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TO	Sue Mavor & Nick Carroll, Taupō District Council
FROM	Jack McConchie
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SUBJECT	Wave run-up

Background

The risk of flooding, and potential depth of any inundation, to land adjacent to Lake Taupō are primarily controlled by the water level in the lake relative to the elevation of the adjacent land surface. The water level changes daily, seasonally and annually and has the potential to be affected by predicted climate change. In addition, the elevation of the land relative to the lake can change as a result of tectonic deformation.

As discussed in detail in Ward *et al.* (2014), the various controls on water level have been assessed and the hazard posed by the 1% AEP (i.e. the so called 100-year event) design flood level quantified.

The flood hazard posed to properties on the shoreline of Lake Taupō, however, can be compounded by the effect of wind-generated waves. As a wave breaks at the shore, swash from the wave runs up the beach increasing the area at threat to flooding beyond the ‘static’ water level of the lake. Therefore, although waves do not affect the ‘static’ water level they can increase the effects of high lake levels, and consequently worsen inundation, through wave run-up and erosion.

Run-up modelling

Modelling waves, and more specifically wave run-up, around the shoreline of Lake Taupō is considerably more complex and problematic than modelling water levels. This is because of the variability in controls on both wave generation (e.g. wind speed, wind direction, fetch and offshore bathymetry) and wave run-up (e.g. beach slope, character, material, permeability, vegetation, and any beach protection etc.).

The prevailing winds across Lake Taupō are from the west and south-west, although strong winds from the NE can occasionally affect the western shore. Strong winds are caused by either: major storms moving in from the south-west that tend to last several days; or, northerly winds associated with tropical depressions. Assuming that fetch is the limiting factor in wave formation, areas most vulnerable to wave run-up are on the northern and eastern shores of Lake Taupō. The southern end of the lake is generally sheltered from the dominant wind direction, as are enclosed areas such as Acacia Bay.

Hicks *et al.* (2002) and Hicks (2006) modelled wave run-up for the entire lake shore using the wind record from Taupō Airport. Qualitative assessments of the accuracy of the results have been undertaken by Hicks *et al.* (2000) and McConchie (2015) using an analysis of the wave regimes shown in oblique photographs and the effect of large waves combined with high water levels on the shoreline at various locations. It has been concluded that the results from the modelling are acceptable at a broad scale, although more limited in small embayments where wave conditions are affected by refractions and diffraction. The accuracy of the results is also constrained by the limited availability of wind data (i.e. the only long-term wind record is from Taupō Airport), detailed beach characterisation, and high resolution offshore bathymetry.

Wave run-up was estimated at 937 locations around Lake Taupō (Figure 1 below; Figure 10.4 from Ward *et al.* (2014)). The model used a standard beach slope of 7 degrees and a sediment size of 2mm. As a result, this output is more indicative of potential rather than actual wave run-up but still indicates variability of wave run-up around Lake Taupō. Greatest wave run-up is apparent around the NE shore of the lake, particularly along Taupō Foreshore and south along Five Mile Beach as far as Waitahanui. Acacia Bay is particularly sheltered and as a result the wave run-up is very low. These results are consistent with experience during the 1998 flood event which resulted in significant erosion of the beaches on the eastern shore.

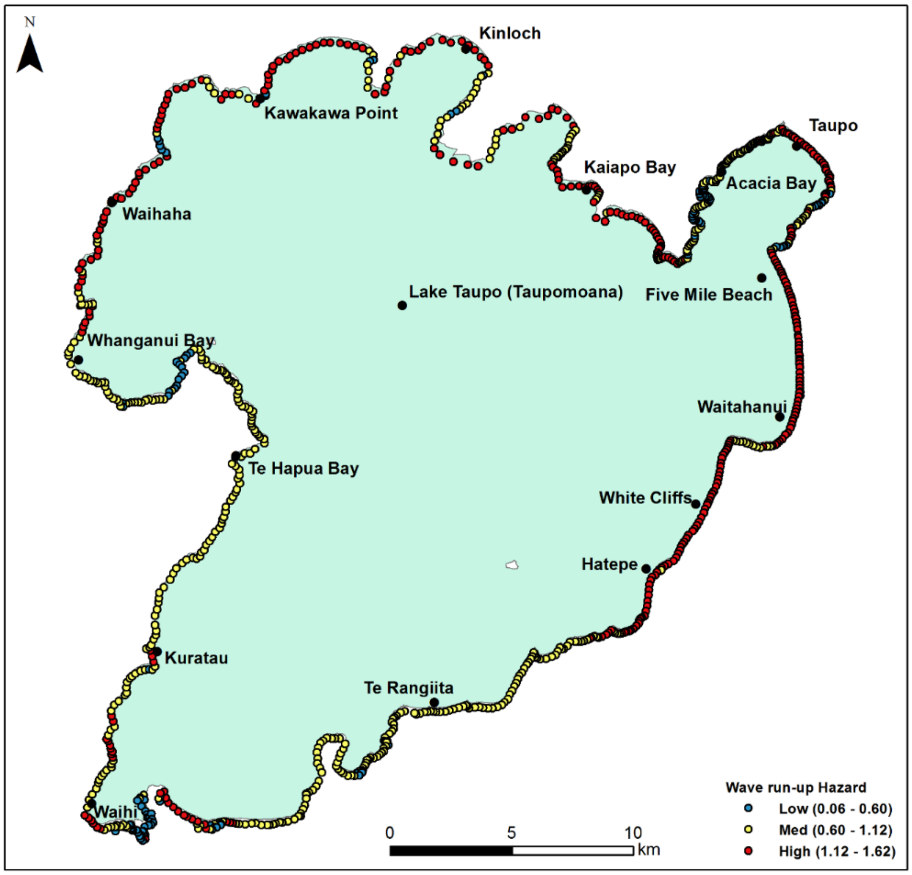

Figure 1: Wave run-up hazard around the shoreline of Lake Taupō.

Ward *et al.* (2014) provide detailed analysis of wave run-up behaviour using zone-specific values of beach slope, sediment size and density, porosity etc. within 10 zones around Lake Taupō where similar wave run-up behaviour might be expected (Figure 1). For example, the wave environment of the Taupō Foreshore is likely to be similar to that at Kaiapo Bay, but distinctly different to that of Acacia Bay. Likewise, the wave run-up environment at Kuratau is similar to that at Waihaha but distinctly different to Whanganui Bay.

This in-depth analysis provided further information regarding the potential for wave run-up and discrimination between various zones (Figure 2). These data are also consistent with those from the July 1998 flood (Table 1).

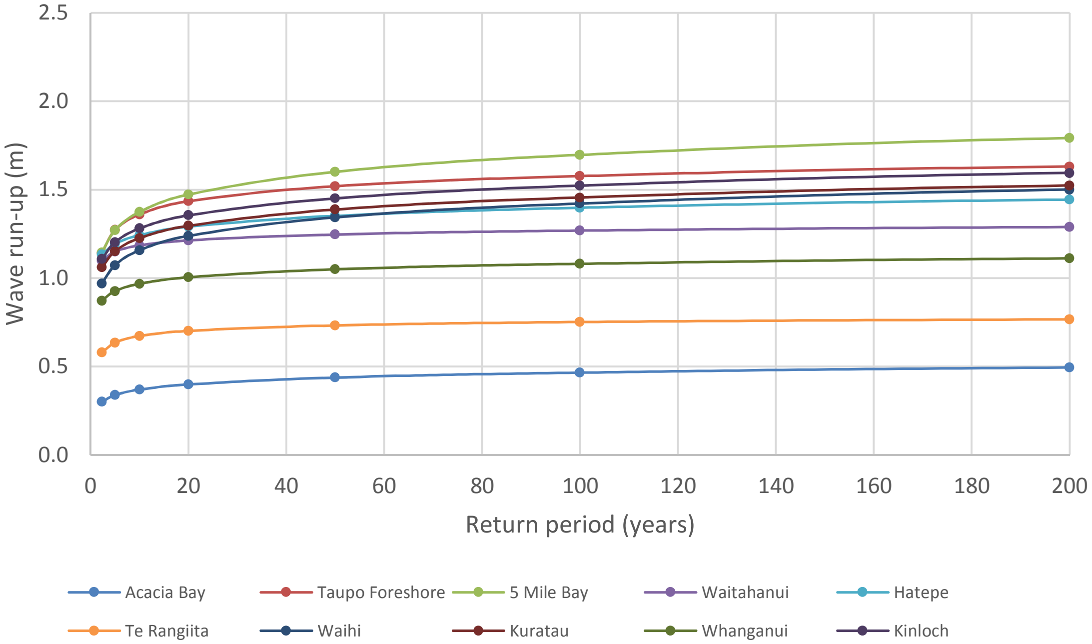

Figure 2: Wave run-up for the different environments at different return periods.

Table 1: Effective water levels (i.e. water level plus wave run-up) during the July 1998 flood.

	Lake Level	Taupō Foreshore	5 Mile Bay	Waitahanui	Hatepe	Te Rangiita
Estimated maximum	*357.49*	*358.51*	*357.92*	*357.80*	*358.27*	*357.71*
Date of maximum	*17 July 1998*	*15 July 1998*	*15 Jul 1998*	*15 July 1998*	*15 July 1998*	*18 July 1998*

	Lake Level	Waihi	Kuratau	Whanganui Bay	Kinloch	Acacia Bay
Estimated maximum	*357.49*	*358.00*	*358.06*	*358.00*	*358.45*	*357.55*
Date of maximum	*17 July 1998*	*9 July 1998*	*9 July 1998*	*26 July 1998*	*15 July 1998*	*18 July 1998*

Uncertainty

The constraints of data availability and the modelling, however, mean that analysis at the scale of individual properties is not possible. In fact, even considerable investment in field characterisation and modelling may not allow robust estimates of potential wave run-up at any specific property.

Defining the hazard from wave run-up with reference to a specific design event is also problematic. This is because the magnitude of the hazard within a zone subject to a 1% AEP wave run-up event is highly variable i.e. the entire zone and all properties are not subject to the same level of risk. For example, properties closest to the shore of Lake Taupō have a greater likelihood of being affected by wave run-up than those properties further back. Also, since the wave run-up hazard is defined solely as a function of elevation, and does not take into account buildings and other infrastructure, properties behind existing structures are actually 'protected', thereby mitigating the assessed wave run-up hazard. The definition of wave run-up zones on the basis of elevation will also include areas which are not 'connected' to Lake Taupō. Consequently there will be non-contiguous wave run-up zones. These can be removed, as they were with respect to flooding caused by the high water levels, but this would be more subjective since wave run-up is unlikely to migrate inland via a pipe or drainage network.

Therefore there is considerable variability within the wave run-up environments or a design wave run-up hazard zone. This means that, unlike the static water level of Lake Taupō, a single value or zone cannot be used to define the wave run-up hazard with a high level of confidence. The complexity of wave run-up, and constraints of this project, mean that individual site analysis is impractical.

Risk

Throughout the Taupō District flood study the 'design event' has been assumed to be the 100-year ARI or 1% AEP flood. The magnitude of this event has then been adjusted for the effects of climate change, tectonic deformation etc.

However, the 1% AEP flood is a statistically-defined event. Such an event is therefore associated with a degree of uncertainty. For example, it is possible for multiple 1% AEP events to occur within a single year, although this is extremely unlikely, or to not occur at all within a 100-year period.

The binomial risk formula can be used to estimate the risk or probability that a flood with a specified annual exceedance probability (i.e. AEP) will be equalled or exceeded during a specified interval, such as the next 100 years. The risk r of an event with a particular AEP being exceeded at least once in the next L years is:

$$r = 1 - (1 - AEP)^L$$

For example, a 10% AEP (or 10-year ARI) event has a 41% chance of occuring within a 5-year period, an 88% chance within 20-years, a 99% chance within 50-years but a 100% chance only after 100-years (Table 2).

The 1% AEP (i.e. 100-year ARI) design event, as used in the Taupō District flood study, has a 5% chance of occuring within a 5-year period, an 18% chance within 20-years, a 39% chance within 50-years and only a 63% chance only after 100-years (Table 2).

Table 2: The likelihood or risk (%) of an event with a particular design frequency occurring within a certain period of time.

Frequency		Period				
ARI	AEP %	5-yrs	10-yrs	20-yrs	50-yrs	100-yrs
5	20	67%	89%	99%	100%	100%
10	*10*	*41%*	*65%*	*88%*	*99%*	*100%*
20	5	23%	40%	64%	92%	99%
50	2	10%	18%	33%	64%	87%
100	*1*	*5%*	*10%*	*18%*	*39%*	*63%*

Confidence

As a result of the above constraints, and the uncertainty inherent in wave run-up modelling, it is impossible to place a precise level of confidence on the risk from wave run-up. There is uncertainty as a result of the modelling, the statistics used to define the design event, and the risk as a function of the duration of the planning period.

Over the 100-year planning timescale adopted in the Taupō District flood study it is highly likely that a 20% AEP design wave run-up will affect the immediate shoreline. As the frequency of the design event decreases, however, the risk to the immediate shoreline increases. For the 1% AEP design event there is only a 63% chance that the 'upper limit' of wave run-up will be reached over a 100-year period, but it is almost certain that a smaller wave run-up (i.e. that from a 20% AEP event) will affect the immediate shoreline.

Obviously any protection, either natural or engineered, will reduce the risk from wave run-up. Also the risk decreases with increasing distance from the shoreline and elevation; however, this uncertainty is impossible to define.

Consequently, while the confidence is higher that smaller design events will affect the shoreline, the actual risk from such events is likely to be small. While the risk is higher for larger, less frequent, design events these are associated with greater uncertainty.

Recommendation

Given the constraints on defining wave run-up to a high level of confidence, at a scale appropriate for assessing the risk to individual properties, it is suggested that the information in Figure 1 (Figure 10.4 from Ward *et al.* (2014)) be used as the guide for all property owners and land development. That is, the potential risk from wave run-up be assessed using a simple 3-tier hazard classification (i.e. Low, Medium, and High). Such an approach would:

- Recognise the potential risk posed by wave run-up, particularly when 'superimposed' on high lake levels;
- Recognise the variability in wave run-up potential around Lake Taupō;
- Recognise the multi-parameter nature of the controls on wave run-up;
- Recognises the impracticality of defining wave run-up to a high level of accuracy at the scale of individual properties; and
- Recognises that although high lake levels and large wave run-up are independent their combination can exacerbate the risk of flooding and erosion.

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