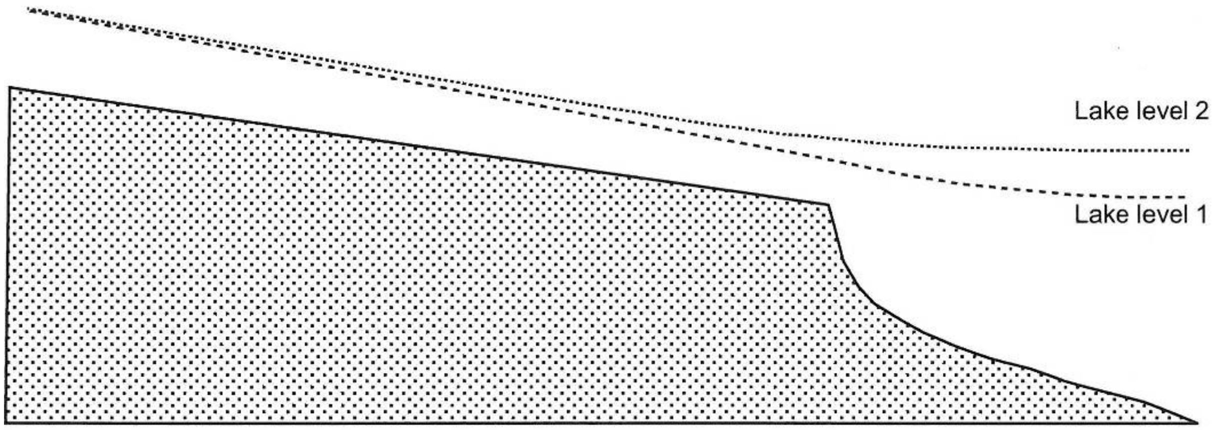


Figure 7.1: Backwater profiles for river flow discharging into a lake (constant discharge).

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 7.1, 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 New Zealand rivers including the Hinemaiaia, 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 7.1 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.

The sensitivity analysis also showed that the effect of increasing the lake water level by 0.3m was only noticeable over the first 300m of the river upstream of its mouth. Beyond this lake level has a negligible impact on the water levels resulting from a 100-year ARI flood event, even when adjusted for the potential effects of climate change.

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 small effect on the extent, depth, and velocity of inundation during major flood events.

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).

7.2 Flood inundation maps

The expected flood inundations resulting from a 100-year ARI event in the Hinemaiaia, both with and without the potential effect of climate change, are shown in Figures 7.2 & 7.3. Both maps show a very similar pattern of inundation, and are consistent with what was observed during large flood events in 2000 and 2010.

During such large flood events the Hinemaiaia overtops its banks and water flows over the adjacent flood plain. Overbank flow also results from flood waters ‘shortcutting’ some of the meander bends.

The accuracy of the hydraulic model should be considered when analysing areas potentially at risk from flooding. The horizontal resolution of the data used in the model is 5m. Therefore, when considering the horizontal flood extent a ±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 made (LiDAR cannot penetrate vegetation and water surfaces).

7.3 Maximum velocity maps

Figure 7.4 shows the maximum velocities during the 100-year ARI event; adjusted for the potential effects of climate change. Faster velocities occur in the river channel, and in particular where the channel is narrow. Higher velocities also occur where the water exits the river channel and enters Lake Taupo.

The highest velocities are in the main river channel as expected, with velocities of up to 3.6m/s simulated. Although relatively high, these velocities appear to be realistic for a steep confined channel such as the Hinemaiaia.

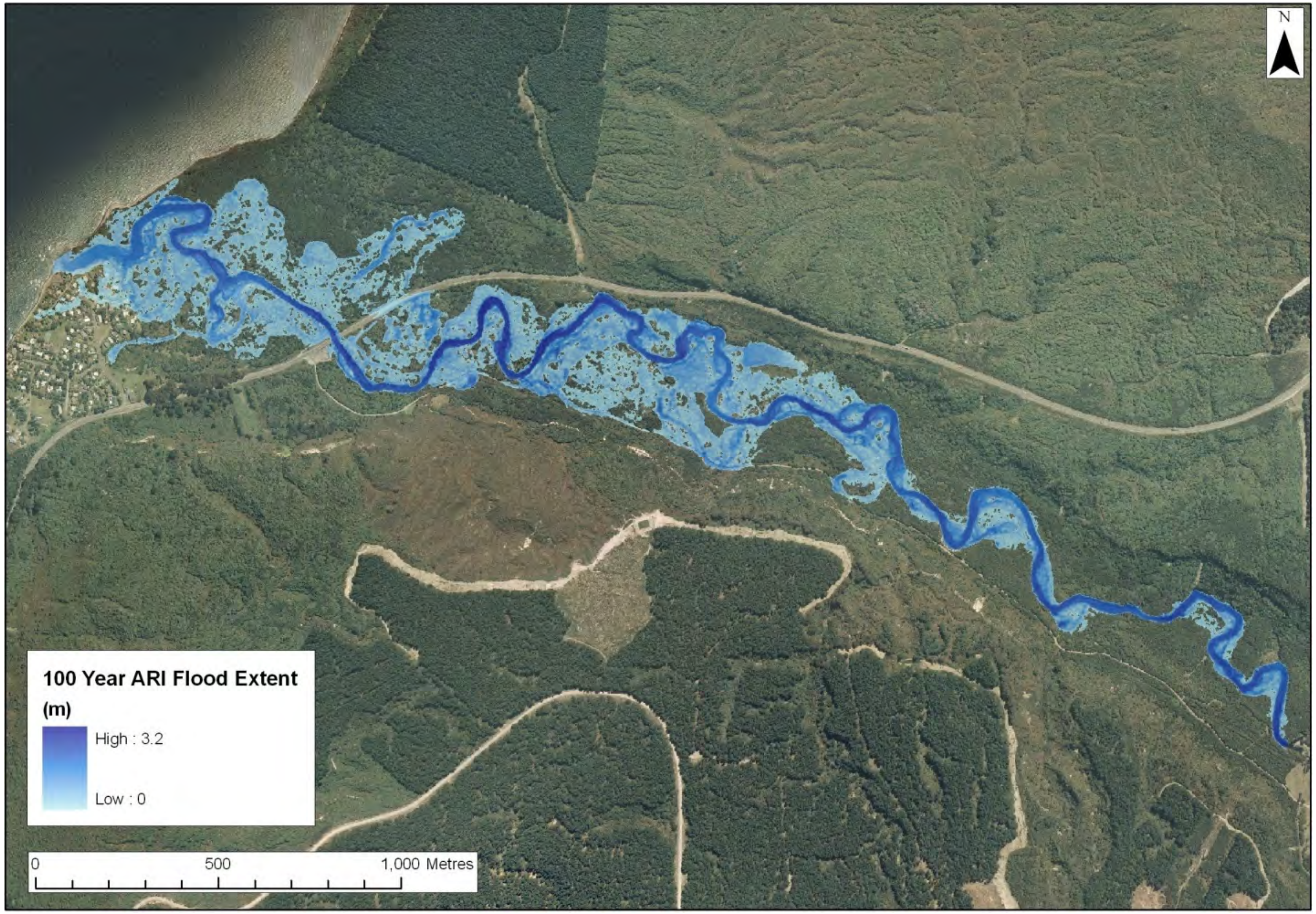


Figure 7.2: **100-year flood event predicted from the existing instrumental flow record for the Hinemaiaia River.**

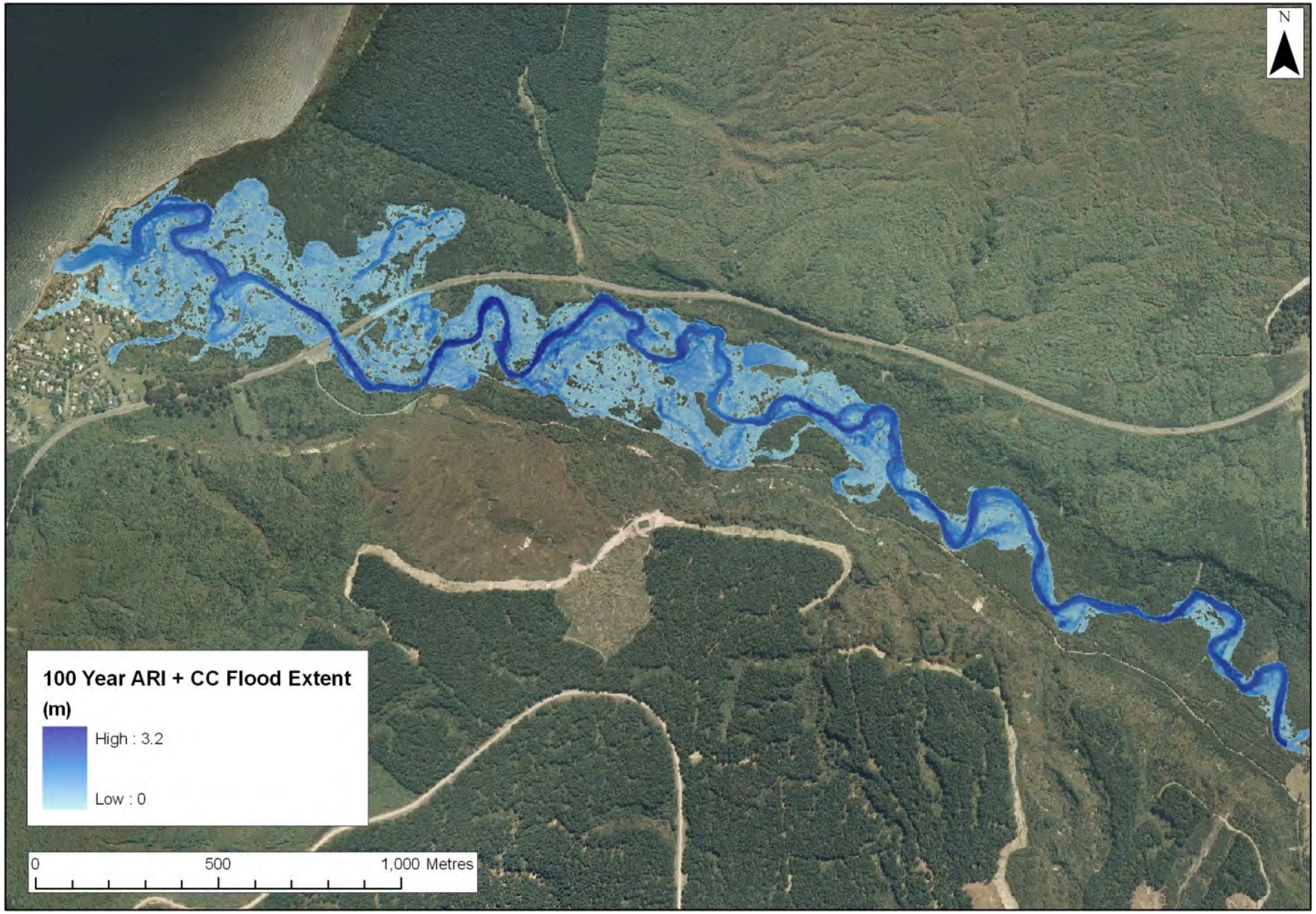


Figure 7.3: **Depth of inundation caused by flooding of the Hinemaiaia; assuming the 'worst case' scenario modelled i.e., 100-year peak flood flow increased to allow for predicted climate change, and a lake level of 357.5m.**

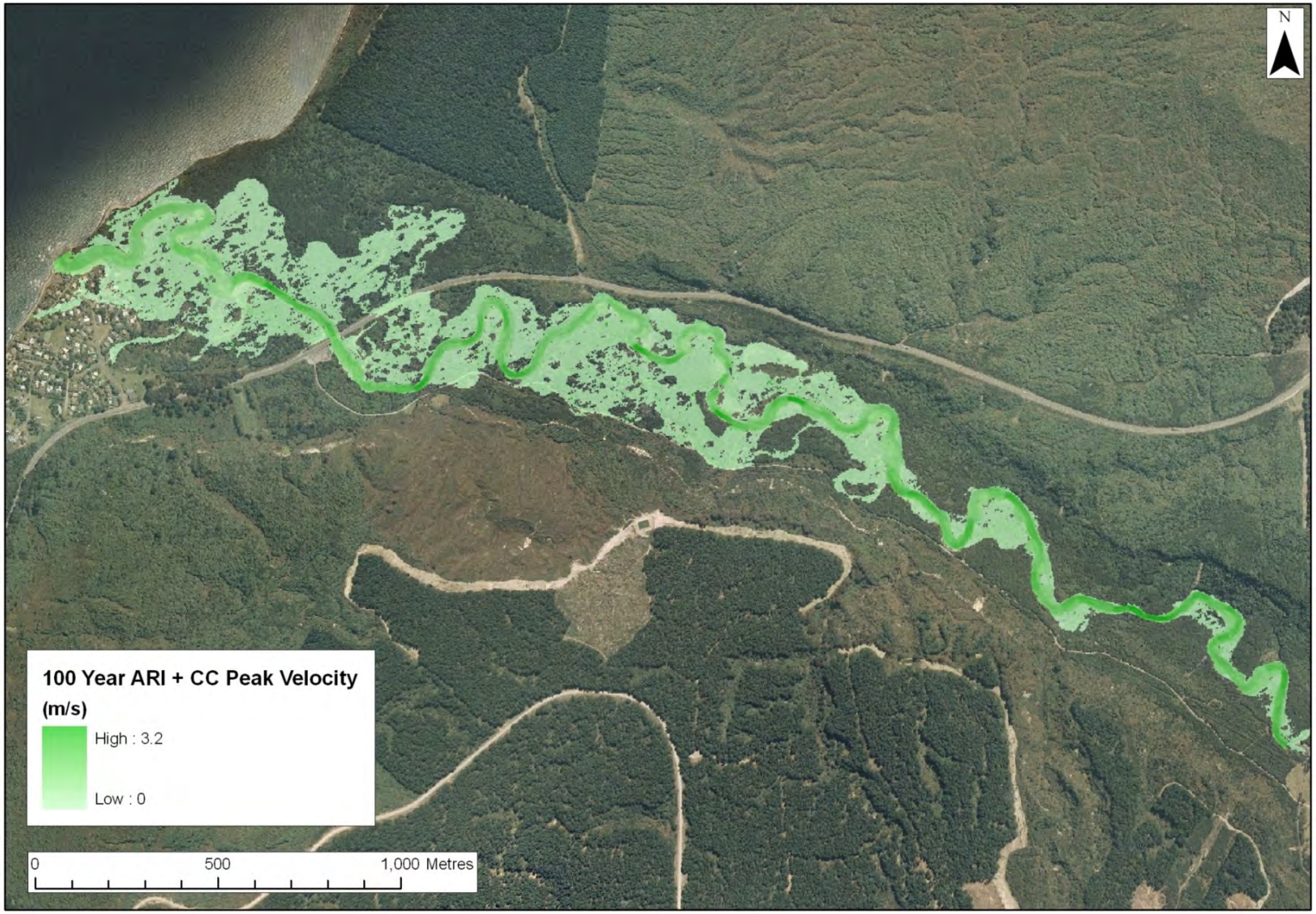


Figure 7.4: **Velocity of flood waters assuming the 'worst case' scenario modelled i.e., 100-year peak flood flow increased to allow for predicted climate change, and a lake level of 357.5m.**

8 River flood hazard classification

8.1 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).

8.2 Significance to people and property

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

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

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

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

These considerations have been translated into a river flood hazard classification. Four distinct levels of river flood hazard have been defined on their likely impact on people and property. These levels are outlined in Table 8.1 (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 product of the predicted depth and speed of the flood waters (Figure 8.1).

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

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

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

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

Table 8.1: 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.	

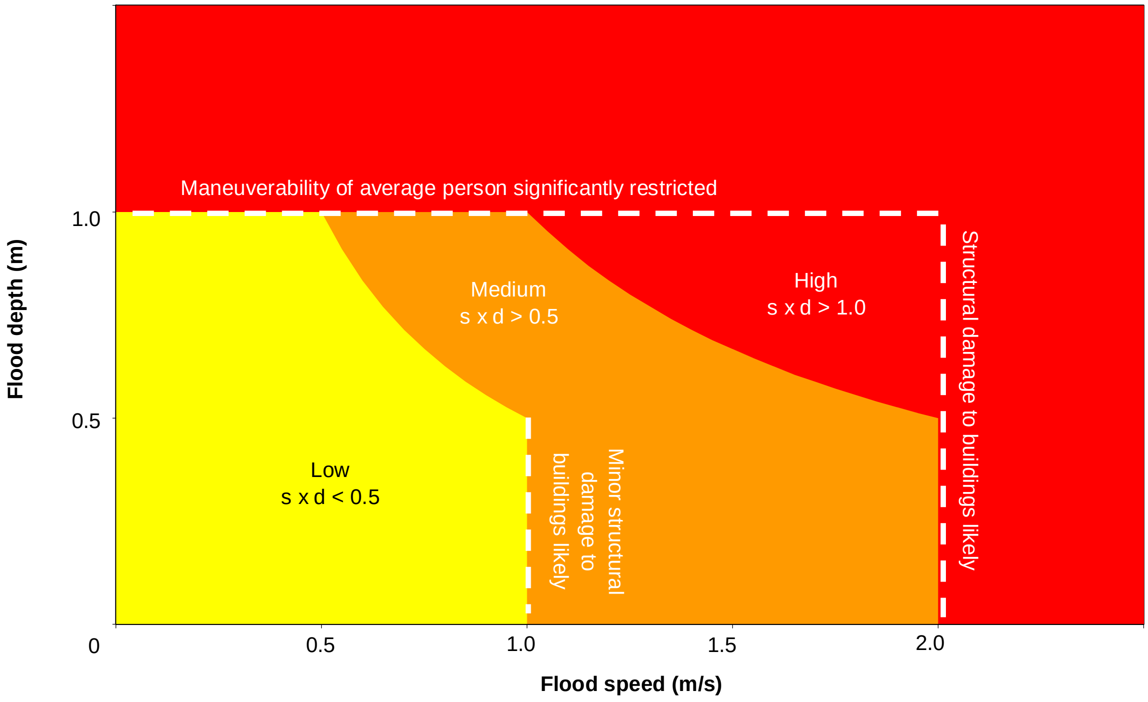


Figure 8.1: River flood hazard classification matrix (Environment Waikato, 2008b).

8.3 Flood hazard assessment

The analysis of flood water levels highlights the fact that the extent and depth of flooding of the Hinemaiaia River are relatively insensitive to the level of Lake Taupo. Therefore the flood hazard posed by the Hinemaiaia 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 depth and extent of inundation during this extreme scenario are shown in Figure 8.2, and the velocity of the flood waters in Figure 8.3.

Multiplying these two risks (i.e., that from the depth of water and that from the flow velocity) together provides a combined measure of the flood hazard (Figure 8.4). Note that in this flood study, flood hazard is calculated from the product of maximum velocity and depth at each point. This definition 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.

It is apparent that while a significant proportion of the Hinemaiaia flood plain is prone to flooding, the risk to life and property over most of this area is relatively low. The majority of the settlement of Hatepe is unaffected by flooding; even under the extreme scenarios which were modelled. In those few areas of the settlement which could potentially be effected by flooding the hazard is low. This is because both the water depths are shallow and the velocity of any flood water is slow.

The areas subject to the greatest risk are the main channel and the adjacent floodplain. Some of the older abandoned channels which form secondary flow paths during large floods also pose a greater hazard. This is because these areas generally have deeper water and faster velocities.

Therefore, although a large area of the Hinemaiaia floodplain ‘gets wet’ during the 100-year event, the hazard outside of the obvious channels and flow paths is generally low.

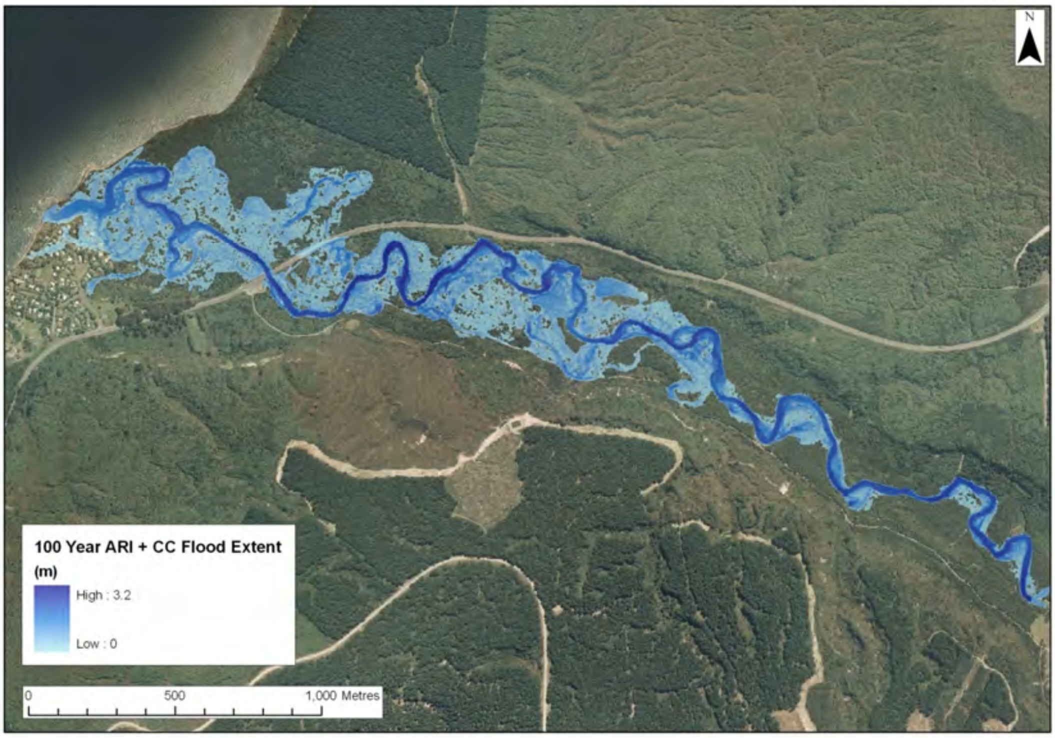


Figure 8.2: **Water depth during the 100-year flood event in the Hinemaiaia allowing for the effects of climate change. Lake level assumed to be at 357.5m.**

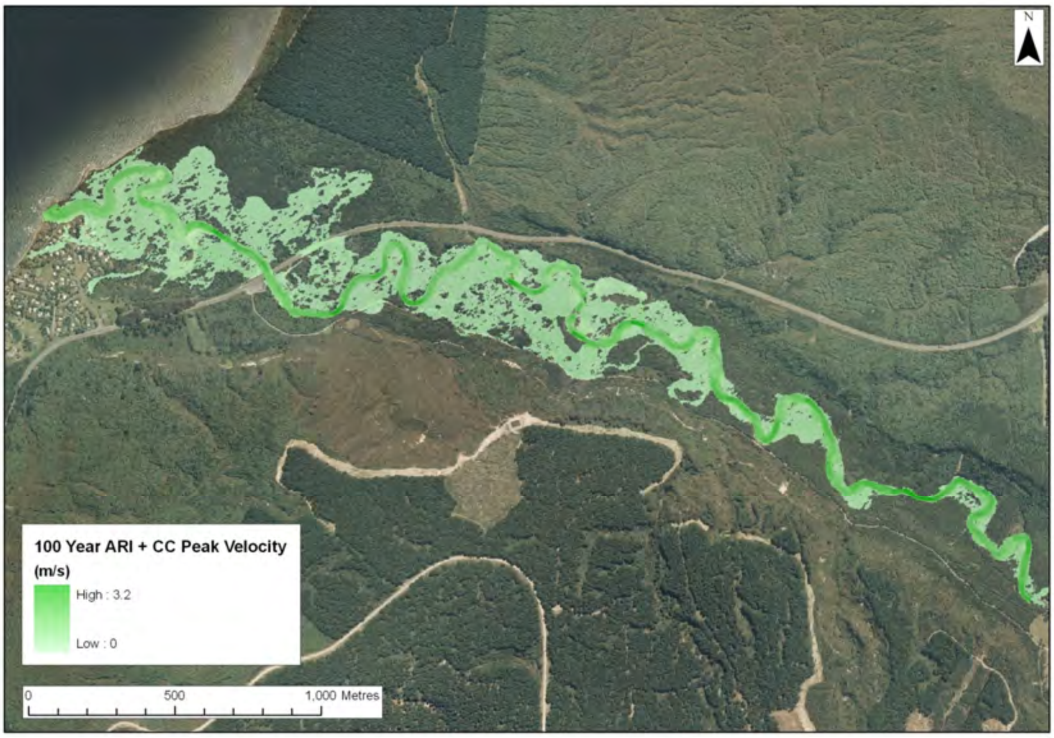


Figure 8.3: **Water velocity during the 100-year flood event in the Hinemaiaia allowing for the effects of climate change. Lake level assumed to be at 357.5m.**

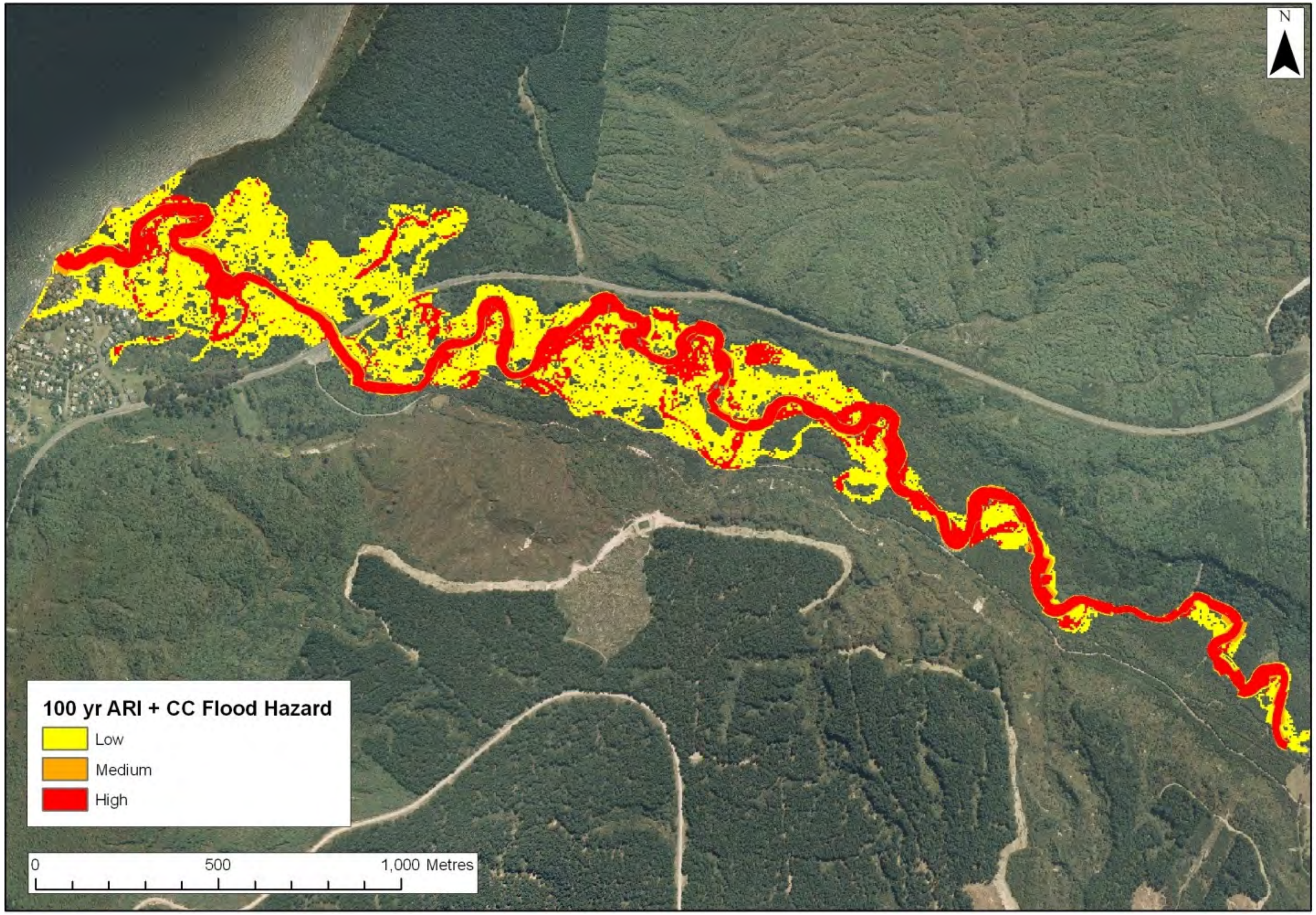


Figure 8.4: **Flood hazard classification during the 100-year flood event in the Hinemaiaia allowing for the effects of climate change. Lake level assumed to be at 357.5m.**

8.4 Summary

A MIKE FLOOD hydraulic model was created to simulate the velocity, extent, and depth of flood water during extreme events as accurately as possible, and to allow the potential impact of flood flows to be quantified.

The hydraulic model for the Hinemaiaia River covers 6.1km downstream of the HB dam to Lake Taupo. The topography of the channel and flood plain is based on LiDAR information 'captured' during 2009. The model was calibrated qualitatively against observations of the water levels during the major flood of 2000 and a 2010 event. Following calibration the model is believed to provide realistic, although conservative, estimates of the likely water depth and velocity during large flood events.

The calibrated model was used to estimate the 100-year flood extent; both with and without the effect of predicted climate change. Under the more extreme scenario water levels increase along the entire modelled reach by 100-130mm.

Now that a base hydraulic model has been established it can be updated to reflect improved calibration data, refined design flood estimates, or to explore any scenario; including climate change, channel works, flood protection options etc.

9 Conclusion

Flooding in the Hinemaiaia River is a persistent and ongoing process. The extensive flood plain in the lower valley shows that flooding is not new, and is a natural occurrence. 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 to the Hatepe settlement is relatively low. The majority of the settlement would be unaffected by flooding, even under the extreme scenarios modelled. Those small areas which could be potentially affected are subject to a low flood hazard because of shallow water depths and low flow velocities.

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

9.1 The river flood hazard

Flows have been recorded within the Hinemaiaia at various locations and over different time periods. Combination and correlation of these records has allowed the development of a continuous flow record for the Hinemaiaia below the HB Dam. This 30-year flow record allows the characteristics and dynamics of large floods to be identified and quantified.

The floods tend to both arrive and dissipate rapidly. High intensity rainfall events produce sharp, short duration flood peaks while longer duration rainfalls 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.

Despite the variability of specific storms, there is a high degree of similarity in the response of the catchment to large floods. The four largest floods on record all have very similar shapes and characteristics. It is also significant that three of these events show a sustained but more attenuated rise in discharge after the principal flood peak has passed. It is likely that this secondary peak is a function of the storage reservoirs upstream and their effect on attenuating large storm runoff events.

Rainstorm durations leading to significant flood events are usually 12-24 hours in duration. The resulting floods typically have one major peak, often with a secondary peak 24 or more hours later. Water levels rise and fall rapidly with the main body of the flood lasting up to 48 hours.

The flow record for the Hinemaiaia contains all the major flood events since 1981. This record therefore provides reliable data from which to estimate the magnitude and frequency of large flood events within the catchment. These flood discharges can be adjusted for the predicted effects of climate change out to 2090 (Table 9.1).

Table 9.1: Increased flood discharge for the Hinemaiaia as a result of global warming.

Return Period	Flood peak discharge estimated from the synthetic record	Flood peak discharge 2040 – highest temperature prediction (m^3/s)	Flood peak discharge 2090 – average temperature prediction (m^3/s)
2.33 (annual)	38.9	42.9	42.4
5	50.9	57.5	56.7
10	61	70.2	69.1
20	70.8	83.0	81.5
50	83.6	99.7	97.6
100	93.2	111.1	108.9

The small size and limited storage volume of the reservoirs associated with the Hinemaiaia hydro scheme, especially relative to large floods, mean that they have little effect on a flood's peak discharge, although the overall flood hydrograph may be attenuated slightly.

Consequently the effect of these reservoirs on flood hydrology was not considered within the hydraulic modelling.

Given the similarity of the four largest flood events these hydrographs can be used as the type-hydrograph for defining the likely characteristics of various design storm events. The type-hydrograph can be scaled any the peak discharge of the design storm. This hydrograph can then be used as a robust input to the hydraulic model.

9.2 The combined flood hazard

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

The detailed modelling discussed in this report has identified those areas at risk from flooding of the Hinemaiaia 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, and only relatively small increases in water depths.

9.3 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.

9.4 Uncertainty

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

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

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

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

The regional flood frequency indices are currently being revised and updated to include all information collected since the original report (i.e. since 1985). Once these new indices are available it may be appropriate to undertake a revision of the design flood estimates. If the revised design flood estimates are significantly different to those used in this study then consideration should be given to re-running the hydraulic model for Hinemaiaia Stream.

10 References

Chow, V.T. 1959: Open-Channel Hydraulics, McGraw-Hill, New York, 1959.

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).

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.

Hicks, D.M. and Mason, P.D., 1991: Roughness Characteristics of New Zealand Rivers, DSIR Marine and Freshwater, June 1991.

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.

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.

Opus, 2009: Tongariro River and delta flood model. Report prepared for Environment Waikato, Opus International Consultants Ltd, Wellington.28p.

11 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