Taupo District Flood Hazard Study

TAURANGA TAUPO RIVER

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

July 2010

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Date: July 2010
Reference: 39C125.N4
Status: Final A

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1 Overview

1.1 Purpose

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

This study has been prompted by:

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

The primary objective of this *Taupo District Flood Hazard Study,* and its various phases, is to identify the flood risk to land adjacent to Lake Taupo. Flooding can be triggered by processes acting within and upon the lake, and its major tributaries. These processes can act either individually or collectively to produce various extents and depths of inundation. Maps of the flood hazard from different levels and types of risk, resulting from various factors, have been developed. These maps were analysed individually, and cumulatively, to identify those areas at greatest risk. This allows the formulation of various standards for development in areas subject to particular levels and types of risk. The information in this report will subsequently be incorporated into Environment Waikato's regional plans and policy statements, and Taupo District Council's District Plans and land use planning.

Phase 1 of the study investigated the flood and inundation risk of those areas immediately adjacent to Lake Taupo. This report specifically addresses flooding of the Tauranga Taupo River. Subsequent phases will investigate the flood risk associated with the other major tributaries of the Lake Taupo catchment.

2 Tauranga Taupo catchment

2.1 Description of the Tauranga Taupo catchment

The headwaters of the Tauranga Taupo River (Figure 2.1) are in the Kaimanawa Ranges reaching elevations of approximately 1570masl. After leaving the mountains the river flows northwest, discharging onto the south eastern shore of Lake Taupo. After the Tongariro River, it is the largest of the tributaries flowing into Lake Taupo, with a catchment area of approximately 220km^2. Much of the catchment is in steep mountainous terrain. The settlements of Oruatua and Te Rangiita lie on the floodplain of the river between SH1 and Lake Taupo.

The geology of the Kaimanawa Ranges is basement rock, mainly indurated greywacke and argillite (Hancox, 2002). Greywacke is non-porous and relatively impermeable. Catchments within this material respond rapidly to rainfall events creating storm hydrographs with distinct and sharp flood peaks but relatively low baseflows. In the lower catchment, west of the Kaimanawa Ranges, are pumice alluvium and ignimbrite volcanic deposits from the 181 AD Taupo eruption (Figure 2.2). The more permeable and highly porous nature of these deposits means that they can absorb the majority of rainfall from all but the most extreme events. The Tauranga Taupo River therefore has a highly variable flow regime. It is characterised by long periods of low flow conditions interspersed with short duration flood events.

The Tauranga Taupo River has formed a relatively extensive floodplain along its lower reaches (Figure 2.3). This is composed of both pumice and other alluvium eroded from the upper catchment. The flat alluvial deposits between the settlements of Oruatua and Waitetoko to the east indicate a significant and extensive flood history (Figure 2.4). Impeded drainage of the Tauranga Taupo River during mid to high lake levels can cause a backwater effect. At low river flows this tends to slow the velocity leading to the deposition of any sediment. During flood conditions high lake levels raise water levels and exacerbate the flood risk to the surrounding area. Significant flood protection and river management works have been undertaken to reduce the flood risk to the settlements in the vicinity.

The Tauranga Taupo catchment is predominantly under forest. This includes indigenous native forest within the Kaimanawa Forest Park, managed by the Department of Conservation; and exotic plantation forestry managed by New Zealand Forest Managers (Turangi). There is a mixture of exotic forestry and pasture (grazed and fodder crops) on the left bank of the lower floodplain (Figure 2.5). The floodplain also contains the communities of Oruatua and Te Rangiita, and network infrastructure (i.e. roading and electricity). Landuse within the catchment is summarised in Table 2.1.

Figure 2.1: Location of the Tauranga Taupo River.

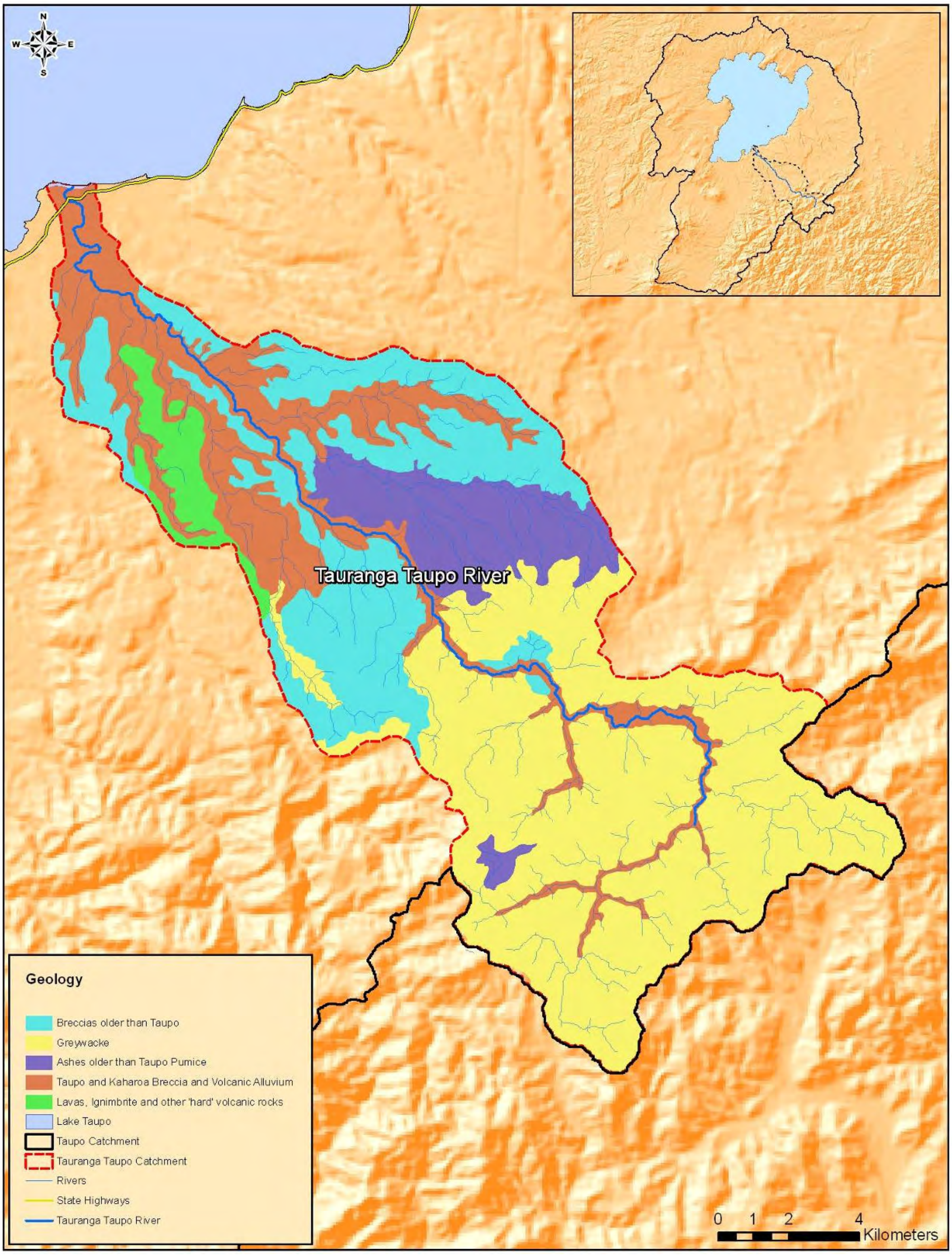

Figure 2.2: Catchment geology of the Tauranga Taupo River.

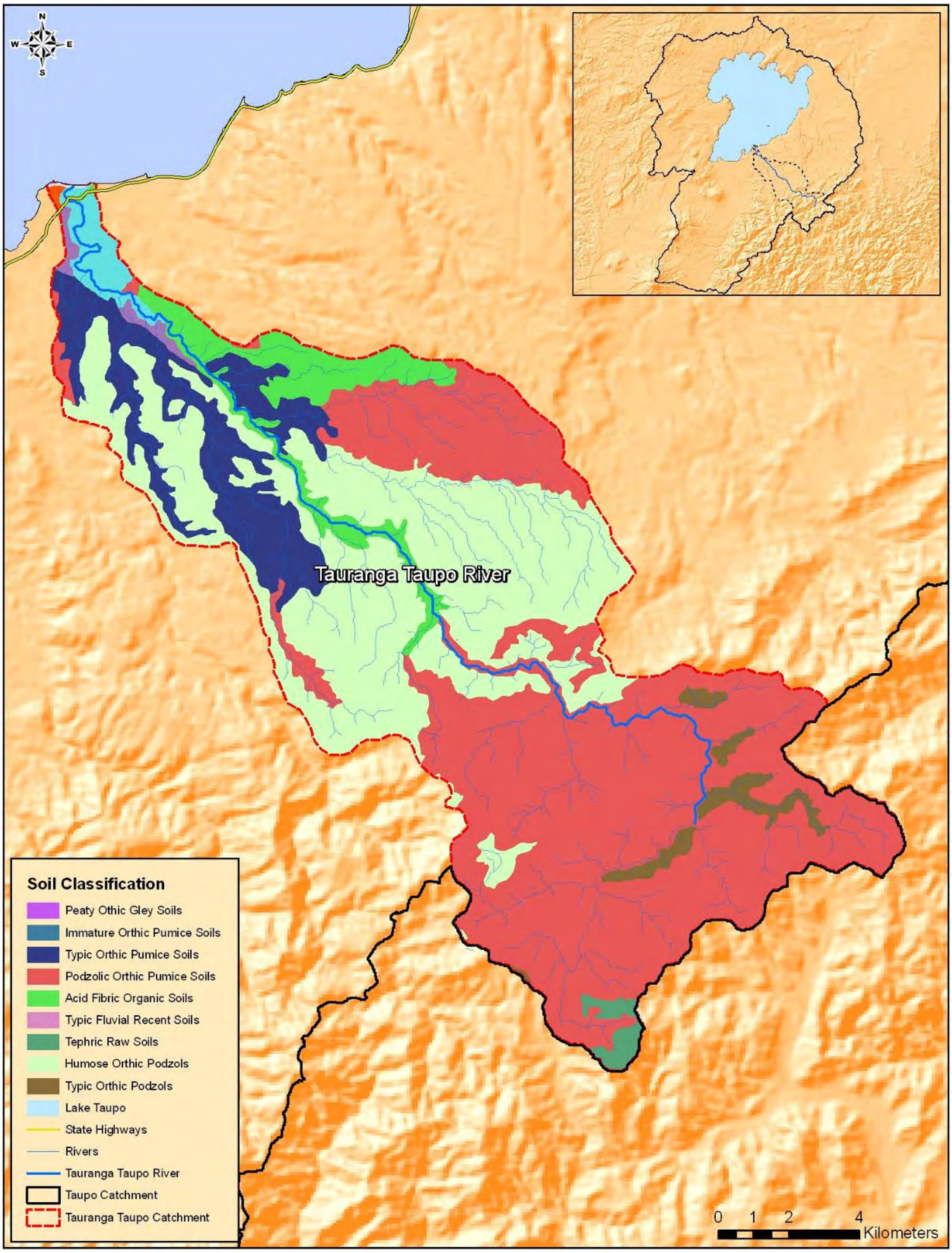

Figure 2.3: Soils of the Tauranga Taupo catchment.

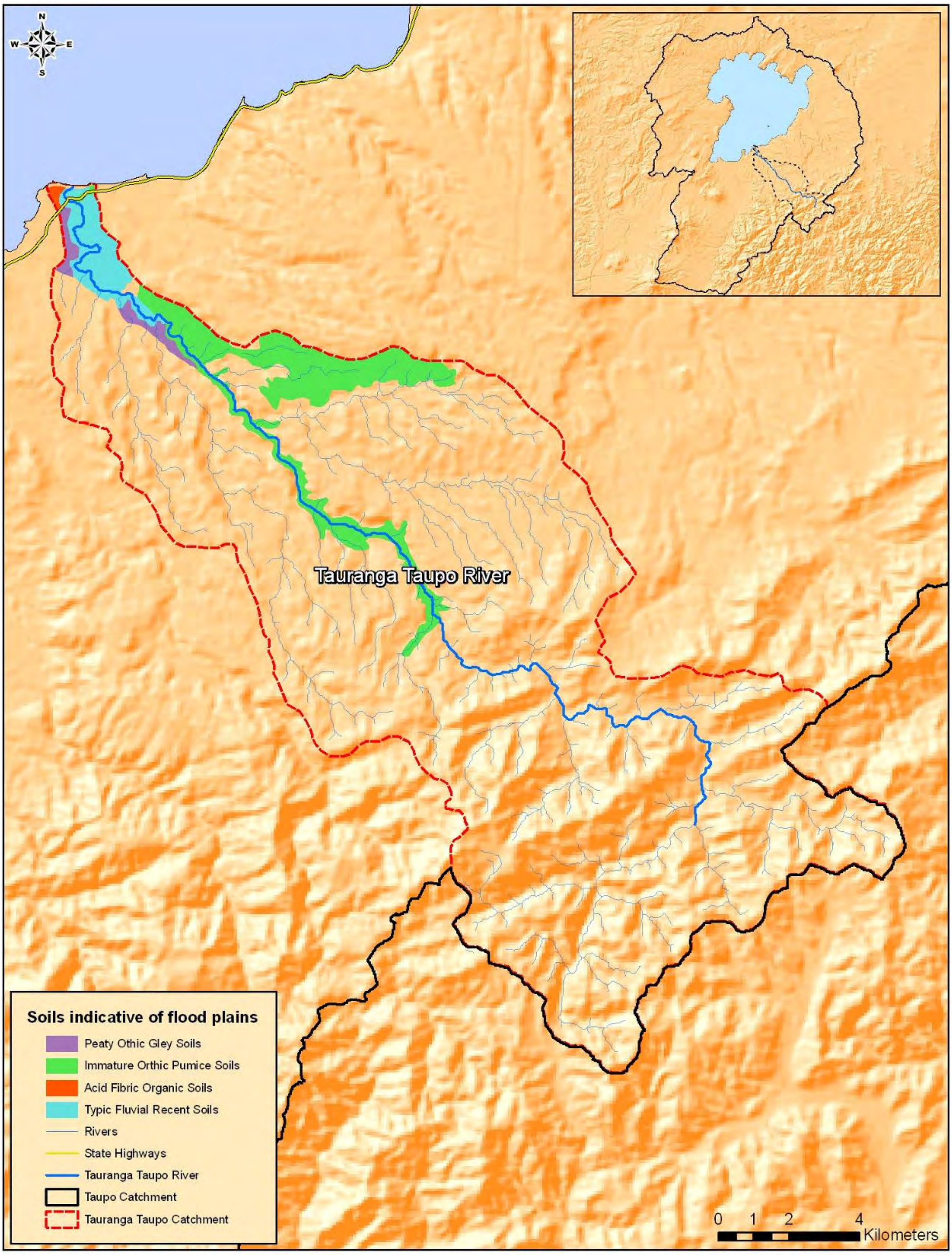

Figure 2.4: Flood deposits of the Tauranga Taupo River.

Figure 2.5: Land use within the Tauranga Taupo catchment.

Table 2.1: Land use within the Tauranga Taupo River catchment.

Land use	Percentage
Indigenous Forest & Alpine Tussock	67.5%
Exotic Production Forest	30.3%
Pasture	0.8%
Quarry	0.2%
Urban / Settlements	0.1%
Roading	0.3%
Shrub	0.4%
Other	0.4%
Total	**100.0%**

The Tauranga Taupo catchment has a very steep rainfall gradient. The mean annual rainfall in the headwaters, the area likely to produce the greatest runoff, is approximately 2100mm. Rainfall reduces rapidly, as a function of altitude, throughout the lower catchment. At Lake Taupo rainfall is only about 50% of that in the headwaters (i.e., 1100mm).

The main channel of the Tauranga Taupo River is approximately 45km long from its headwaters down to Lake Taupo. Over this distance the river drops 1243m. The river can be divided into two main reaches based on steepness (Figure 2.6) and vegetation cover.

The Upper River is above the Te Rangiita Quarry. This reach is approximately 38km long dropping some 1200m, with a relatively steep gradient (~2°). The reach is characterised by steep mountainous slopes under native vegetation within the Kaimanawa Forest Park, and steep to rolling slopes under exotic plantation forestry further downstream. The river is predominantly confined to a single channel between steep, incised banks. These physical characteristics are reflected in the high velocity, short time of concentration, and high erosive energy that shifts material from the bed and banks downstream. While the Tauranga Taupo is a dynamic high energy river, the channel in this reach is relatively stable (Environment Waikato, 2005).

Between Te Rangiita Quarry and Lake Taupo the river drops only 43m over 7km. This reach is therefore very flat when compared to the upper river. Because this reach receives high energy flows from upstream, loaded with bed material and debris, the river tends to meander. This creates a number of secondary channels and ponding areas. These absorb the energy and volume of flood flows resulting in the deposition of sediment. Consequently, this lower reach of the Tauranga Taupo River is characterised by:

- An unstable main channel, with significant erosion and deposition during flood events;
- Unpredictable changes in the course of the main channel; and
- A wide floodplain with multiple overflow points and relict river channels (Environment Waikato, 2005).

It should be noted that these features reflect the natural floodplain and delta building processes of a dynamic gravel-bed river such as the Tauranga Taupo. The effect of these processes is apparent in the alluvial sedimentation shown in Figures 2.3 & 2.4.

Under normal flow conditions, the sediment load of the Tauranga Taupo River consists of sands and silts in suspension. This is transported through the lower reaches of the river to Lake Taupo. However, floods mobilise significant quantities of bed load and these high energy events are the dominant channel forming process. The lower river often changes course during flood events because of the relatively limited capacity of the main channel, and the erodible nature of the material forming the bed and banks. While not an ideal location for development, it is within this reach that the main development has occurred. Hence, the flood control scheme and river protection works are located within this reach (Environment Waikato, 2005).

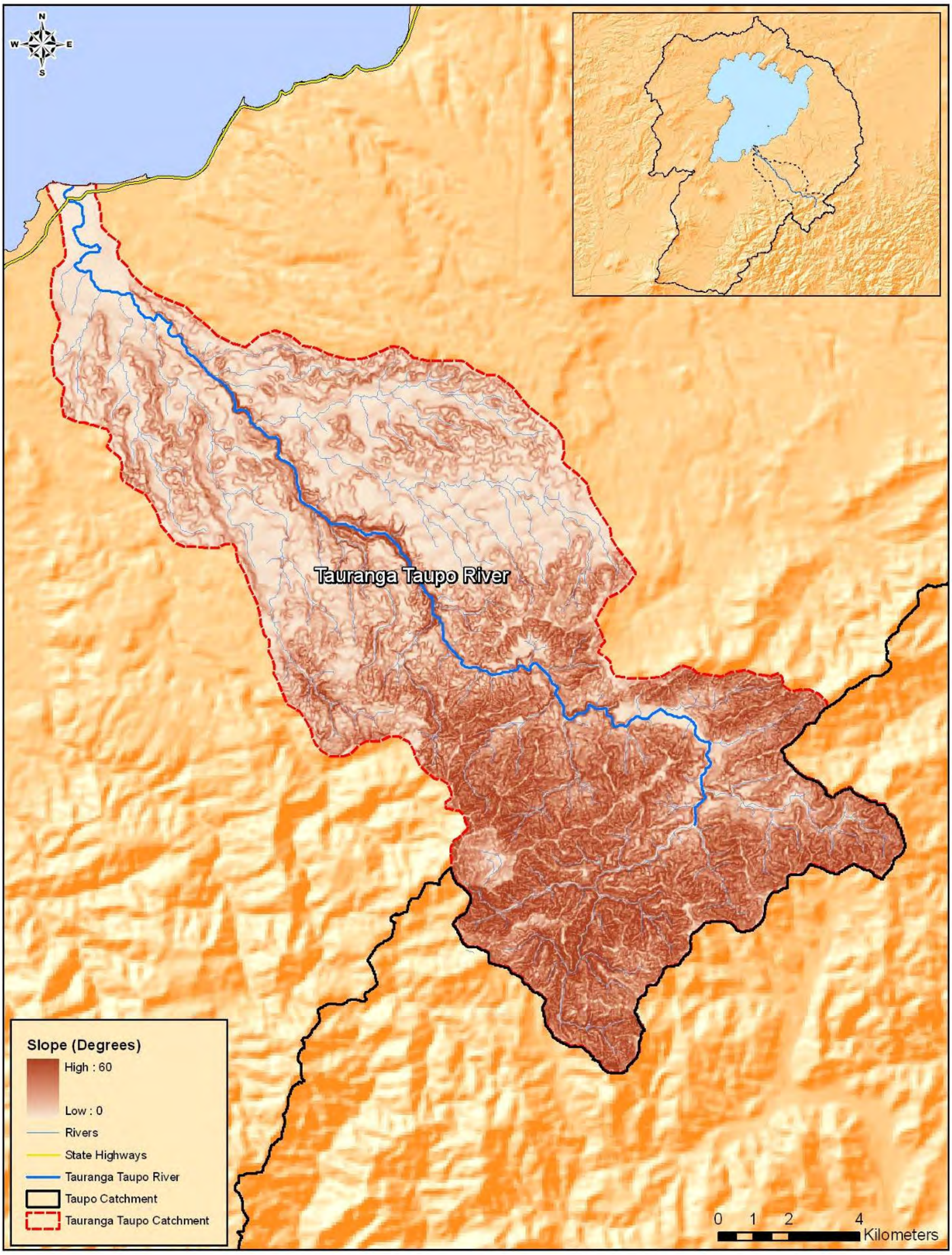

Figure 2.6: Slope within the Tauranga Taupo catchment.

3 Flow regime of the Tauranga Taupo River

3.1 Tauranga Taupo River @ Te Kono

Water levels, and therefore flows, of the Tauranga Taupo River have been continuously recorded since February 1976 at the Te Kono gauge (Figure 3.1). This gauge is located approximately 7km upstream of the river mouth, but tributary flow contributions below this point are small. Consequently, the flow record from Te Kono provides a robust measure of the flood magnitude and frequency history of the lower catchment (Figure 3.2).

Figure 3.1: Location of flow and rainfall sites.

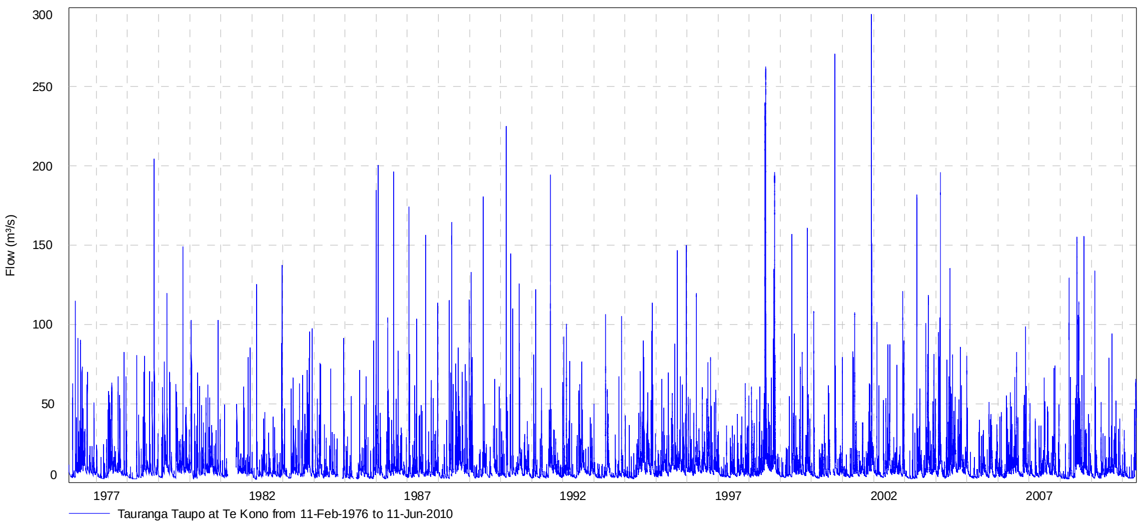

Figure 3.2: Flow record for the Tauranga Taupo River @ Te Kono (1976-2010).

3.2 Stationarity

Stationarity is a key assumption in all frequency analyses, including those used in this study. Stationarity implies (and it is therefore assumed) that the annual maxima or minima used in the analysis exhibit no trends or cycles; and that 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.

3.3 Flow characteristics

Overall the flow record from Te Kono appears to be of good quality, containing a relatively complete history of all the major flow events in the Tauranga Taupo River since 1976. There is, however, one gap in the record of 100 days which occurred in 1981. Over the period for which rainfall data are also available for this site, the largest gap is only 4 days.

Although there appears to have been a period of increased flood activity from the late 1990s to 2002, the flow record appears to show a relatively consistent annual pattern of flow variation. There are no significant trends or cycles apparent in the data. This flow record therefore provides a reliable set of data to use in frequency analyses.

The summary of flow statistics (Table 3.1and Figure 3.3) show that the Tauranga Taupo is characterised by long periods of relatively low flow, interspersed with short duration but high magnitude flood events. The significance of these flood events on the summary statistics is that the mean flow is approximately 30% higher than the median.

Table 3.1: Summary of flow statistics (m^3/s) for the Tauranga Taupo (1976-2010).

Site	Minimum	Mean	Median	Maximum	Standard deviation	Coefficient of variation
Tauranga Taupo	2	10	7	296	10.0	1.035

Table 3.2 lists the largest flood event in each of the years of record. It should be noted that in some years e.g., 2005 and 1997; the largest recorded flood was a relatively small event. For example, the largest flood in 2005 was only 17% of that in 2001, the year with the largest flood on record. This variability of flood events highlights a major difficulty when predicting the likely magnitude of floods for particular return periods.

Table 3.2: Annual maximum flows recorded at Tauranga Taupo @ Te Kono, 1977-2010.

Rank	Year	Flow (m^3/s)	Rank	Year	Flow (m^3/s)	Rank	Year	Flow (m^3/s)
1	2001	296	**12**	1988	165	**22**	1980	103
2	2000	271	**13**	1999	161	**23**	1992	100
3	1998	263	**14**	2008	156	**24**	2006	99
4	1990	225	**15**	1995	150	**25**	1983	98
5	1978	205	**16**	1979	149	**26**	1984	91
6	1986	201	**17**	1982	137	**27**	1985	90
7	2004	196	**18**	2009	134	**28**	*1981*	*86*
8	1991	194	**19**	2002	121	**29**	1977	82
9	2003	182	**20**	1996	120	**30**	2007	76
10	1989	181	**21**	1994	114	**31**	*2010*	*66*
11	1987	174	**22**	1993	106	**32**	1997	63
						33	2005	51

Note: There are a number of gaps in the record, including a 100 day gap from March 1981. 2010 only includes data recorded up until June.

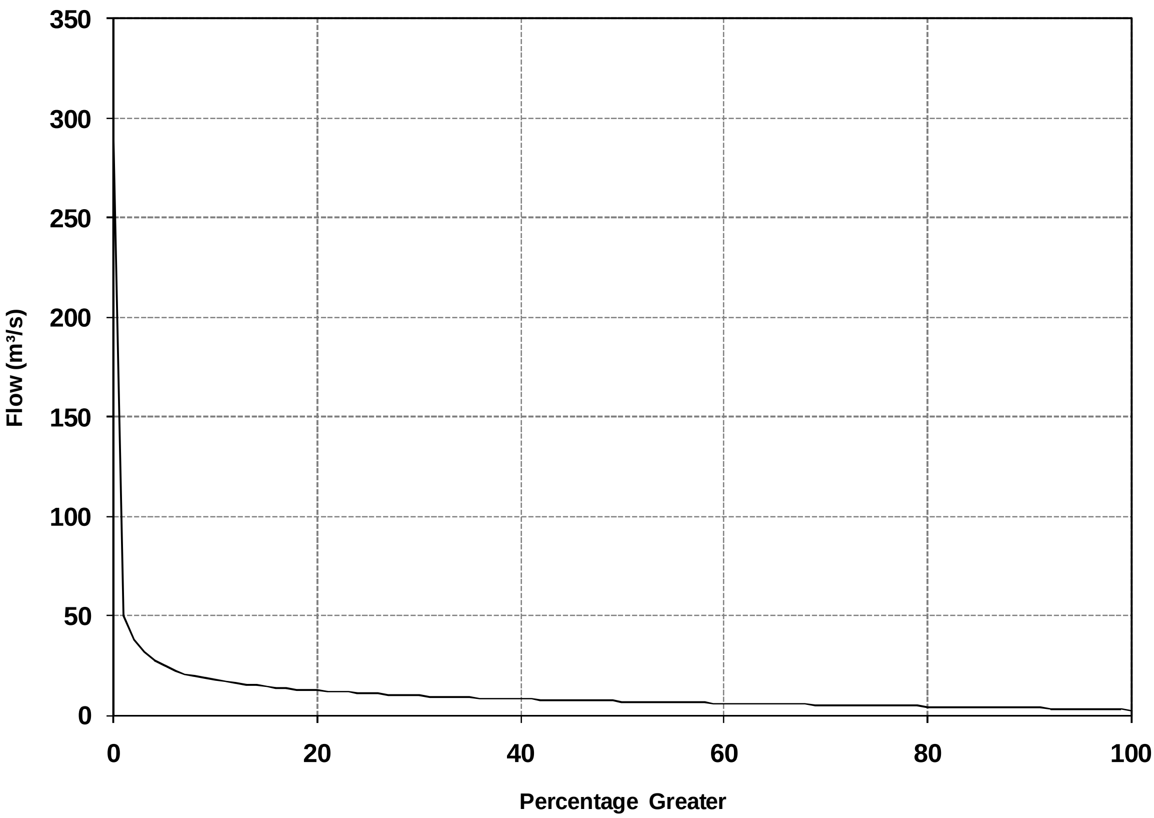

Figure 3.3: Flow duration for the Tauranga Taupo River @ Te Kono (1976-2010).

Figure 3.4 shows the flood hydrograph for the largest flow on record i.e., 7 December 2001. This hydrograph highlights a number of features of flood events in the Tauranga Taupo catchment. In general, it takes rainfall events of approximately 12 hours duration to generate a significant flood. High intensity rainfall events produce a sharp, short duration flood peak. Longer duration rainfall events tend to produce more sustained flows, but with a lower peak discharge. Also, once the catchment has been 'wetted up' i.e., all the storage is full, the river responds rapidly, sharply, and more significantly to any additional rainfall.

Analysis of the flood hydrographs of the four largest recorded floods on the Tauranga Taupo River indicate a relatively consistent pattern of response. Rainstorms leading to significant flood events are between 12-24 hours in duration. The resulting floods typically have a single peak, and the body of the flood lasts for between 12 to 18 hours. These findings are consistent with those presented in Tonkin & Taylor (2002b).

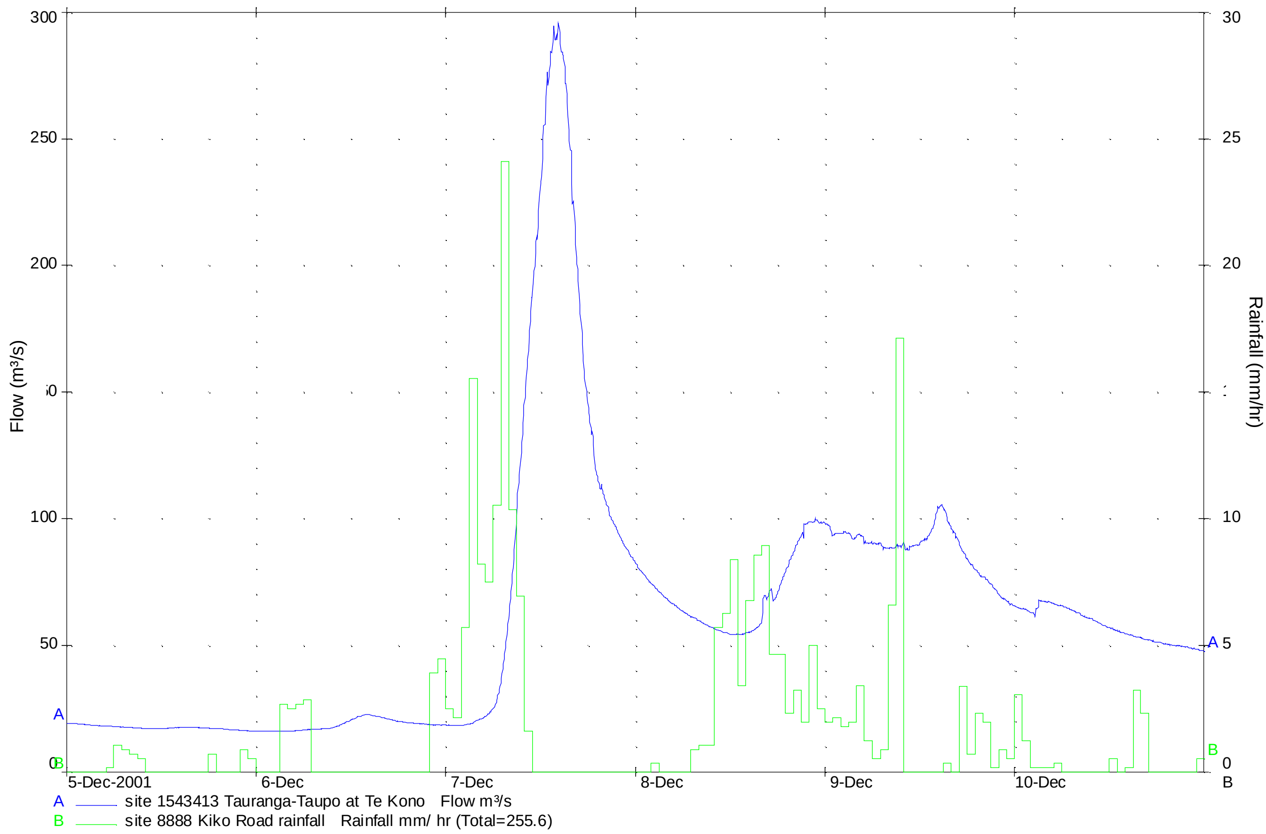

Figure 3.4: Flood hydrograph of the largest flow (m³/s) on record. Rainfall is in mm/hr.

3.4 Recent flood history and mitigation measures

Major flood events occurred on the Tauranga Taupo River in 1958 and 1964. This prompted flood protection investigations for the communities of Oruatua and Te Rangiita. Several options and schemes were developed by the then Waikato Valley Authority in 1966 and 1975. However, these were not adopted because of funding constraints within both the Waikato Valley Authority and the Taupo County Council (Environment Waikato, 2005).

A final scheme was adopted in 1981 and partially implemented. Works included: the construction of stopbanks in the vicinity of Kiko Farm; formalisation of the natural overflow at Maniapoto Bend (Kiko Overflow), to allow peak flows to bypass the settlements of Te Rangiita and Oruatua; and the construction of the Kiko Culverts under State Highway One.

Floods in July 1998, October 2000, December 2001, May 2003 and February 2004 highlighted the ongoing risks to both rural and urban land in the catchment. During the largest flood on record, that of 7 December 2001, the Tauranga Taupo River broke through its banks into the excavated quarry area and formed a new channel. This breakout effectively de-watered a substantial length of the previous natural course of the river (Environment Waikato, 2005).

In December 2003 the river was diverted back into its original course with the construction of an embankment at the breakout point into the quarry. Significant works were undertaken to improve the hydraulic efficiency of the natural spill area at Maniapoto Bend, a grassed spillway channel was formed, and the capacity of culverts under State Highway One were increased (Environment Waikato, 2005).

The area affected by flooding of the Tauranga Taupo River following these works is shown on a flood hazard map (Figure 3.5). This map is based on historical survey of flooded areas following the 1964 flood. It should be mentioned that the 1958 flood was greater than the 1964 event, but no actual survey of its extent was carried out at the time (Environment Waikato, 2005).

3.5 Flood control scheme

The flood control scheme on the lower Tauranga Taupo aims to provide protection to the community and assets on the floodplain (Figure 3.6). The quarry is used for flood storage, and the Kiko Spillway takes part of the flow directly to Lake Taupo, bypassing the lower section of the river. The scheme was designed to accommodate either a flow of 318m^3/s at the Te Kono water level recorder, or 209m^3/s at the State Highway One bridge (Table 3.3). This was the nominal 1 in 50-year flood event.

Table 3.3: Design flows for the flood control scheme (Environment Waikato, 2005).

Flow at key locations (m^3/s)	Flood return period (years)						
	2.33	**5**	**10**	**20**	**50**	**100**	**200**
Te Kono gauge	150	197	235	271	318	353	388
Overflow into quarry via spillway	0	0	1.5	11	30	45	62
Kiko overflow (spillway and side inflows)	23	45	60	72	82	91	99
Right bank overflow – across SH1	0	0	0	0	0	12	20
Under SH1 bridge	125	146	164	175	209	235	246

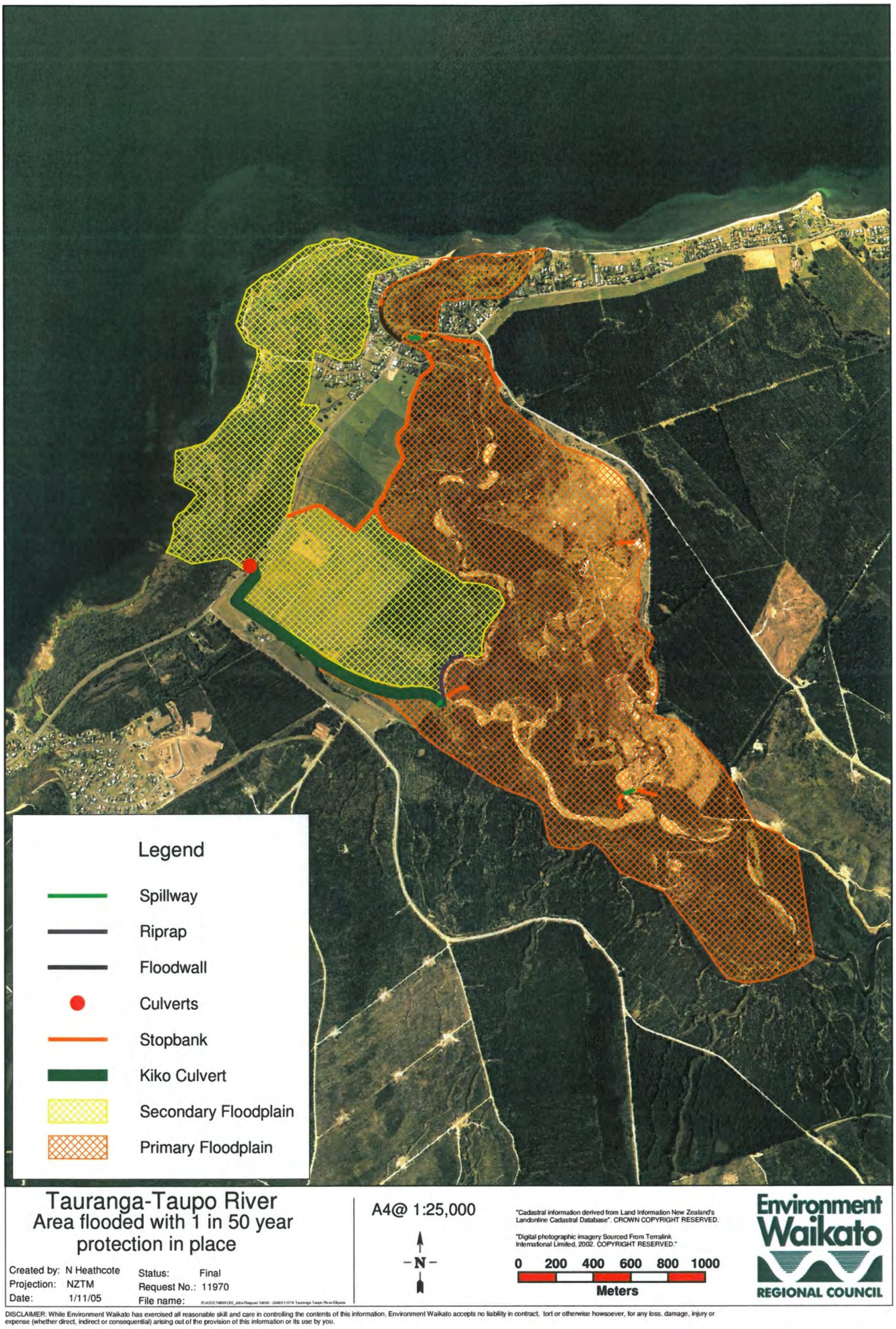

Figure 3.5: Areas affected by flood events on the Tauranga Taupo River (Environment Waikato, 2005).

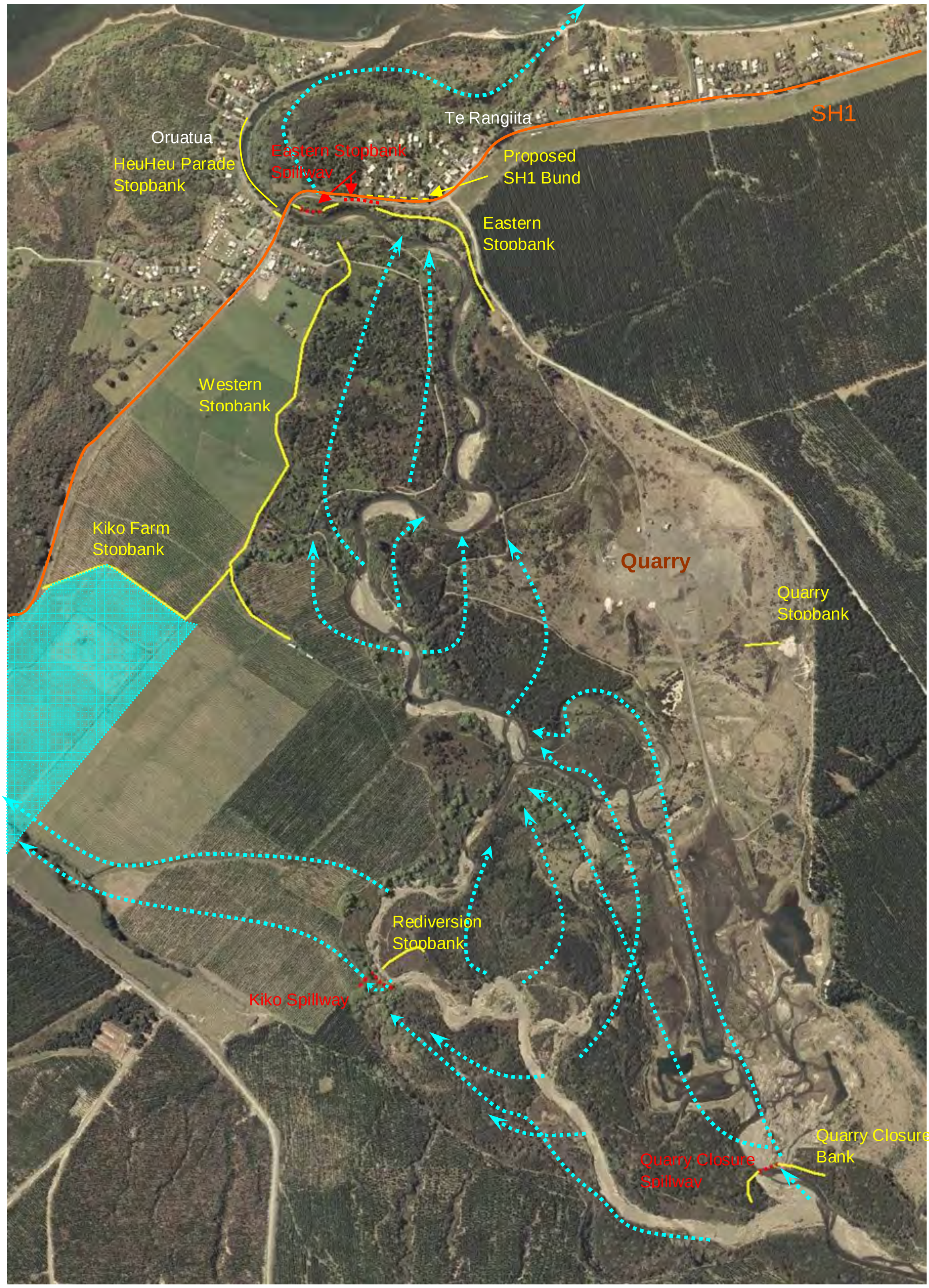

Figure 3.6: The Tauranga Taupo flood mitigation scheme and flow paths (Basheer, 2008).

Following completion of the flood control scheme the flood hazard was reduced. An annual works programme ensures the stability and reliability of the scheme. The Tauranga Taupo Catchment Management Plan (Environment Waikato, 2005) has as one of its objectives:

> *To maintain the stability of the river and floodplain in terms of its capacity and ability to perform within the design parameters of the scheme. This will be achieved by ensuring that the main channel and identified overflow channels are free from obstruction caused by vegetative debris and gravel where these have the potential to increase flood levels and cause erosion or damage to scheme structures.*

The assumption in this present flood assessment is that the work and river maintenance programme summarised above ensures that the capacity of the channel, and as a result the flood mitigation scheme works to its design specifications.

A considerable amount of resources have been invested in modelling flood flows through the lower Tauranga Taupo River (Tonkin & Taylor, 2002a). The river was modelled using 1-dimensional MIKE11 software from the river mouth up to the gauging station at Te Kono. Modelling scenarios were run to replicate the 5, 10, 20, 50, 100, and 200-year return period flood levels.

More recently Basheer (2008) has developed a MIKE FLOOD (a coupled 1-dimensional and 2-dimensional model) model showing the anticipated extent of flooding and depth of inundation during the 1 in 100-year event. Given the similarity between the estimates of the magnitude of the 100-year event in that report, and that from the analysis of the more recent data, it is considered valid to use that model when assessing the flood hazard in the lower valley of the Tauranga Taupo River.

3.6 Flood frequency analysis

A flood frequency analysis of the annual flow maxima recorded at Te Kono (Table 3.2) was undertaken to provide estimates of the magnitude of flood events with different return periods (Table 3.4). A PE3 statistical distribution provides the best fit to the annual flood maxima series (Figure 3.7).

The results of this most recent frequency analysis are consistent with those from previous studies (e.g., Tonkin & Taylor, 2002; Environment Waikato, 2005). The addition of the past few years of river flow information, containing a number of lower than usual floods, has reduced the estimates of peak flows with specific return periods. This is seen when comparing the flood estimates at Te Kono in Table 3.3 with the values in Table 3.4. It is also apparent that the addition of only the last three years of flow data has reduced the flood estimates further; comparing columns 2 and 3 in Table 3.4. The modelling undertaken by Basheer (2008) is therefore likely to be slightly conservative; predicting slightly greater flood extents and depths during the 100-year event. Any uncertainty relating to the flood modelling is, however, likely to be within the accuracy limits of the flow record.

Table 3.4: Flood estimates for the Tauranga Taupo River at Te Kono showing the effect of an additional 3-years of flow data (assuming a PE3 distribution).

Return Period	1976-2007 (m^3/s)	1976-2010 (m^3/s)
2.33 (annual)	146	144
5	195	191
10	233	228
20	268	263
50	312	305
100	344	336
200	375	365
500	414	404

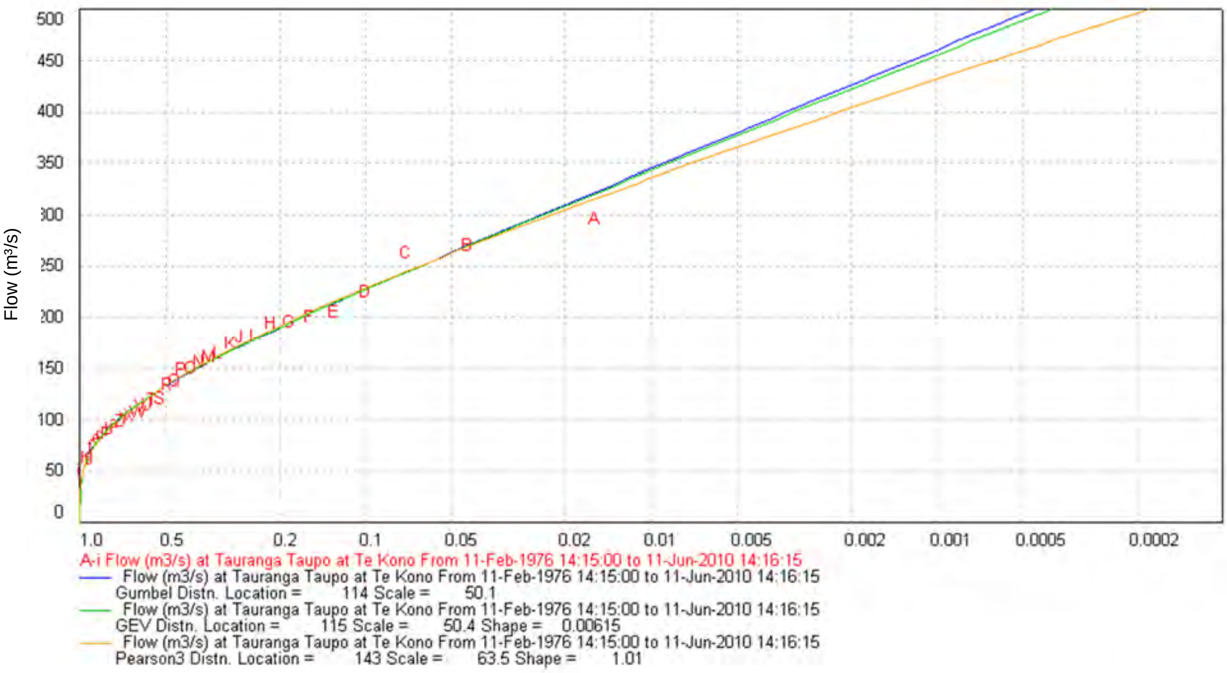

Figure 3.7: Flood frequency analysis of the Tauranga Taupo River (1976-2010).

3.7 Flood extent

Using the MIKE FLOOD model developed by Basheer (2008), and the estimates of the magnitude of the 100-year event, the extent of flooding across the lower flood plain can be assessed (Figure 3.8). The majority of the overbank flow occurs in three general locations. The first is the quarry, on the right-hand bank downstream of Te Kono, which takes most of the excess flow. Some of the flood water also passes through the Kiko Spillway. This water moves in a westerly direction, via secondary flood ways, to Lake Taupo. The remainder of the excess flow is contained within the western stop bank on the left of the river. The model shows that the 100-year event also remains within the stop banks and expected secondary flow paths. That is, the flood control scheme appears to be working above its design specifications. This is because the increase in peak discharge between the 1:50-year and 1:100-year event is only about 10%; a relatively small increase in flow compared to the magnitude of the 1:50-year flood. The 'extra water' during the 100-year event inundates areas within the stop banks that remain dry during the smaller 50-year event.

3.8 Inundation depth

The water depth from the MIKE FLOOD model (Basheer, 2008), in combination with a high resolution LiDAR-derived digital terrain model, allows the depth of inundation across the flood plain to be assessed (Figure 3.9). The majority of the area flooded by the 100-year event is covered by water less than half a metre deep. Areas which are affected by greater depths of water, up to 4m in isolated places, are within the quarry and along old river courses. A considerable depth of ponding also occurs between the State Highway and the Kiko Farm Stop bank.

3.9 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

There has been a significant change in the land cover of the Lake Taupo catchment in the past. However, much of the Tauranga Taupo catchment is under indigenous forest and tussock (67.5%). This is protected within the Kaimanawa Forest Park, and administered by the Department of Conservation. A remaining 30.3% is managed as exotic production forest. Therefore, land use within the catchment is unlikely to change in the foreseeable future.

At present approximately 65km^2 of the catchment is under exotic forestry (LCDB2-2004). The most dramatic, although highly unlikely, land use change that could affect the hydrologic regime of the Tauranga Taupo River would be the conversion of all these forestry lands to pasture. Using the information presented in Table 3.5, this would have the potential effects summarised in Table 3.6. It should be noted that most of the exotic forestry is on porous and permeable soils. Land use conversion on this area would therefore have less dramatic consequences than would be likely should the conversion take place elsewhere in the catchment.

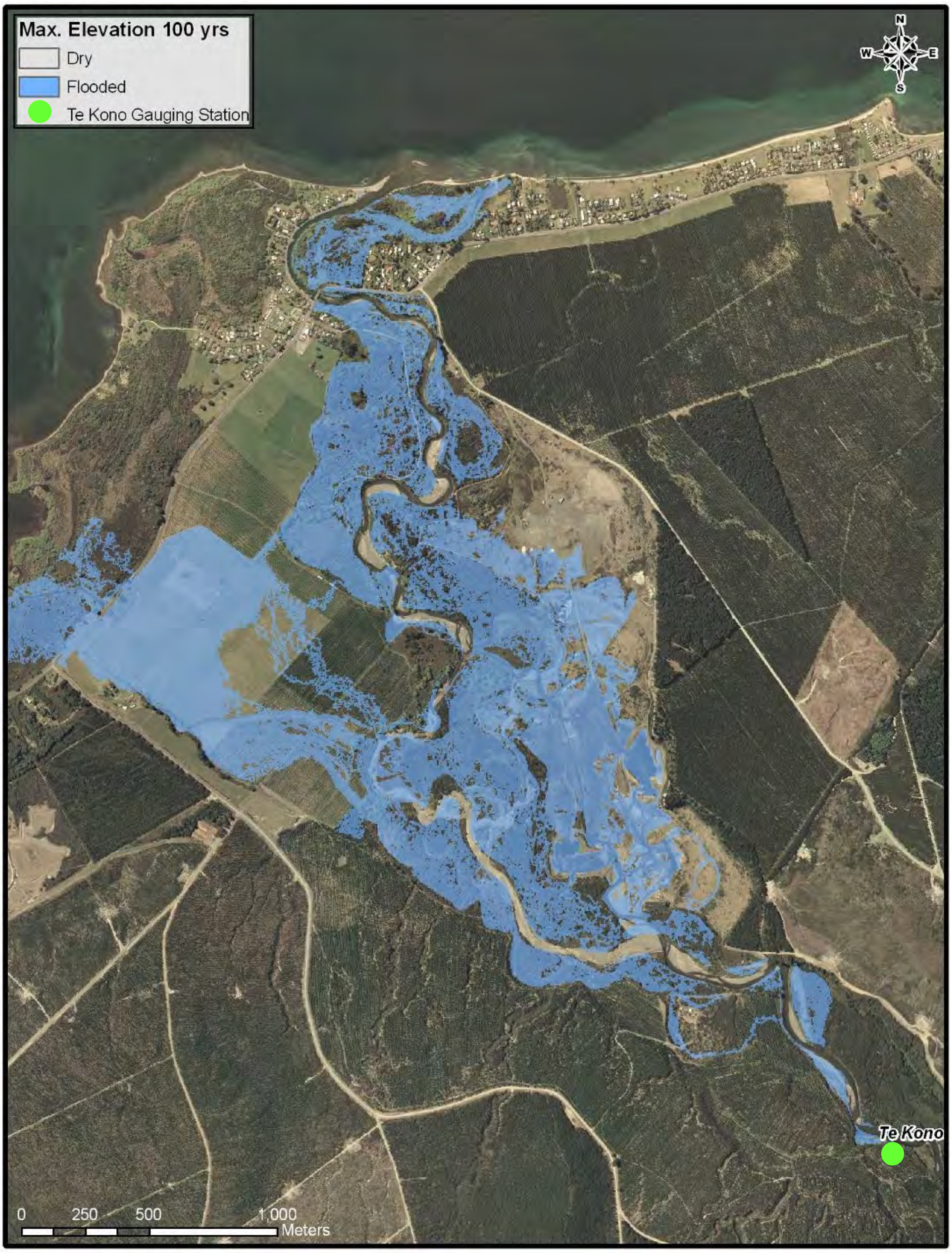

Figure 3.8: Flood extent during the 100-year event in the Tauranga Taupo River.

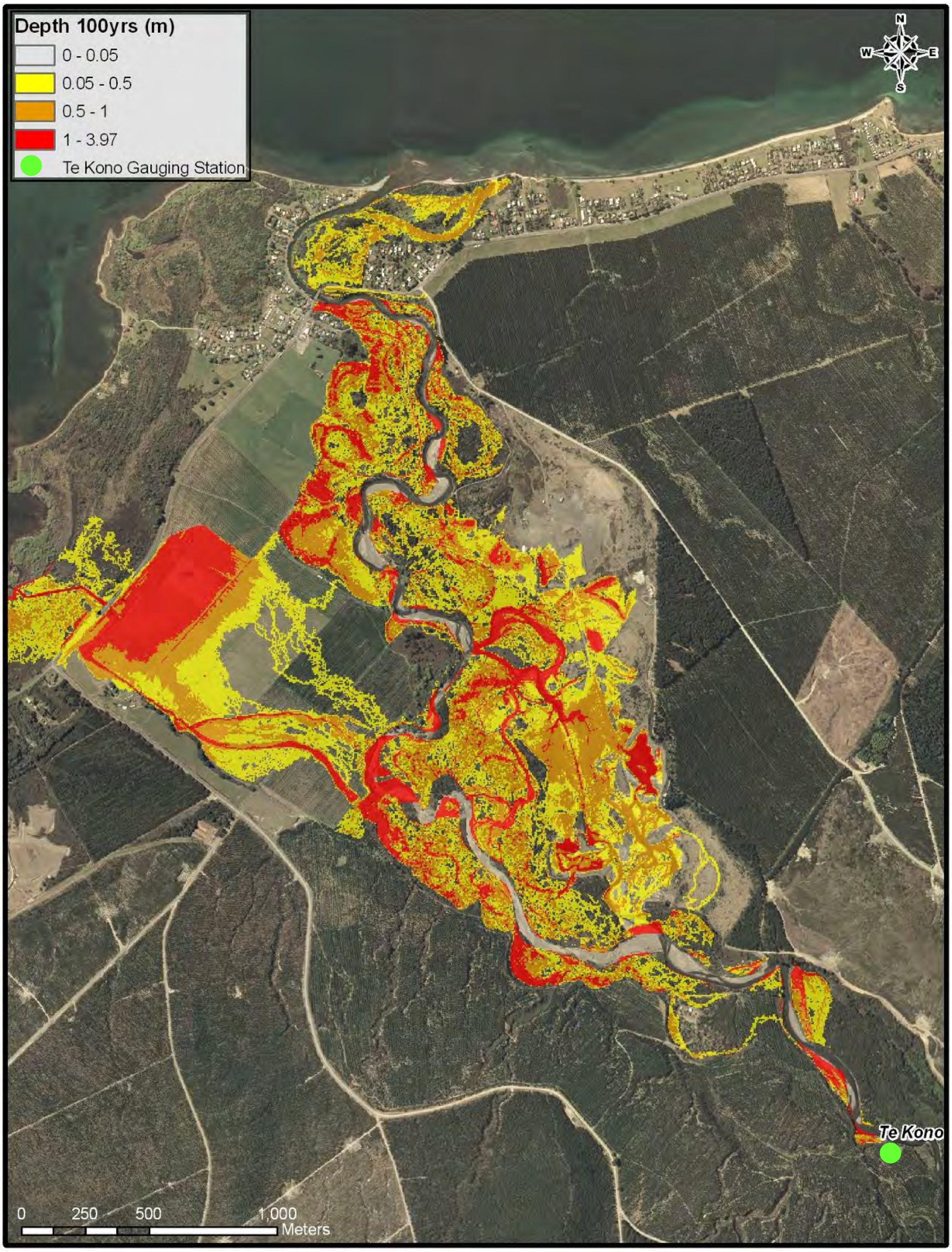

Figure 3.9: Flood inundation depths for the 100-year event in the Tauranga Taupo River.

Table 3.6: Potential effect on the hydrologic regime if all 65km² of exotic forest lands within the Tauranga Taupo catchment were converted to pasture.

	Average increase in peak discharge per km² converted (m^3/s)	Increase in peak discharge if all converted (m^3/s)	Average increase in flood runoff volume per km² converted (m^3)	Increase in flood runoff volume if all converted ($m^3 \times 10^6$)
2	0.18	11.7	0.019	1.24
10	0.40	26.0	0.033	2.15
20	0.54	35.1	0.042	2.73
50	0.78	50.7	0.057	3.71
100	1.03	67.0	0.072	4.68
200	*1.45*	*94.3*	*0.091*	*5.92*
500	*2.18*	*141.7*	*0.125*	*8.13*

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

From the perspective of the flood hazard it is the potential increase in peak discharge that is of most concern. The changes in the estimated flood peak caused by converting all the area currently under exotic forestry to pasture would be 16% for the 50-year event, and 19% for the 100-year event.

Flood peak discharge estimates from the frequency analysis should therefore be increased by the amounts indicated in Table 3.6 if it is considered that this land use change is a real possibility. Since at this stage it seems unlikely that any such conversion will occur, its potential effects have not been included in the later analysis of flood risk.

3.10 Potential effects of climate change

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

A methodology has been developed for determining the projected increase in rainfall as a result of climate change in New Zealand (Ministry for the Environment, 2008). The mean annual temperature for the Lake Taupo catchment is predicted to increase by between 0.2 and 2.4°C by the 2040s and 0.6 and 5.6°C by the 2090s (Figure 3.10). These data are summarised in Table 3.7.

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 3.8).

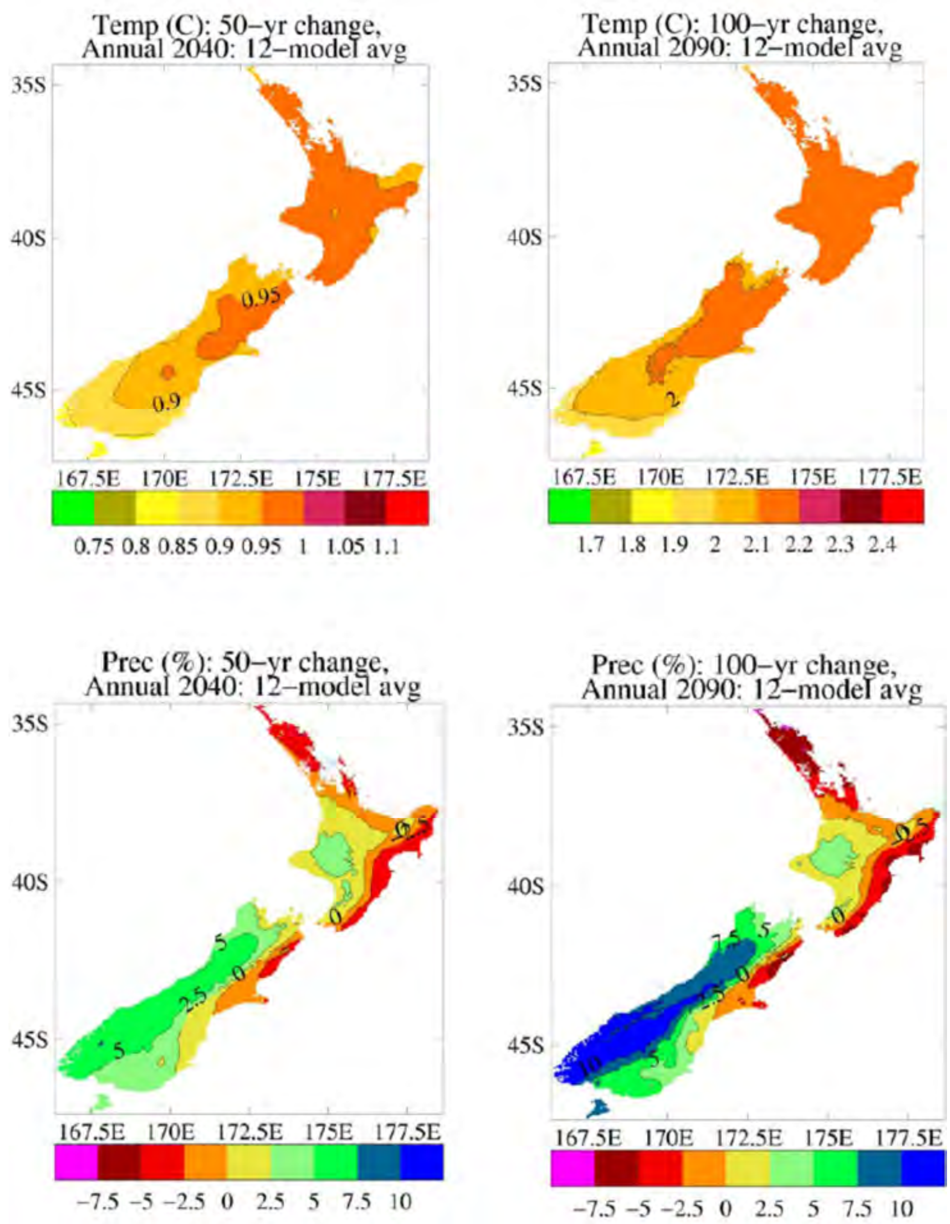

Figure 3.10: Projections for increases in mean annual temperature and rainfall by 2040 and 2090 relative to 1990; average of 12 climate models for A1B emission scenario (Figure 2.3, Ministry for the Environment, 2008).

Table 3.7: Projected increases in mean annual temperature by 2040 and 2090 for the Lake Taupo catchment. (Ministry for the Environment, 2008).

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

Note: These data are from Tables 2.2 and 2.3 in Ministry for the Environment (2008). The original tables cover the period from 1990 (1980-1999) to 2040 (2030-2049) and 2090 (2080-2099) based on downscaled temperature changes for 12 global climate models, re-scaled to match the IPCC global warming range for six illustrative emission scenarios.

Table 3.8: Percentage increase in rainfall per degree of temperature for different rainfall durations.

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

Source: Table 5.2, Ministry for the Environment, 2008.

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

Assuming temperature increases of between 0.2°C and 2.4°C (2040s) and 0.6°C and 5.6°C (2090s) for the respective scenarios, the 100-year return period rainfall will increase by a maximum of 19.2% by 2040 and 44.8% by the 2090s (Table 3.9). This is based on the upper limits of the various global warming scenarios. The percentage increase will vary depending on the actual temperature increase, storm magnitude, and storm duration.

Table 3.9: Estimated percentage increase in 12-hour rainfall totals for the Tauranga Taupo River as a result of global warming.

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

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

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

Therefore, the percentage increases in rainfall listed in Table 3.9 have been translated directly to percentage increases in flow.

Table 3.10 lists the increases in peak discharge as a result of predictions of global warming. The maximum predicted increases in temperature were used to estimate the increases in flood peak discharges by 2040. The average temperature increases were used for 2090 (Table 3.8). 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 3.10: Increased flood discharge for the Tauranga Taupo River as a result of global warming, using average predicted temperature change.

Return Period	Flood peak discharge estimated from the current instrumental record	Flood peak discharge 2040 – highest temperature prediction (m^3/s)	Flood peak discharge 2090 – average temperature prediction (m^3/s)
2.33 (annual)	144	161	159
5	191	218	214
10	228	264	259
20	163	309	303
50	305	364	356
100	336	401	392

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 Tauranga Taupo River consists of sands and silts in suspension. Because this material is in suspension, it is generally transported through the lower reaches of the river to Lake Taupo. This sediment therefore has little effect on the flow capacity, and therefore the potential of flooding. However, flood events mobilise significant quantities of bed load which is eroded from the upper catchment. While this material can be transported through the steep upper reaches, it is deposited on the lower floodplain. The lower reach of the river, where the flood risk is greatest, is therefore characterised by changes in course during flood events. This is compounded by the relatively limited capacity of the main channel, and the erodible nature of the material forming the bed and banks.

The deposition of material within the channel, and changes in channel geometry, can both affect the capacity of the channel to contain flood flows; and as a result 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 capacity is maintained in accordance with the Flood Management Plan (Environment Waikato, 2005), any adverse effects of sedimentation in the channel should be minimised.

4.2 Lake level

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

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

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

4.3 Tectonic deformation

The risk of flooding and inundation within the Tauranga Taupo 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 depth of inundation.

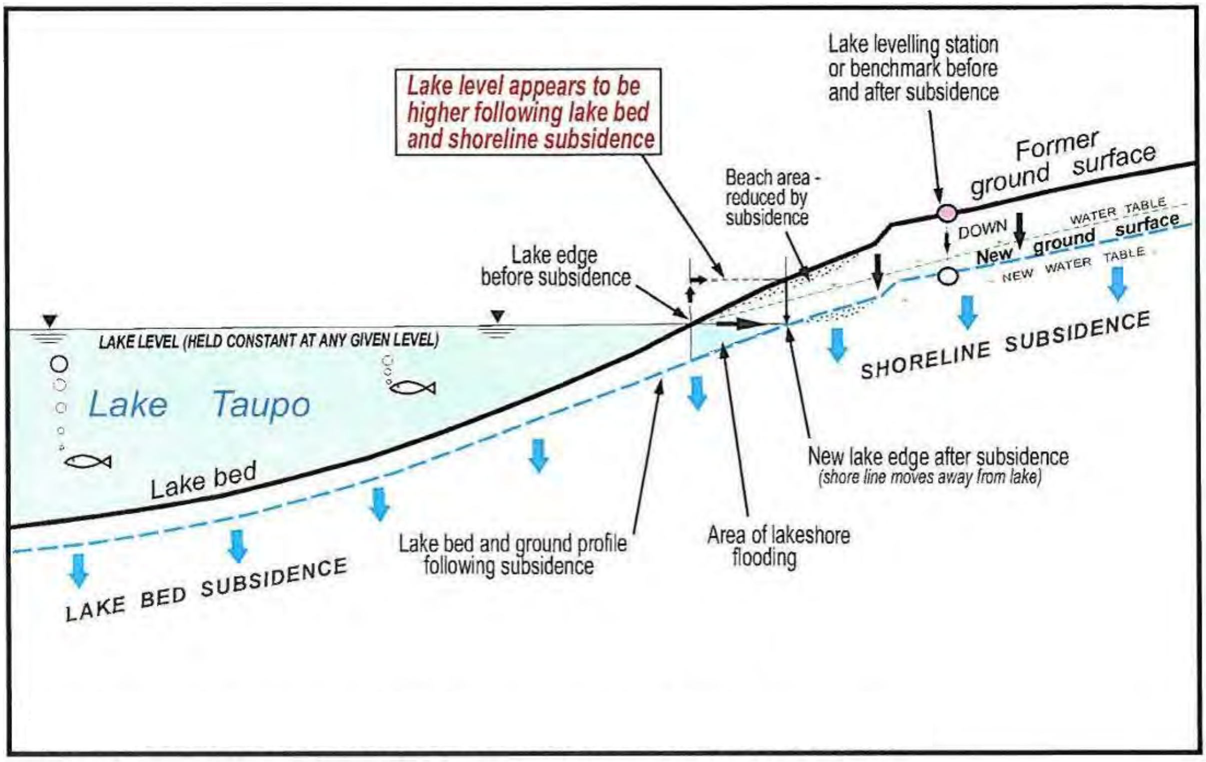

Figure 4.1: Effect of ground level subsidence on relative lake levels (Hancox, 2002).

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

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

Table 4.2 lists the deformation rates for particular locations around Lake Taupo. The total amount of movement over particular time periods is also shown. These data were then 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

From Figure 4.2 it can be seen that the land in the vicinity of the Tauranga Taupo River is subsiding at a rate of 1-2mm/yr. Over a 100 year period therefore the river bed is likely to subside 100-200mm. The effect of this on the flood risk is that lake levels will be relatively higher. This, in combination with reduced channel slopes, will likely increase the extent, duration, and depth of flooding caused by large storm events.

Of particular note, and an area of potential future investigation, is the apparent difference in subsidence rates over the lower reaches of the river. The more inland areas appear to be subsiding faster than land near the river mouth. If this is occurring, it could potentially increase the extent of flooding over the longer term. It is considered more likely, however, that ongoing erosion and sedimentation processes within the lower Tauranga Taupo River will offset any effects of differential subsidence.

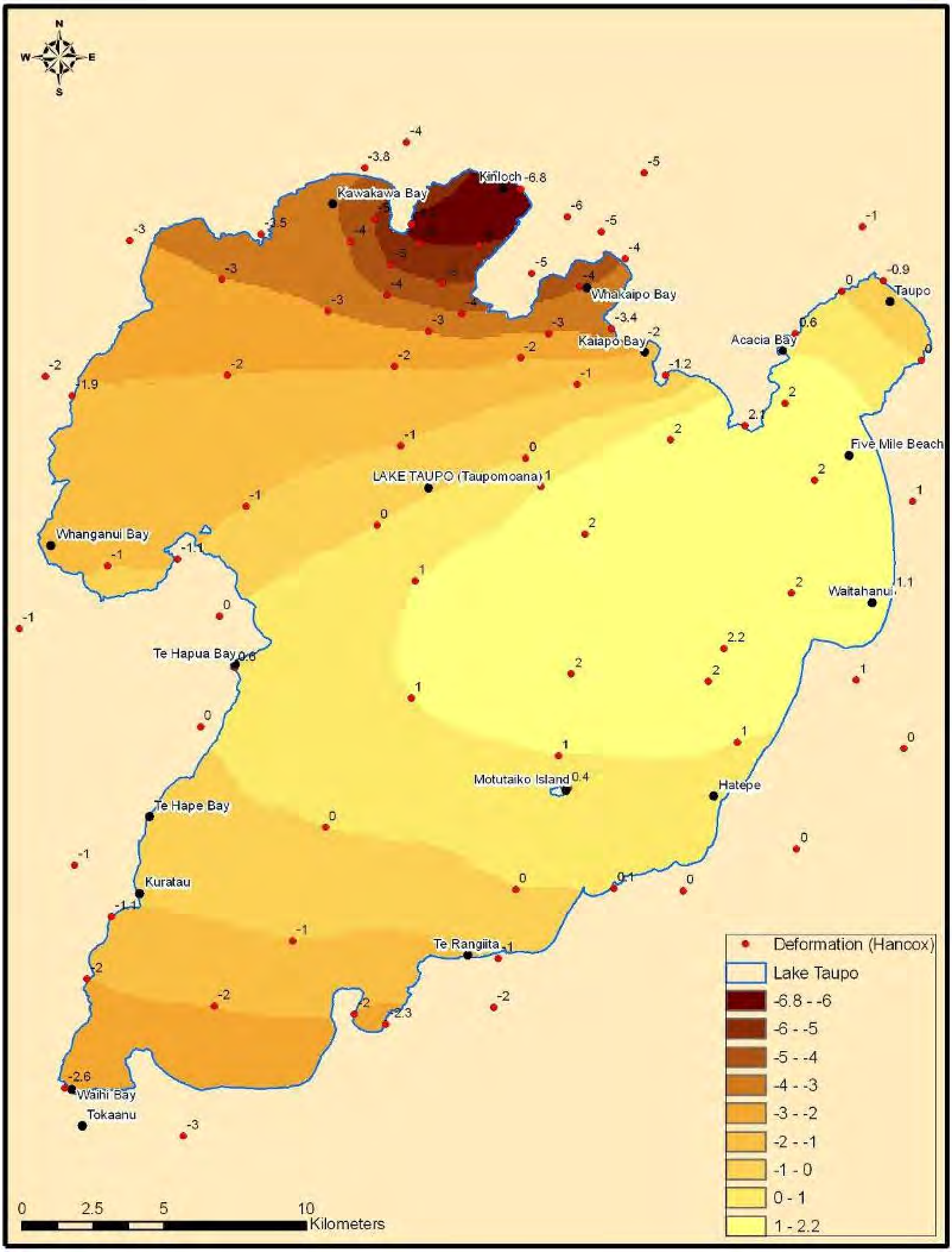

Figure 4.2: **Average rates (mm/yr) of tectonic deformation between 1979 and 2002 (After Hancox, 2002).**

4.4 Waves

Although waves do not affect the river level and flooding directly, they can increase the effects of high lake levels; and consequently worsen inundation. A full discussion of the wave environment and its likely effects in the vicinity of the Tauranga Taupo River is contained in McConchie *et al.,* (2008). The Tauranga Taupo discharges into the Te Rangiita wave environment (Figure 4.3).

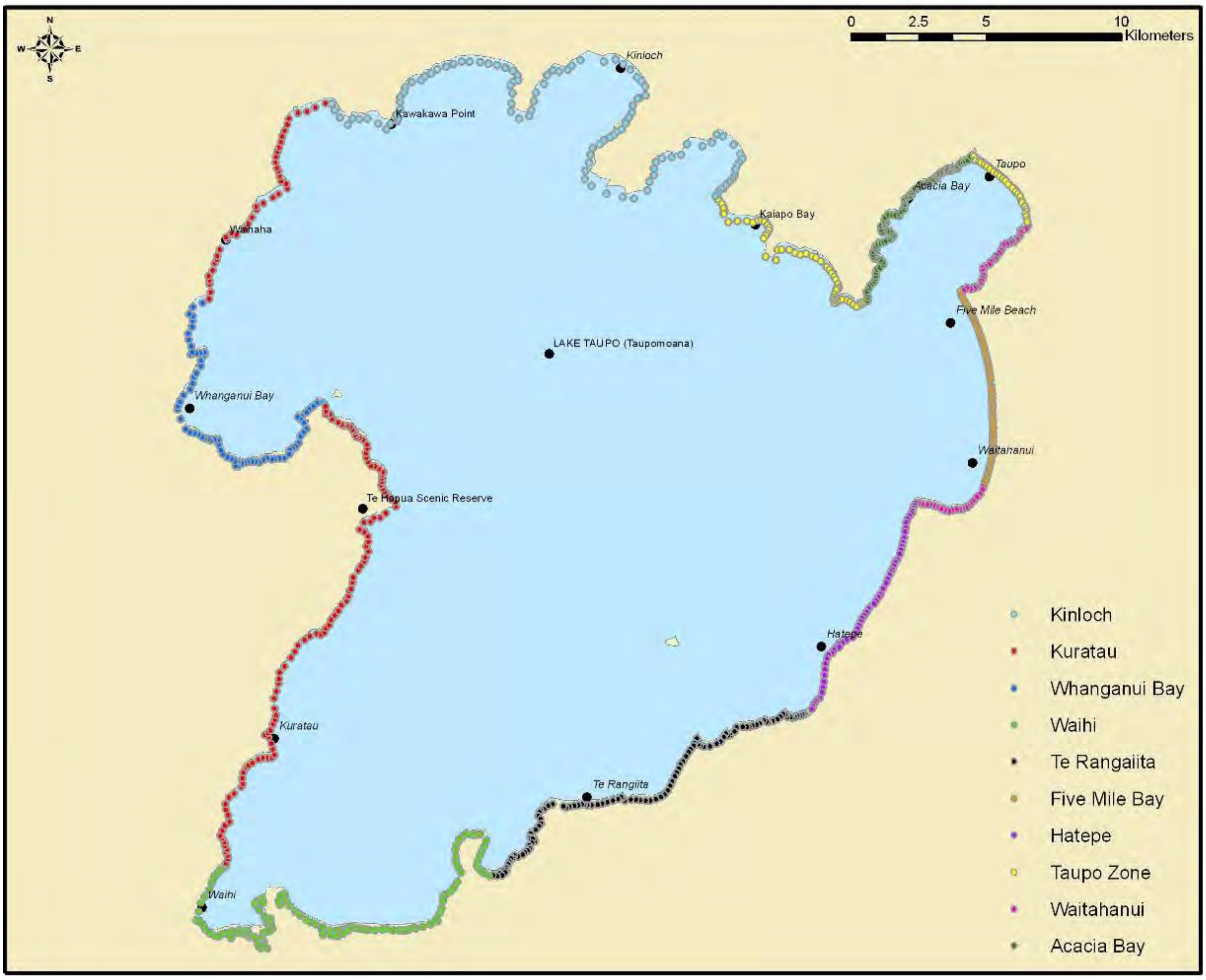

Figure 4.3: Wave run-up environments around the shore of Lake Taupo.

A frequency analysis of the wave run-up data at Te Rangiita shows that a PE3 distribution fits the data well providing good estimates of the magnitude of wave run-up events for particular return periods (Table 4.3). 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 and there is a dramatic reduction in frequency for a relative small increase in wave run-up.

Table 4.3: Estimated 2% exceedance wave run-up height (m) at Te Rangiita.

	Te Rangiita
Best-fit distribution	*PE3*
Return Period	
2.33	0.85
5	0.98
10	1.09
20	1.19
50	1.32
100	1.42
200	1.52
500	1.65

4.5 Summary of lake effects

The various factors that affect lake level were analysed in McConchie *et al.,* (2008) and two hazard zones were defined. The first (Flood Hazard Zone 1) is the maximum static water level, relative to the current land surface, that is likely to be experienced over the next hundred years. It is defined by the maximum 100-year lake level combined with the effects of climate change, seiche, and any tectonic deformation. The second (Flood Hazard Zone 2) is a buffer zone, higher than the first, where the effect of wave run-up might be significant. These two zones are shown on Figure 4.4.

It is apparent that much of the floodplain below the State Highway is likely to be affected by flooding as a result of a combination of high lake levels and ongoing subsidence. Because this region of the lake shore is also prone to relatively high waves, Flood Hazard Zone 2 extends a considerable distance inland. It should be noted, however, that this buffer zone to accommodate the effect of waves is solely based on elevation. As a result, if there are any barriers to the inland movement of waves, areas behind these are not likely to be affected even though they are below the run-up elevation. Therefore, although the area inland of the State Highway is shown to be potentially affected by waves this is unlikely. The foundation of the highway, and the highway itself, will prevent any waves moving inland. The majority of the remaining area affected could best be termed ‘recent beach’, or it is aligned along the current river channel and flood-ways.

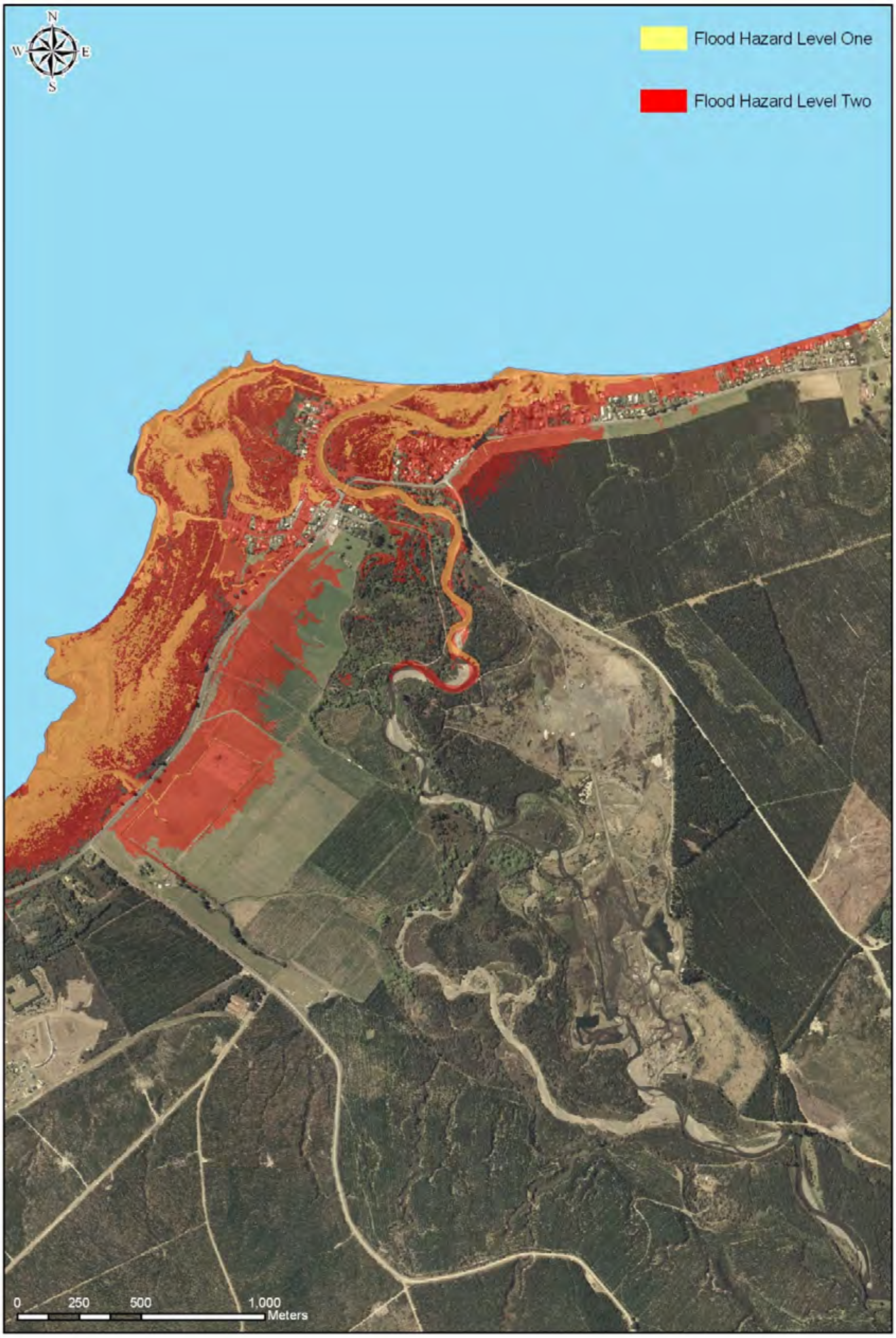

Figure 4.4: **Lake flood hazard zones from McConchie *et al.,* (2008).** ***Note: The colours are slightly different from the legend because they are transparent so that the image underneath can be seen.***

5 Flood risk for the Tauranga Taupo River

The flood risk in the vicinity of the Tauranga Taupo River is a combination of both lake-induced flooding, and overbank flows from the river. Although these two situations may not coincide, the total area potentially affected by flooding needs to be considered in any planning and management framework. The area likely to be affected by either: high lake levels and waves; or the 100-year flood in the Tauranga Taupo River predicted from the instrumental record and assuming a lake level of 357.5m; is shown in Figure 5.1.

There is a high degree of consistency between the areas likely to be affected by flooding caused by either elevated lake or high river levels. This is partly a result of both the flood risks being controlled largely by ground elevation; however, it also provides confidence in the findings.

There is also close agreement between the area likely to be affected under the various flood models, and the distribution of floodplain soils shown in Figure 2.3. This provides independent validation of the above flood risk assessment.

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, the MIKE FLOOD model for the Tauranga Taupo River was run using two additional sets of assumptions (Basheer, 2008). The first was to increase the peak flood discharge to account for the predicted increase in storm rainfall caused by global warming. The second was to raise the lake level during the flood event from 357.0m to 357.5m (Figure 5.2).

It is apparent that the inclusion of climate change, and its effect on flood peaks, results in 61ha of additional land being at risk from flooding. The use of the higher lake level (357.5 as against 357.0m) increases the area at risk by a further 11ha (Figure 5.2).

The conservative approach to mapping the flood risk involves combining the effects of the lake-related risk; with the risk from river flooding where the flood peaks incorporate the potential effects of climate change and a higher lake level of 357.5m (Figure 5.3).

The area at risk from flooding under this ‘worst case’ scenario is very similar to that using the 100-year flood event predicted from the existing instrumental record and a lower lake level. The major differences are an apparent ‘infilling’ of the flooded area between the boundary of the flood zone and the river channel; and increased flows across the Kiko Spillway.

The MIKE FLOOD model (assuming the ‘worst case’ scenario), in combination with the high resolution LiDAR-derived digital terrain model, allows the depth of inundation across the floodplain to be assessed (Figure 5.4). Figure 5.4 only shows river-derived flooding and not that as a result of higher lake level. The majority of the area flooded has water less than half a metre deep. Areas which are affected by greater depths of water, up to 4m in isolated places, are within the quarry and along river courses. A considerable depth of ponding also occurs upstream of the State Highway and the Kiko Farm Stop bank.

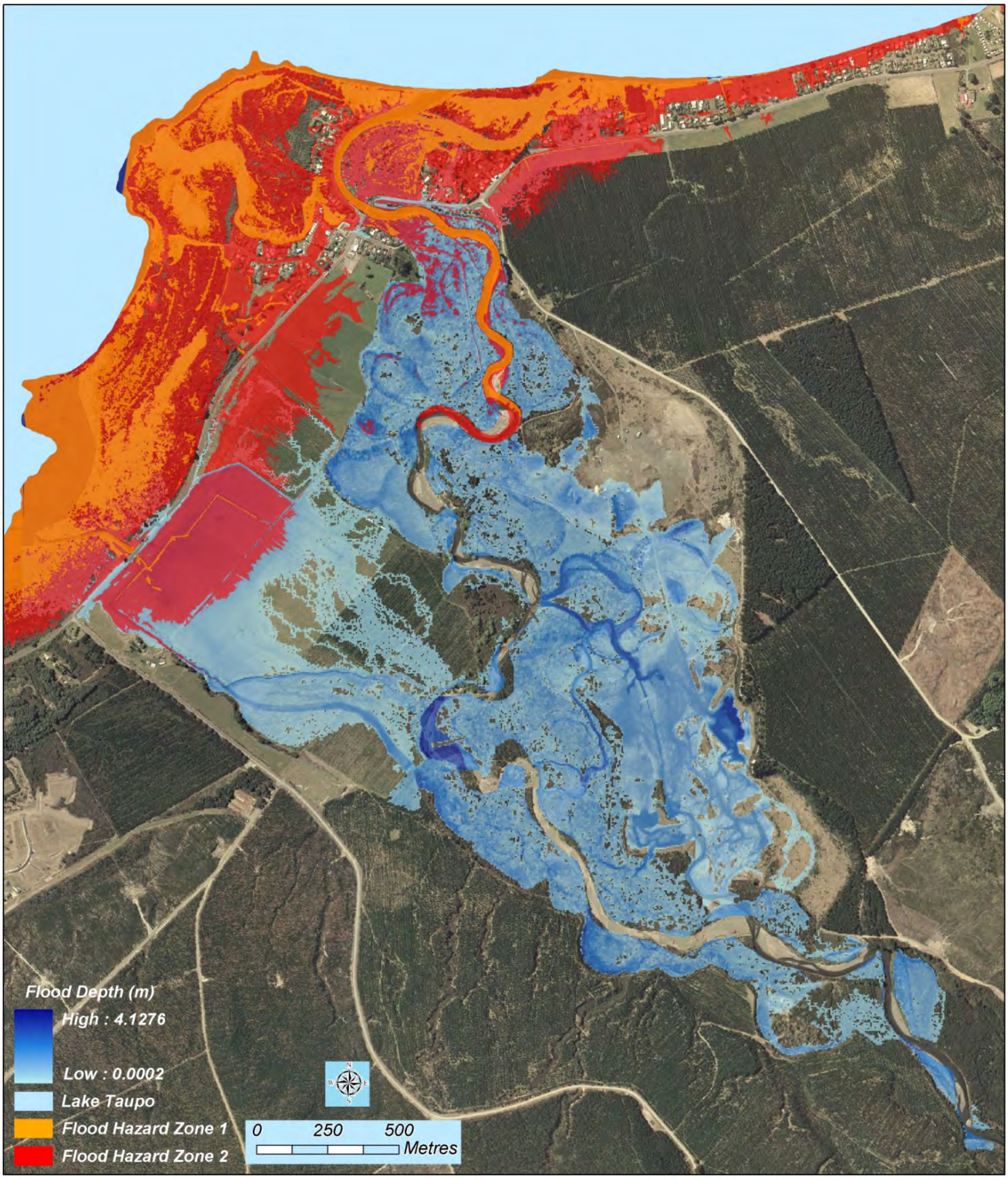

Figure 5.1: **Combined lake and river flood hazard zones; assuming the 100-year flood estimated from the existing instrumental record and a lake level of 357.5m.** ***Note: The colours are slightly different from the legend because they are transparent so that the image underneath can be seen. The Flood Hazard Zones are those defined in section 4.5.***

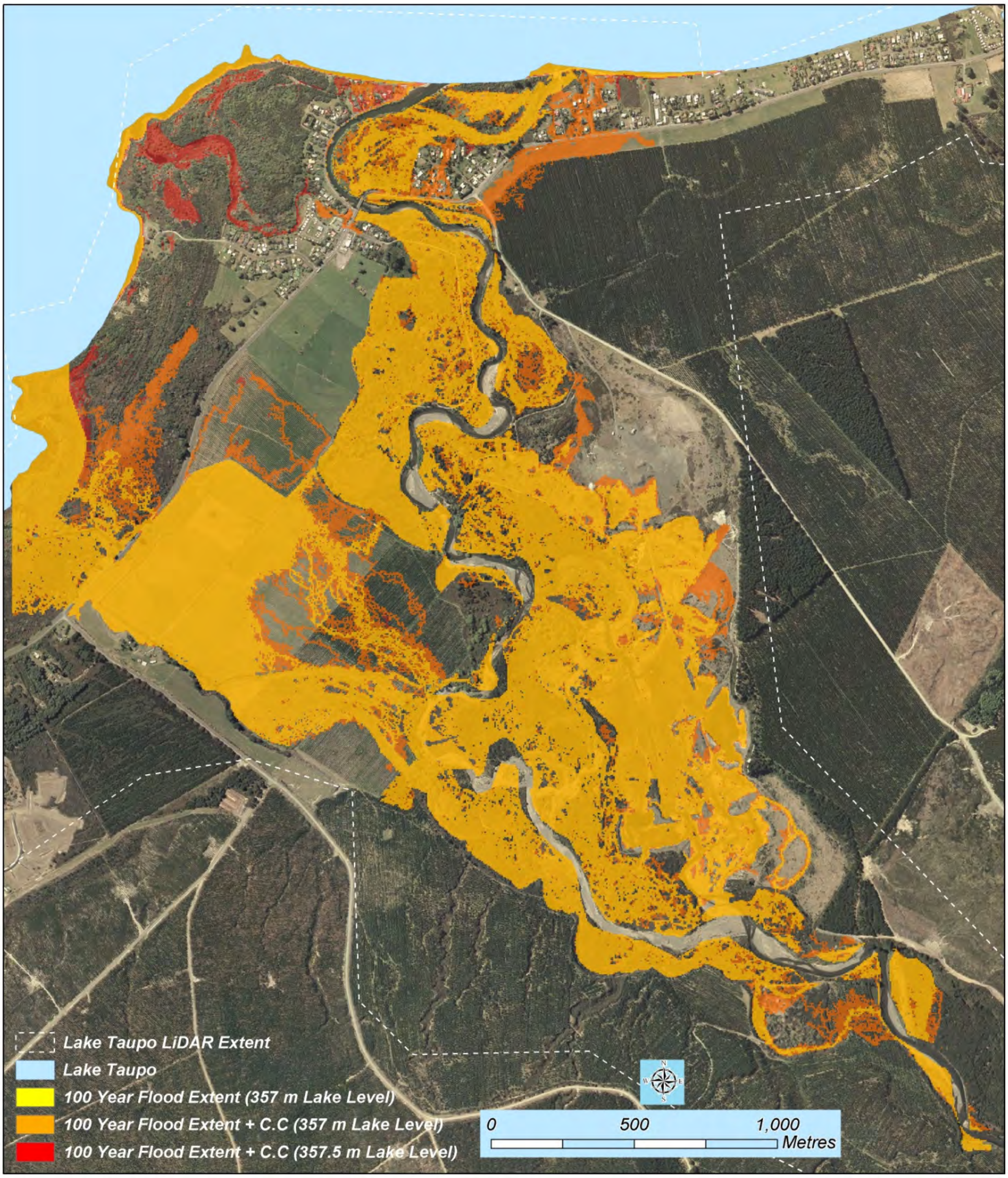

Figure 5.2: The effect of different assumptions on the extent of flooding of the Tauranga Taupo River. The effect of predicted climate change has only been added to the river flows. In general, any effect of climate change on inflows to Lake Taupo will be controlled by lake level management.

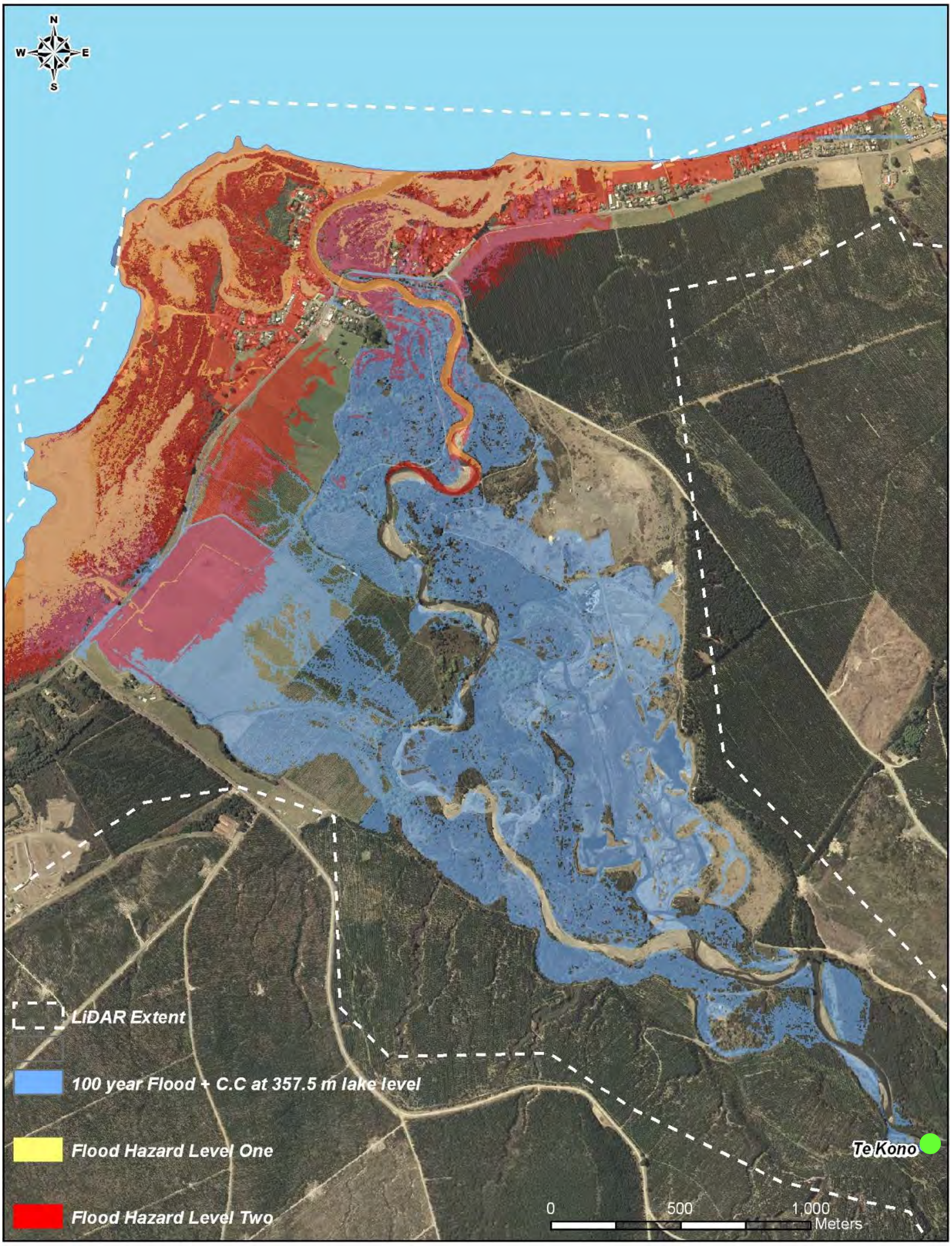

Figure 5.3: Combined lake and river flood hazard zones; assuming the 'worst case' river flooding scenario, i.e. 100-year flow + climate change and a lake level of 357.5m. The effect of predicted climate change has only been added to the river flows. ***Note: The colours are slightly different from the legend because they are transparent so that the image underneath can be seen. The Flood Hazard Zones are those defined in section 4.5.***

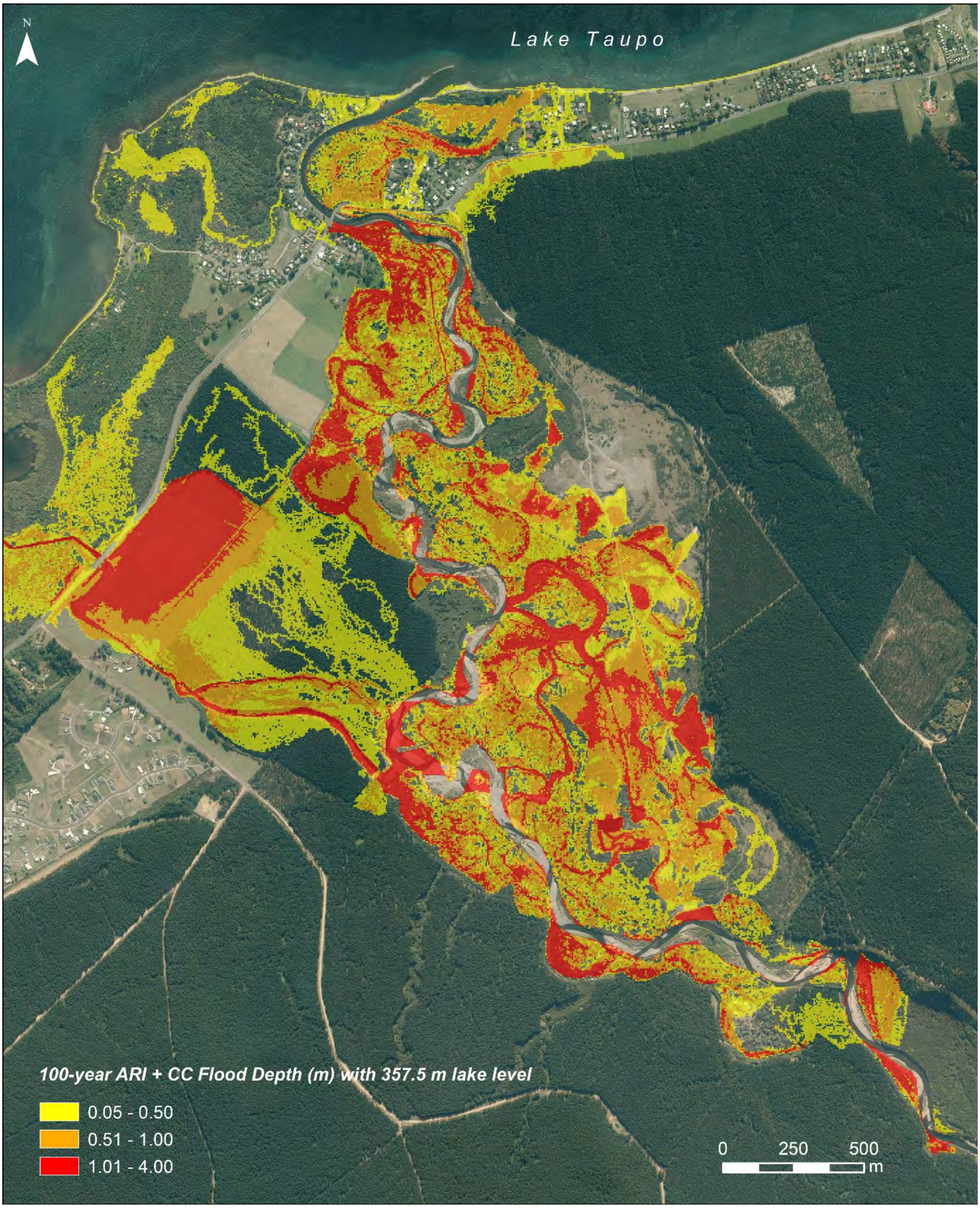

Figure 5.4: Depth of inundation caused by flooding of the Tauranga Taupo River; assuming the 'worst case' scenario modelled i.e., peak flood flows increased to allow for predicted climate change, and a lake level of 357.5m. This figure shows only river-derived flooding. It does not show flooding as a result of higher lake levels.

6 River flood hazard classification

6.1 Introduction

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

6.2 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 6.1 (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 6.1).

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

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

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

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

Table 6.1: 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.	

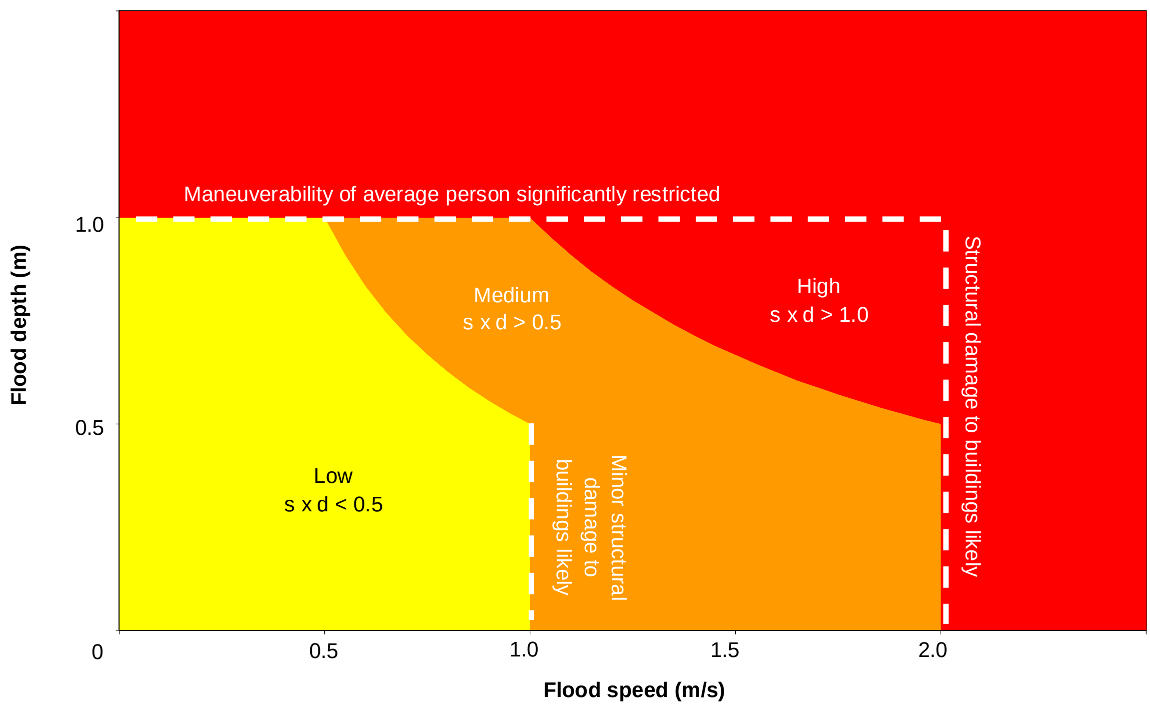

Figure 6.1: River flood hazard classification matrix (Environment Waikato, 2008b).

6.3 Flood hazard assessment

The analysis of flood water levels discussed previously highlighted the fact that the extent and depth of flooding of the Tauranga Taupo River are relatively insensitive to the level of Lake Taupo. Therefore the flood hazard posed by the Tauranga Taupo River during the 100-year event was assessed assuming a lake level of 357m, but with river flows increased to allow for the potential effects of climate change. The magnitude of these effects was discussed previously.

The water depth during this scenario is shown in Figure 6.2, and the flow velocity is shown in Figure 6.3.

Multiplying these two risks (i.e., that from the depth of water and that from the flow velocity) together provides the combined measure of the flood hazard (Figure 6.4). Within the flood zone evaluated using this classification system the hazard may be low, medium, or high. It is important to recognise that, although flood the hazard classification may be low, this does not mean that the area will not flood. It simply means that the depth of inundation and flow velocities during a flood, when combined, present only a low risk to life and property.

It is apparent that while a significant proportion of the Tauranga Taupo floodplain is prone to flooding, the risk to life and property is generally low. This is because of the relatively shallow overbank flows, and their low velocity. Once the flood waters break out of the channel of the Tauranga Taupo River they can spread out over the extensive low lying flood plain. Consequently, even a large volume of water can be accommodated by inundation to a relatively shallow depth. Likewise, once any flood water leaves the channel, the depth of flow is generally shallow and so friction slows the velocity dramatically.

Therefore, although a large area of the Tauranga Taupo floodplain 'gets wet' during the 100-year event, the hazard created by this flooding is generally low. While the cost of flooding and inconvenience may still be high, the actual risks to life and property are not great.

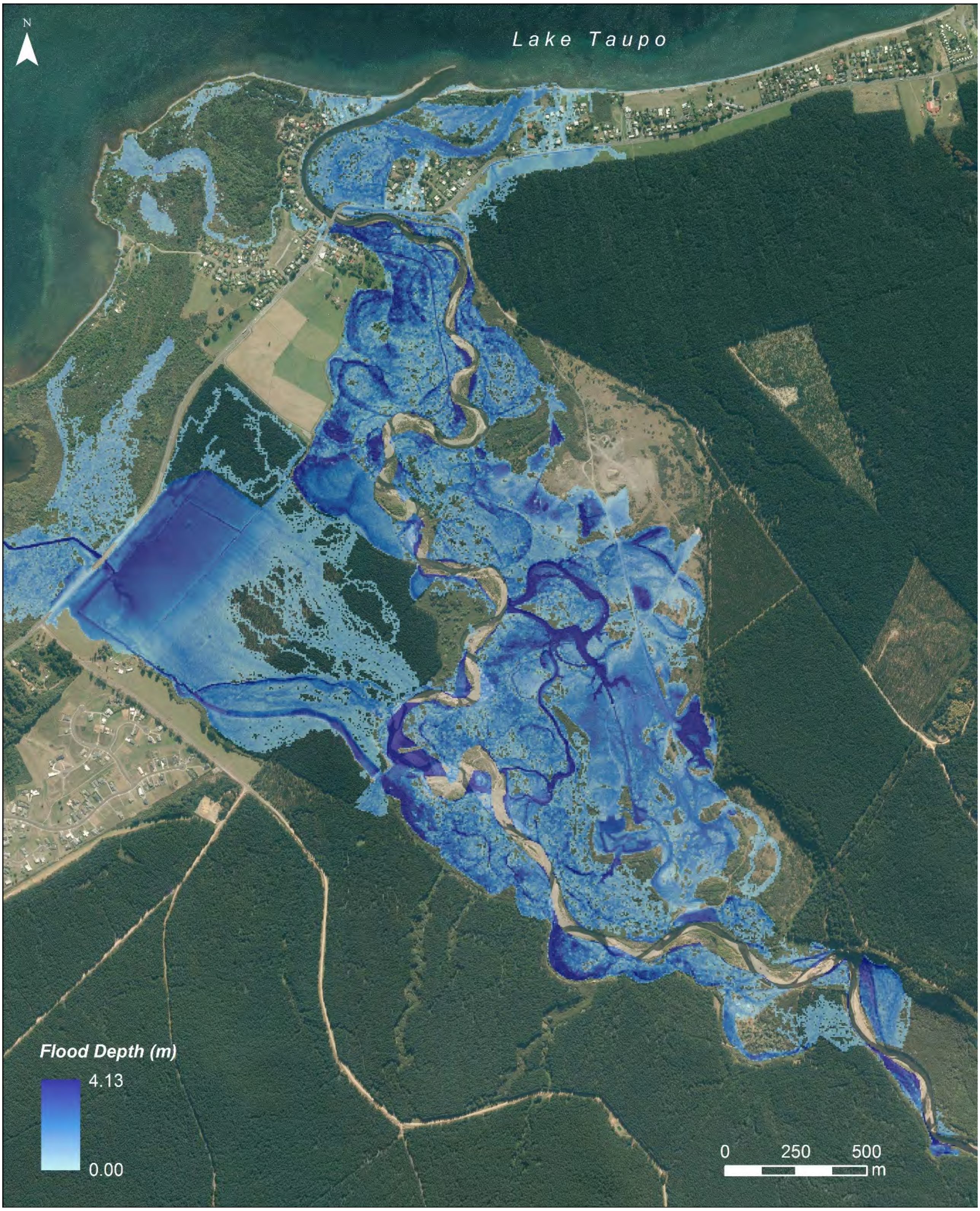

Figure 6.2: Water depth during the 100-year flood event in the Tauranga Taupo River allowing for the effects of climate change on runoff from the catchment. Lake level assumed to be at 357.5m.

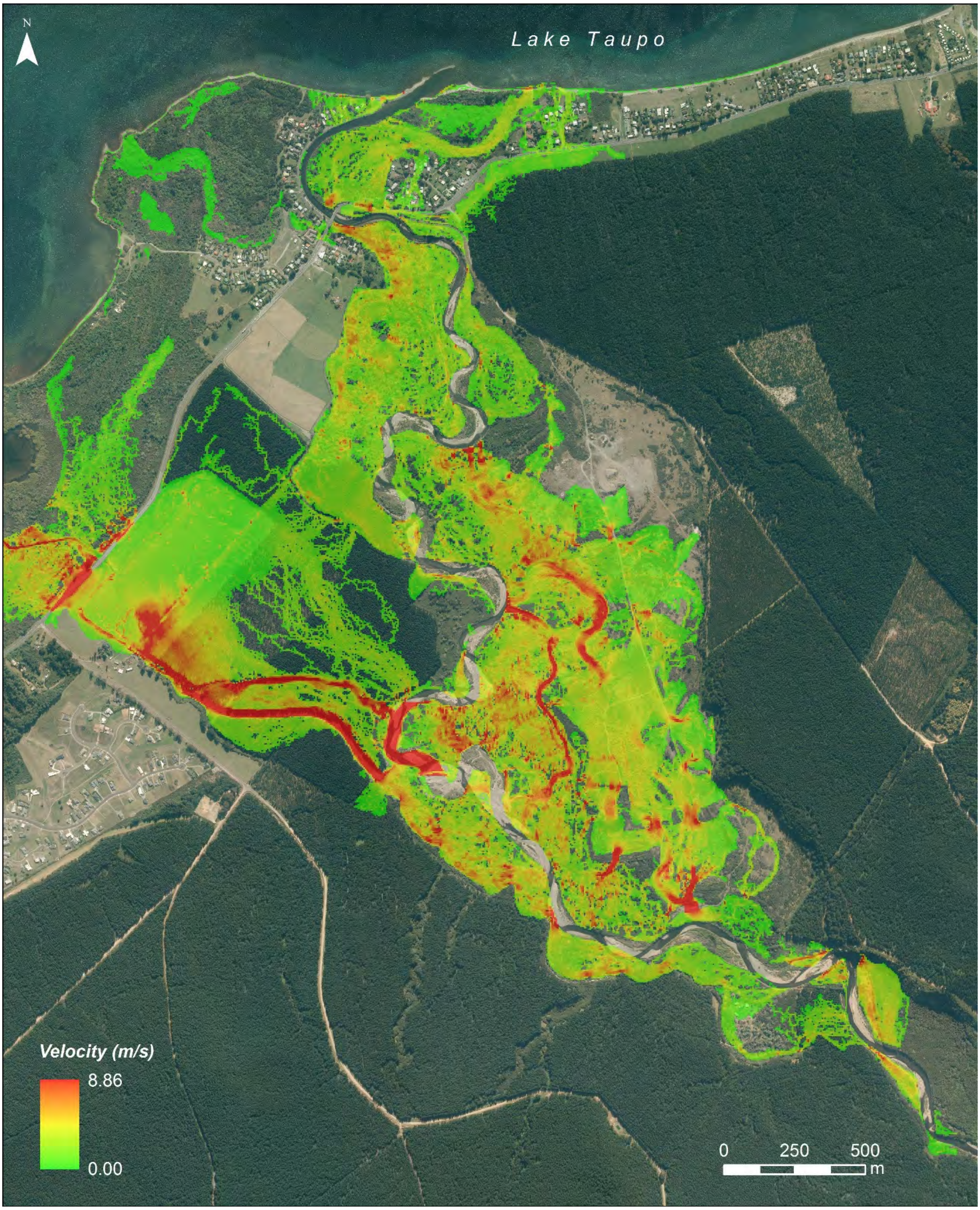

Figure 6.3: Water velocity during the 100-year flood event in the Tauranga Taupo River allowing for the effects of climate change on runoff from the catchment. Lake level assumed to be at 357.5m.
Note: Only 3 cells have velocities >5m/s. The majority of cells have velocities from 1-3m/s which are realistic. The highest velocities are over the Kiko Spillway designed to accommodate these speeds.

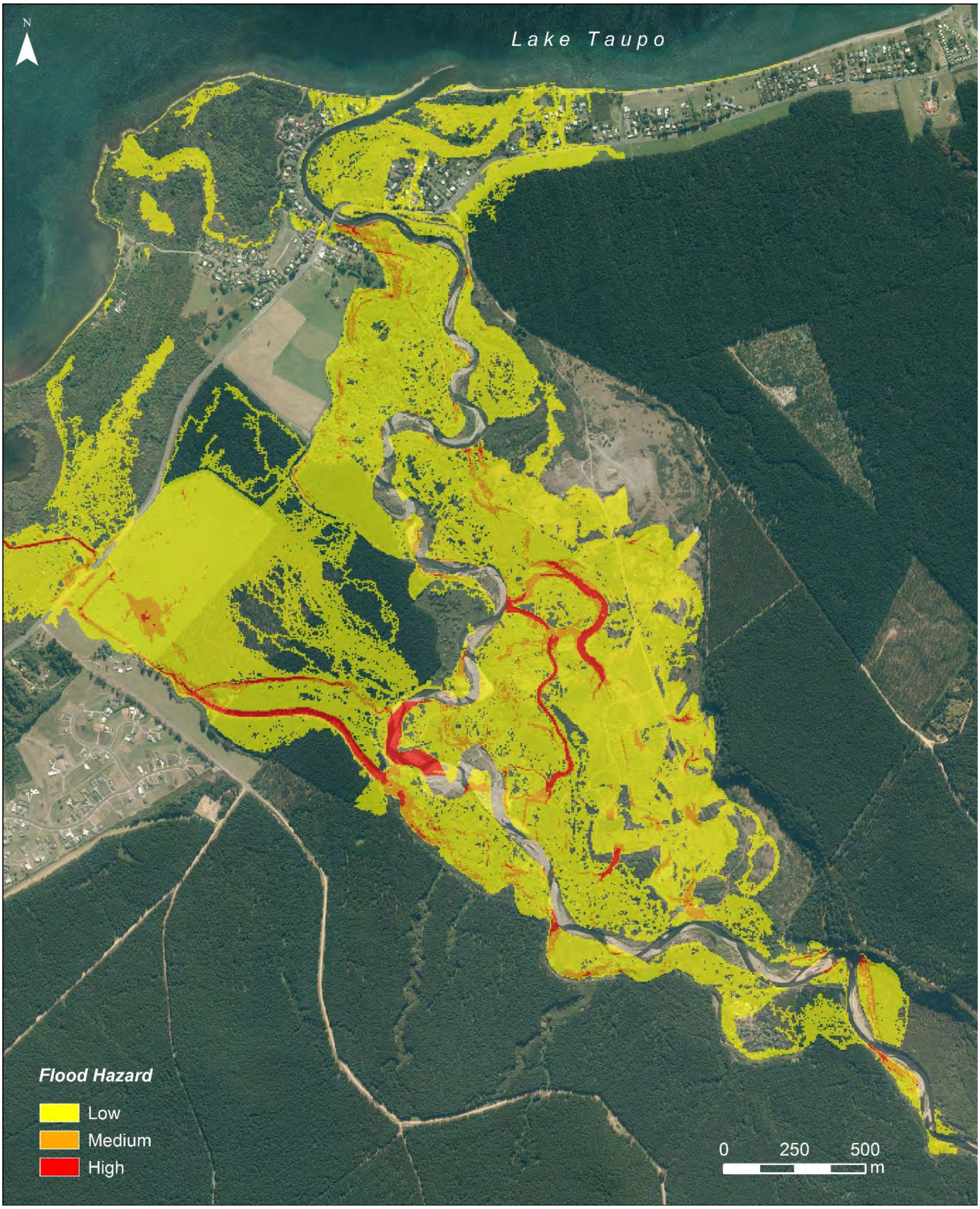

Figure 6.4: **Flood hazard classification during the 100-year flood event in the Tauranga Taupo River allowing for the effects of climate change on runoff from the catchment. Lake level assumed to be at 357.5m.**

7 Conclusion

Flooding in the Tauranga Taupo 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.

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

7.1 The river flood hazard

The Tauranga Taupo River has a highly variable flow regime characterised by long periods of quiescence, low flow, interspersed with short duration high energy flood events. The largest flood since 1977 was 296m^3/s in 2001. Analysis of the largest floods recorded over the past 33 years indicates that a flood of 336m^3/s or greater might be expected every 100 years. Based on the latest estimates of the potential effects of climate change on the rainfall regime, the magnitude of the 100-year flood might increase to 401m^3/s by the 2040s.

Modelling of an extreme event of this magnitude (i.e., 401m^3/s) shows that the flood will still be contained upon the floodplain, and that flow will be largely constrained by the existing flood control structures. The fastest (2-4m/s) and deepest (up to 4m) flood waters will be within the existing active channel, in some of the older abandoned river channels, and across the Kiko Spillway to bypass the lower river. The majority of the area flooded would be subject to relatively low velocities and shallow inundation.

When both the depth and velocity of flood water are considered together, the majority of the area is subject to a relatively low flood hazard. Although a large area of the flood plain is inundated, the risks to life and property are generally low. The highest flood hazard is limited to the currently active river channel, some of the old abandoned channels, and the Kiko Floodway.

7.2 The combined flood hazard

The total flood hazard in the vicinity of the Tauranga Taupo 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 large 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 Tauranga Taupo 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 between the current flood limit and the river channel, and some additional flow across the Kiko Spillway to the Kiko Floodway.

7.3 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.

7.4 Uncertainty

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

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

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

Given the preliminary and 'screening' nature of this flood study, and constraints regarding precise calibration, it is considered that conservative flood estimates, and consequently flood extents, velocities and depth, are reasonable. For example, it will be easier to 'retract' or 'reduce' flood hazard areas as more information becomes available than to try to 'expand' them once development has taken place.

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

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9 Glossary

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

Inundate – to cover usually dry land with flood waters.

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

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

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

Risk – The possibility of suffering harm or hurt.

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

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

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