Peer review of Taupō District flood hazard reports

Prepared for Taupō District Council

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Prepared by:
Mr Roddy Henderson
Mr Maurice Duncan
Dr Murray Hicks

For any information regarding this report please contact:

Roddy Henderson
Group Manager
Applied Hydrology
+64-3-343 7873
roddy.henderson@niwa.co.nz

National Institute of Water & Atmospheric Research Ltd
PO Box 8602
Riccarton
Christchurch 8011

Phone +64 3 348 8987

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Reviewed by	Approved for release by
Richard Measures	Charles Pearson

Executive summary

NIWA has been engaged by the Taupō District Council (TDC) to provide technical peer review of seven flood hazard reports prepared for the council by Opus International Consultants Ltd. Three NIWA experts in flood hydrology, flood hydraulic modelling, and lake shore erosion and wave issues carried out the review. Dialogue between TDC, NIWA and Opus staff since the first draft of this review has led to the production of a Technical Compendium by Opus (McConchie, 2015). This revised peer review document includes consideration of matters covered in the technical compendium.

Aspects of the flood hydrology have been well handled, in particular dealing with potential climate change effects in a conservative manner, and making use of all available time series data in each catchment. There are however some areas of concern both across all reports and in each report. These include: only using the flow record in each catchment for estimation of the design events rather than using the currently accepted regional flood methods to gain statistical support from all the data, and not dealing with uncertainty of flood design estimates that is inherent in measurement, statistical sampling and distribution fitting procedures such as are employed here.

We recommend that extrapolation of flood frequency distributions be informed by a regional approach as a precursor to providing new flood peak estimates with uncertainty included to better inform any future design decisions that may be required.

The extent and hazard caused by river flooding has been estimated by using the well accepted MIKE 21 two dimensional model or the MIKE FLOOD modelling system that uses the one dimensional MIKE 11 model for channels coupled with two dimensional modelling for flood plains. The design events are the 100-year return period floods with, and without, the effects of climate change, using the 100-year lake-level, based on historical data, as the downstream boundary. What is not emphasized is that this combination of independent events is much rarer than a 100-year event. In areas near the lake where lake levels have an influence on the extent of river flooding this approach is likely to overestimate flooding from 100-year river floods. The technical compendium (McConchie 2015) notes that there is very little (14 cm) difference between the 1/10 AEP and 1/100 AEP lake levels and so the overestimation will be slight and diminish rapidly with distance from the shore where the river bed slope is steep.

Apart from the Tongariro model the hydraulic models are compromised by inadequate or absent calibration data. As a result the models have had to rely on the model physics, adequate digital terrain modelling and river cross-sections, and the choice of flow resistance factors for their credibility. The digital terrain modelling was based on recent high quality LiDAR coverage and the model cells sizes appeared appropriate. The flow resistance factors used (McConchie 2015) are within the range of commonly accepted values. River cross-sections were based LiDAR observations complemented by surveys for 2 rivers. Thus, apart from having no model calibration and or verification for most of the flood models the floods study results give conservative estimates of inundation and can be relied upon to provide indicative information on flood hazard.

The Tongariro River model was explained in more technical terms in a previous report by Maas and Webby (2008). This model calibrated relatively well and the flow resistance values used were within the range of commonly accepted values. Thus the model results provide realistic data on flooding for general planning.

It is recommended that for the design of structures such as stop banks, information on flood levels and extents for model calibration is required for all the rivers considered here apart from the Tongariro where this data is already available. When the district is subject to a large flood, priority needs to be given to recording (photographing and locating) flood levels and extents for later levelling to provide information for calibrating the existing models.

The predicted flow velocities and depths have been combined to provide flood hazard categories for risk to life and property defined by a Waikato Regional Council report. While the categories are well considered and similar to those derived by others, the low hazard category does not appear to consider the economic and social cost of water depths that are likely to be above building floor levels.

For estimating design flood levels around the shore of Lake Taupō, the authors recognise that water levels are controlled by a number of factors, including inflows, human control on outflows (for HEP generation and flood management down the Waikato River), the characteristics of the lake outlet structure, subsidence and uplift around the lakeshore, seiching, and wave runup. Moreover, they consider that future inflows (and so lake level) have the potential to be influenced by climate change and land use change. The effects of static lake-level variation, tectonic subsidence/uplift, seiche, and climate change are combined linearly, simply adding each component at matching return period to the lake level expected for a given return-period event. The component due to tectonic effects is varied around the shore as indicated by historical ground deformation data. The joint probability of high static lake levels and wave runup events is estimated from analysis of a series of annual maximum values of effective water level, which is the sum of the static water level and hindcast runup records generated along segments of the shore considered to have uniform wave climates.

The approaches used for analysis of extreme static water levels are reasonable, and the compromise in period of record adopted appears justified given the importance of having a lake level regime that is as stationary as possible.

The general approach followed and the concept of using effective water levels to manage the joint probability issue of wave runup and lake level is also reasonable. We have suggested it would have been timely to upgrade to a more modern wave hindcast model and to undertake a more spatially detailed analysis of wave runup around segments of built-up shore, notably the eastern shore of Taupō Bay, which contains substantial variability in shore-type, protective structures, and expensive assets. However, we understand from McConchie (2015) that use of a more modern and technical wave model was constrained by the project scale and scope. We agree that the use of the Taupō Airport wind data for hindcasting waves around the southern shore of the lake will overestimate the effective lake levels along this shore. Field evidence (such as erosion trim-lines, vegetation edges, and crests of beach ridges) has been used by McConchie (2015) to reasonably verify the estimates of the design effective lake levels, considering the uncertainty in effective lake level prediction, expected overestimation of effective lake levels at the southern end of the lake, local variability in the elevation of shoreline features, and the role of wind in building up beach crest height at some locations.

The linear addition of the effective lake levels with climate change and seiche effects at a given return period appears to be overestimating the true combined lake level at that return period. We expected that seiche would have been incorporated in a way similar to wave runup. However, since the extreme seiche amplitude is small relative to the static lake level and wave runup extremes, we do not consider that the conservative treatment of seiche is of much significance. The choice to ignore land use change effects on lake inflows and lake levels appears reasonable.

In our review and in discussion with Opus, we have noticed that the sequence of estimation necessary in a project of this nature has tended to gradually increase the overall risk being assessed. This is because at each step of the way, ‘conservative’ assumptions are used and their effect is generally additive. We recognise that this provides a higher level of protection, or conversely a larger area considered to be at risk and thus subject to planning control. However we believe that this approach can be carried too far, as the actual level of protection is difficult to assess and may in fact be at a very high level, or very low annual exceedance probability (aep).

If these studies were to be used for major capital works for protection of assets or for denying planning approval to large projects, we suggest that our recommendations regarding alternative frequency analysis methods, dealing with uncertainty, potential compounding of probabilities, and aspects of data collection for hydraulic model calibration, be addressed.

1 Introduction

Taupō District Council (TDC) has engaged Opus International Consultants Ltd over the last three years to prepare a series of reports about flood hazard in the Taupō District. These reports have focussed on flood hazard from six rivers flowing into Lake Taupō (six reports), and from the lake itself (one report). NIWA has been engaged to provide a peer review of these seven reports, as listed below:

1. Paine, S. and Smith, H. 2012. Taupō District Flood Hazard Study: Whareroa Stream. Opus International Consultants for Environment Waikato and Taupō District Council. June 2012. 48p.
2. Smith, H. Paine S. and Ward, H. 2011. Taupō District Flood Hazard Study: Kuratau River. Opus International Consultants for Environment Waikato and Taupō District Council. July 2011. 52p.
3. Paine, S. and Smith, H. 2012. Taupō District Flood Hazard Study: Tokaanu Stream. Opus International Consultants for Environment Waikato and Taupō District Council. June 2012. 50p.
4. Maas, F. and McConchie, J. 2011. Taupō District Flood Hazard Study: Tongariro River. Opus International Consultants for Environment Waikato and Taupō District Council. July 2011. 59p.
5. Knight, J. and McConchie, J. 2010. Taupō District Flood Hazard Study: Tauranga Taupo River. Opus International Consultants for Environment Waikato and Taupō District Council. July 2010. 48p.
6. Paine, S. and Smith, H. 2012. Taupō District Flood Hazard Study: Hinemaiaia River. Opus International Consultants for Environment Waikato and Taupō District Council. June 2012. 46p.
7. Ward, H., Morrow, F. and Ferguson, R. 2014. Taupō District Flood Hazard Study: Lake Taupō. Opus International Consultants. Draft for internal review, June 2014. 108p.

The peer review should:

- Evaluate the assumptions and methodology used to determine the level of potential flood hazard in a 1% annual exceedance probability (aep) event.
  - Review the hydrology aspects of the reports, including but not limited to factors such as use of recorded flow data, assessment of the quality of the available flow data, extension of rating curves, use of regional flood estimation to allow confident extension to high return periods, and statement of uncertainty.
  - Review the methods used in the inundation modelling, including but not limited to such factors as use of observed flood levels, use of survey data including LiDAR, assessment of terrain roughness, sensitivity assessment and statement of uncertainty.
- Assess whether the methodology has been consistently applied across the suite of reports.

- Highlight any weaknesses (if any) in the preparation of the reports or with the data that has been used.
- Highlight any other issues that become apparent over the course of the review.

To this end three experts undertook the review: Mr Roddy Henderson reviewed the flood hydrology aspects of the six river flood hazard reports (section 2); Mr Maurice Duncan reviewed the hydraulic modelling aspects of the six river flood hazard reports (section 3), and Dr Murray Hicks reviewed the Lake Taupō Foreshore hazard report (section 4).

2 River Hydrology

2.1 Flood frequency analysis

Essential features of river hydrology when considering flood hazard can be divided into two major areas: estimation of the design flood peak flow, and sometimes the design hydrograph; and estimation of the inundation and damages that would result from the occurrence of the design flood. This section is concerned with the first of these components.

The following list describes the steps that we recommend are undertaken when considering the derivation of design flood peak values and hydrographs for use in inundation models.

1. Determine the flow records that will be of use in the study. Ideally these are on the river and close to the location for which flood risk is needed.
2. Perform some quality assurance on these records with particular attention to the way in which the river level to flow rating curves have been defined for flood flows. This is because calibration measurements are often obtained at lower flows and the extrapolation to higher river levels can be problematic. This may involve checking with the data authority about their confidence in the flood values at the particular river flow recorder.
3. Extract the largest values from the river flow record. This is either done by selecting the largest value in a fixed time period through the length of record (usually a year) or by selecting all flood values above a threshold value (often selected to give twice as many values as the length of record in years). The advantage of the second approach is that it results in a dataset of the largest floods, which is more appropriate to estimation of small aep events. An analysis of peaks over threshold or maxima from periods shorter than a year can generate an increased number of points for analysis from a short record. For record lengths of more than 10 or 20 years however, there is little difference in accuracy in the results obtained from the peaks over a threshold method when compared with analysis of annual maxima. There may be increased precision using the greater sample size of a peaks over a threshold analysis. The annual maxima approach is recommended as we are often in a position of having ten or more years of records.
4. In flood frequency analysis the assumption is made that an annual maxima series is randomly drawn from a statistical distribution and so is free from serial correlation and trends. These assumptions can be tested on long records with a variety of tests as detailed in McKerchar and Pearson (1989).

5. To estimate the likelihood of rare events and thus define a design flood peak value, a frequency distribution is fitted to the maxima data. There are many methods for choosing and fitting, but our current preference is use of linear moments as provided in the software packages Tideda and Hilltop. However there are a number of caveats with this procedure, and in particular ways to deal with shorter records, and choice of distribution. An important principle is that choice of distribution should be informed by the analysis of many sites in a region.

6. In general terms an individual flow record should not be used to estimate an annual exceedance probability (aep)[1] for a period longer than about 5 times the record length. This means for example that twenty years of data are needed to estimate a 1% aep flood (i.e., the "100-year return period flood) as is to be used in the inundation modelling for the six rivers in these reports. In situations where records are not long enough the regional flood estimation procedure of Pearson and McKerchar (1989) or other regional methods should be used to provide additional support for the extension. This uses the pooled results of many sites in a region to guide the extension to lower aep, and reduce uncertainty in the estimate.

7. Because the regional method is based on older datasets, another regional technique that can be applied is to pool the recent records from the sites in question, in a dimensionless way to provide a larger dataset that allows extrapolation with greater confidence. Either method gives higher confidence in the result, and helps to avoid effects of occasional large events in short records, that can bias the answers at low aep.

8. Estimates for design event peak flows should be provided with an estimate of their uncertainty, or at least acknowledgement of this as a guide to the use of values for subsequent inundation modelling, where notions of added freeboard etc. are common.

9. Estimation of a design hydrograph shape is best managed by examining the largest floods in the flow record, normalising these to the peak flow, averaging the hydrograph shape, and scaling the result to the desired peak value. If no hydrographs are available from the catchment or neighbouring catchments, then some form of rainfall-runoff estimation is required. Calibration of such models in areas without data is difficult and should be supported by use of manuals or other guidance that may be available from local or regional authorities.

10. Consideration of future changes to the flood frequency derived from data may be made based on notions of likely landuse change and/or scenarios of climate change. This latter assessment is now mandated by many local authorities based on guidance from Ministry for the Environment. Explicit techniques have yet to be developed however except in the case of rain intensity, and the translation of this to effects on flood magnitude has received little attention to date.

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[1] Annual Exceedance Probability: the likelihood of a flood of a given size being equalled or exceeded in any one year.

Each report also deals with the potential effects of future climate change on the flood hazard, and the river flood reports also deal with the possible effects of landuse change in their respective catchments.

2.2 Lake Taupō tributaries flood frequency analysis

This section first describes some general points that apply to most if not all of the reports, and then follows with specific issues about each report in turn, proceeding from west to east around the lake shore. This order is replicated in the discussion of hydraulic matters (section 3).

2.2.1 Flow Data

For each of the six rivers continuous time series records of river flow are available from which estimated design flood values can be derived. These time series are of different levels of usefulness, depending on the length of record available, the proximity of the flow recording site to the sites where flood hazard is of concern, and the quality of the flow record available. In general these flow records have been selected appropriately, and where necessary modified by catchment area considerations.

2.2.2 Data quality checks

Most of the reports do not comment on any issues of data quality especially as it relates to the flood flow values, and whether or not rating curve extensions have been examined. McConchie (2015) remedies this providing a description of the range of flow gaugings, rating curves, and how they relate to the maximum flood flows at each site.

2.2.3 Extraction of maxima data

Although not stated we assume that the data extraction and subsequent analysis was performed using the Hilltop software suite.

2.2.4 Statistical tests

Stationarity is the property that parameters of a distribution do not change over time in a significant way. Examples of non-stationarity issues include trends and step changes. Some of these effects can be adjusted for before analysis, and others require a change of method. Most of the river flood reports contain fairly generic statements about stationarity of time series. Ideally test results should be provided to demonstrate the likelihood of trends, etc. rather than presentation of a total hydrograph with a subjective statement about lack of evidence. The relevant dataset for any testing is the maximum series, not the total hydrograph.

Another important statistical property to be discussed is serial correlation, which if present, violates assumptions in the fitting of distributions. Several of the flood reports attempt to make up for short records by using monthly maxima rather than annual maxima. It is claimed that this gives a better representation of the flood series. There are two problems with this approach:

1. Many small events and in some cases aspects of the hydrographs that may not even constitute a flood, are included. The first effect of this is to bias the 'annual' flood downwards by the inclusion of many small events and non-events. The second is that these many small events have undue influence on fitting of whatever frequency distributions are tested and subsequently chosen.

2. Use of monthly maxima for a frequency analysis runs a great risk of violating the principle of independence of sampling. In catchments with both significant soil storage and a pronounced winter moisture maximum, such as those draining to Lake Taupō, this is likely to be a significant issue.

Many of the smaller monthly maxima as can be seen in the frequency plot are very small events, and indeed some may not be 'events' at all. Analysing monthly maxima is not a recommended practice.

We note that the re-analysis of maxima described in McConchie (2015) uses annual maxima throughout.

More statistical strength and confidence is available when the dimensionless results from a number of records in a region are used to extend the analysis to smaller aep. This is the case when using the regional flood frequency methodology as described in Pearson and McKerchar (1989). Although the data used to derive the method are somewhat dated, it can still be used with existing data to achieve improved estimates, and at the very least should be a component of a study such as this where answers are required at several sites in the same region. There has been no attempt in these reports to apply the Pearson and McKerchar methodology, nor to examine any grouping of frequency results with a view to developing a regional picture. We recommend an approach of this sort for the production of 1% aep flood estimates, and certainly for estimating floods of smaller aep, where these are to be used for input to subsequent models such as a hydraulic model for inundation modelling.

We do not agree with the assertion in McConchie (2015) that use of the regional method on records that were used to derive it would result in "circularity and bias" (p8). The regional method is specifically designed to allow combination of recorded data and regional estimates to reduce uncertainty when extrapolating frequency curves to low aep. Additionally the method provides a statement of uncertainty for each estimate derived.

2.2.5 Choice of distribution

Many extreme value distributions are available, and this choice can have a marked influence on estimation of small aep event magnitudes. In these situations, consideration of the statistical properties of the extreme data series is an important feature. It is notable that for six rivers in a fairly compact area of the country, with many similarities of catchment characteristics, and similar climate drivers, two different distributions are suggested. There is no evidence presented to support the chosen distributions, beyond the assertion that a particular distribution provides the best fit in each case. Nor is there any demonstration of the 'best fit' of the chosen distributions. A regional approach of pooled extreme value series with consideration of their properties such as their L-moment ratios would have allowed a more objective and consistent means of distribution selection. We recommend this approach for any future work on these flood risk assessments.

2.2.6 Uncertainty of flood estimates

Considerable uncertainty arises in flood estimation even from the choice and fitting of a distribution to the extreme value series. A test fitting by NIWA of a Gumbel distribution to the Kuratau record as part of this review yielded a 95% confidence band for the 1% aep flood of ±18%. While uncertainties for other distributions may be better or worse than this, there is also a trade-off between number of parameters and fit. This is not explored at all in any of the reports.

2.2.7 Climate change effects

Effects of climate change are provided in rudimentary form in publications from MfE and these have been used in the reports to provide estimates of rainfall intensity changes. It is also noted that future developments in this area of work can be incorporated in future. We support this approach as a pragmatic one. The question of whether increases in rain intensity will translate to relatively similar or larger increases in flood intensity is currently unresolved. However our experience with rainfall runoff processes indicates that even in the most severe floods, there are significant losses of rainfall to a variety of processes, and we expect these to still be relevant under increased intensities due to climate change. Thus we accept the use of simple scaling of flood peak as used in the Opus reports.

2.3 Whareroa Stream

2.3.1 Section 3.6 Flood frequency analysis

Use of the Kuratau scaled frequency analysis in McConchie (2015) at Table 3.14, shows that the estimated flood magnitudes, after scaling by the ratio of catchment area raised to the power of 0.8, are approximately twice those from the analysis of the Whareroa annual maxima. This can be resolved if account of the higher flood intensity pf the Kuratau catchment is allowed for. Simple use of the area$^{0.8}$ ratio assumes the catchments lie on the same contour f MAF/A$^{0.8}$. However the data show that this parameter is twice as high at Kuratau (0.5) as at Whareroa (0.25). This factor of two applied to the area ratio estimates results in very good agreement. This is similar to the issues identified below regarding the use of Te Porere floods to estimate Tokaanu stream floods.

2.4 Kuratau River

2.4.1 Section 3.3 Flow characteristics

Calculation of the significant rain accumulation interval for a catchment can be approached in a number of ways. One is to use a time of concentration formula, which considers the catchment shape and slope, and the other is to examine typical rain and flood patterns. It is not clear which method has been applied in the report. The measure here is the time between the rainfall peak as measured at raingauges and the flood peak at the flow recorder. It is rain intensity over durations around the time of concentration that give rise to the peak flow. Looking at Figure 3.4 for both events on 7 December and 9 December, this time difference can be seen as 6-8 hours, rather than the 24 hours of rainstorm duration mentioned in the report. This could lead to differences later in the climate change assessment as the fractional changes are related to rain duration. Some calculations to support these assessments would be desirable.

2.5 Tokaanu Stream

Tokaanu Stream has a complicated topography, including interception of some flood water into the Tokaanu power station tailrace from part of the catchment. The flow records at two locations are short and discontinuous, making reliance on flow data problematic. Two methods are discussed to surmount this obstacle: the rational method, and scaling of a nearby similar catchment flood hydrology.

2.5.1 Section 3.3 Rational Method

The Rational Method gives flood estimates that are perceived as too large. We agree. The total for the four sub-catchments is 62.4 m^3/s. However there is no discussion to support the choice of the

Rational C parameter, and in fact the actual value used is not presented, and nor are the values obtained for time of concentration. McConchie (pers. comm.) stated that published guidance was used for C estimation. This should be referenced. It is thus not possible to further comment on this application. However we note that the Te Porere flow record could have been exploited to calculate a value for the rational method C factor at Te Porere as a guide to possible values for Tokaanu Stream.

2.5.2 Section 3.4 Flow Scaling

Scaling the flood hydrology of Te Porere is an alternative that has some merit. However the scaling chosen (using ratios of area to the power 0.8) is only part of the picture that needs consideration. Examination of the flood intensity maps from Pearson and McKerchar (1989) shows a considerable gradient across the area of interest. In fact the estimated flood intensity factor (Q_{mean}/Area $^{0.8}$) for Te Porere is approximately twice that for the Tokaanu Stream. This means that a catchment of the same size near Te Porere is expected to produce floods of twice the size as the same catchment area near Tokaanu. Thus a factor of 2 should be applied as well as ratio of areas raised to power 0.8, giving a total flood peak of 10.5 m^3/s. This multiplier is related to the different exposure of the two catchments to north-west weather, and the higher elevation of the Te Porere catchment on the side of Mount Tongariro.

Additionally, no consideration has been given to the use of the maps or other aspects of Pearson and McKerchar. Simple application of their method to the four sub-catchments of the Tokaanu Stream suggests a cumulative 1% aep flood magnitude of 13.2 m^3/s, close to the revised Te Porere estimate above. A number in the range 10-13 with an uncertainty of at least 30% would seem like a reasonable compromise, and more realistic than the 21 m^3/s estimated in the report.

Scaling to the total area of the Tokaanu Stream rather than the sum of the individual areas, as detailed in McConchie (2015), yields a 100-year estimate of 16 m^3/s, which is acceptably close to the estimates above.

2.5.3 Section 3.6 Waihi Stream

Use of the recorded flood hydrograph at Waihi Stream as a shape for design hydrographs is reasonable.

2.6 Tongariro River

2.6.1 Section 3.2 Stationarity

The onset of significant diversions from the Tongariro and additions to the flow since 1970, should at least be mentioned, even though it may be generally assumed that the diversions have a small effect on the flood hydrology.

2.6.2 Section 3.8 Flood Frequency Analysis

This discussion would benefit from a presentation of uncertainty about design flood estimates. A 1.5% alteration in flood magnitude depending on period of record chosen is small compared with the estimate of 95% confidence interval on the 1% aep flood magnitude from fitting a Gumbel distribution of 16 to 22%. A hypothesis about the two largest events is that they are of similar aep and that this is less than 1%. The assessment of the lower aep values when too many larger events occur in a record of this length is particularly sensitive to the choice of distribution. While an EV1 (Gumbel) assumption will lead to the inference that these events are of lower than apparent aep, other distributions will account for the two extremes by producing upward curvature to allow a fit. This can lead to some very large estimates at lower aep. For this reason we recommend a regional approach for low aep estimation as discussed in section 2.2.5 so that all available data are used to support the extension of the frequency curves to low aep.

2.7 Tauranga-Taupō River

2.7.1 Section 3.6 Flood Frequency Analysis

Again the uncertainty of fitted distributions far outweighs the changes from selection of different time periods. For example a Gumbel distribution fitted to the Tauranga-Taupo annual maximum series has a 95% confidence interval of 18% at 1% aep, as compared to the 2% differences discussed in the report.

2.8 Hinemaiaia Stream

2.8.1 Section 3.1 Available flow data

Figure 3.2 illustrates a good correlation between flows measured at the current recorder site and the previous recorder site. Coincidentally perhaps the multiplier is similar to the ratio of areas to the power 0.8. While it may have been preferable to perform the correlation exercise using matching flood peaks, this correspondence gives some confidence that the relationship will perform satisfactorily in providing an extended record.

2.8.2 Section 3.4 Effect of Hinemaiaia hydro scheme

The overall effect of the scheme storage is well presented and allows confidence in the flood values from the combined record.

2.8.3 Section 3.5 Flood Frequency Analysis

See comments at section 2.2.4 on general issues about the use of monthly maxima.

3 River Flood Modelling

3.1 Two dimensional hydrodynamic flood modelling

This is a brief description of two dimensional hydrodynamic flood modelling so the reader can understand how it should be carried out as a basis for comparison as to how the flood modelling was carried out for the flood studies being reviewed. The following decisions or choices need to be made or carried out:

1. Choice of modelling system.
2. Choice of extent of the river and flood plain being modelled.
3. Construction of a digital terrain model (DTM) with appropriate cell sizes for the extent of the model.
4. For MIKE FLOOD models the gathering of cross-section data for modelling flows in the main river channel.
5. Choosing flow resistance values for the river channel and for the various land covers on the flood plain.
6. The size and shape of the hydrograph.
7. In the case of rivers flowing into Lake Taupō, the water level of the lake during the flood.
8. Gathering of flood level and extent data from a flood against which to calibrate the model.
9. Model calibration: Ideally a large river flow hydrograph for which flood level and extent data have been gathered is run through the model. Normally, flow resistance data is varied until the modelled and measured data agree to within an accepted tolerance. Sometimes the DTM is manipulated to incorporate scour or to add or remove stop-banks so the DTM (which normally reflects the current topography) represents the topography at the time of the calibration flood.
10. Once the model is calibrated, the design floods with appropriate downstream conditions (in this case the lake level) are run to provide extent, depth and velocity data. The flow resistance values from the calibration are usually retained for the design foods.
11. Often the depth and velocity data are used to indicate the degree of hazard to people and/or economic damage that the design floods might cause.

3.2 Lake Taupō tributaries flood modelling

This section examines the flood modelling for the reports being reviewed, in relation to the steps/choices listed in Section 13.1.

1. The two dimensional (2D) hydrodynamic modelling software MIKE21 software was used to model flooding from the Tongariro River and Tokaanu Stream. The MIKE FLOOD model that has uses one dimensional modelling in the river channel and two

dimensional modelling on the flood plain was used for the Kuratau River, Hinemaiaia River and the Whareroa Stream models. Both software products are used worldwide for flood modelling and are appropriate for use in the Lake Taupō tributaries flood modelling.

2. The modelled extents were appropriate.
3. The DTMs were based on recent LIDAR which is a very good source of topographical data. The chosen model cell sizes were appropriate for most models. In some cases more than one cell size was trialled to determine if larger cells (with reduced computing time) could be used. Buildings were filtered out of the DTM and their significant effect on flows accounted for with flow resistance. DTMs normally do not represent stopbank crests well and as is common practice, as occurred for the Tongariro DTM, to manually raise to the height of the stopbank crests, the grid cells representing stopbanks. However some of the pre-February 2004 stop banks may not have been represented correctly (in all likelihood lower) in isolated locations as they were derived from LiDAR as OPUS was not provide with any as-built data for the stop banks (McConchie 2015). There is a potential effect of increased modelled flooding if the modelled stop banks of lower than the as-built levels.
4. Main channel cross-section data is required for modelling in one dimension the flows in the main channels and can be very important, especially for larger rivers. Information on the number and extent of cross-sections in in McConchie (2015) and it appears that sufficient cross-sections have been surveyed or interpolated for the modelling.
   - Tongariro River model: Cross-sections from a previous 1D model were used.
   - Tokaanu Stream model. The DTM for the 2D model did not include the channel volume below the water surface and was assumed to be very small in relation to flood volume. This is an acceptable assumption given other modelling uncertainties.
   - Kuratau River model: Cross-sections from a previous model were used.
   - Hinemaiaia River and Whareroa Stream: Cross-sections were extracted from high resolution DTMs, but their number and extent have not been documented.
   - Tauranga-Taupo: OPUS used a MIKE FLOOD model developed by Basheer (2008). It is assumed that sufficient cross-sections were used.
   - The flood plains had a variety of land cover and it is normal to vary flow resistance with land cover and to take into account the flow resistance created by buildings.
5. There was no information in any of the flood reports on the range of flow resistance values trialled, but McConchie (2015) lists the flow resistance values used in the models and they are within the range of commonly used values.
6. While the reports have examples of flood hydrographs it is not clear from the flood study reports what hydrograph shapes were chosen for the design floods and how they were scaled to meet the design hydrograph peaks. The shape is critical as it

determines the volume of flood waters and it is the volume that partly determines the extent of flooding. Flood models should use hydrographs rather than steady state flows as steady state flows provide too large a volume and exaggerate flood extents. McConchie (2015) states that steady flows equal to the flood peaks were used. In steep confined rivers where there is little off-channel storage the use of steady state flows may be acceptable, but not where flood plains are flooded. Use of steady state flow results in conservative estimates of flooding, i.e., increases the depth velocity and extent of flooding. An example of this can be seen in the Tongariro report. The use of a steady state flows results in a conservative (over) estimate of flood extent that adds to other conservative estimates.

7. The downstream model boundary is the lake level and for these models the historically based 1/100 AEP lake level was used. In theory the combination of both 1/100 AEP river flood peaks and lake level will result in flooding in excess of a 1/100 AEP event . As the 1/10 AEP lake level is only 14 cm lower than the 1/100 AEP lake level the use of the 1/100 AEP lake level will have very little practical effect for the rivers that are steep all the way to the lake, but it could exaggerate the extent of flooding on the very flat Tongariro River delta. The rarity of the combined events needs more comment.
8. Gathering enough historical flood extents and flood levels for a good calibration is often difficult, but essential, to give really good confidence in the modelling results. Some models have a small amount of calibration data, but most have none. Where there is data, only one study shows one point where its location is reliable and where the observed and modelled flood levels are compared. That data point was modelled within an accepted tolerance. The flood extents for two rivers (Tauranga-Taupō and Tongariro) were based on previous modelling studies and no details are given on their calibration.
9. The reports use a well thought out, categorised, flood hazard for people and buildings developed by Waikato Regional Council. The categories agree for the most part with the NIWA’s own investigations into flood hazard for adults. However, we believe the low hazard category underplays the effect of flooding on buildings. While “low hazard” flood flows may not cause structural damage there is a large step in economic damage once flood levels reach or exceed floor levels. Floor coverings need replacement, furniture is affected, wall linings need replacement, property owners are displaced while repairs are made, and homes may have to be cleaned of sewage and silt contamination. We believe there is room for a category for property damage that recognises this issue – perhaps for flood depths > 0.35 m which is a typical height for a ring foundation or concrete floor. For the study rivers that do not flood residential areas this may not be an issue, however, for others much of the residential area has the potential to be flooded by the events modelled. Thus we do not generally agree that for areas classified as low hazard that the risk to property is generally low. There is room for dividing the low hazard category on the basis of depth and likely property damage by flooding above floor level. There also needs to be recognition in the report that the hazard categories for people apply to healthy adults, and that for children, the elderly and the infirm, areas classified as having a low hazard may have a greater degree of hazard for them.

Where previously established models are used details need to be given about the cross sections and the model calibration.

The reports reviewed above were written for a non-technical audience and so much of the information required to make an assessment of the reliability of the modelling was absent and resulted in the bulk of the critical comments written above. Following the reviews, informal discussions were held with Dr Jack McConchie of OPUS who supplied an earlier report on the Tongariro River modelling (Maas and Webby, 2008) and related correspondence. That report gave technical details on the hydrograph used, the hydraulic roughness range values used and where those values are applied. There were many flood levels along the river against which the Tongariro River model was calibrated. A brief review of that report makes the following observations:

- Good practice would be to use an inflow hydrograph.
- There were numerous water level calibration points along the length of the river and while the fit at particular locations was not ideal the general trend was very good and plausible explanations were given where there were larger differences between measured and modelled levels.
- A table and a map of hydraulic roughness values were provided and the values used were within accepted ranges. We understand the same values were used for the same sorts of land covers for the hydrodynamic models on the other rivers being reviewed.
- No details were given in the on the cross-sections used, except to say that in lower river there were none. The details are in yet another report. Given the good calibration and the dynamic behaviour of the bed the lack of cross-sections in this report is not important.

The technical compendium (McConchie, 2015) provides some of the technical detail missing from the lay audience oriented flooding reports and has increased our confidence in them.

In summary, the Council can have good confidence in the hydraulic modelling of the Tongariro River. The use of hydraulic roughness values from the Tongariro River model in the other models increases the level of confidence that can be had in those models. The way all the data has been applied will probably lead to an overestimate of the extent and hazard of flooding. Examples is the use of steady state flows and the use of the 100-year lake level combined with a 100-year flood. Such a combination is more rare than once in 100 years. This may be satisfactory for planning, but for the building of expensive structures such as stop banks more precise information is required. Information on flood levels and extents for model calibration is required for all the rivers considered here apart from the Tongariro. When the district is subject to a large flood, priority needs to be given to recording (photographing and locating) flood levels and extents for later levelling to provide information for calibrating the existing models.

3.3 Comments on specific report sections

Table 3-1 lists comments relating to specific sections of each report. The comments include information which should be added to the reports to increase confidence in the reported flood hazard as well as specific concerns relating to aspects of the approach used on a particular model.

Table 3-1: River flood modelling comments relating to specific report sections.

Section	Comment
Whareroa Stream	
Section 3. Flow Characteristics	Figure 3.1 should also show the location of the rain gauge featuring in Figure 3.11
Section 6.1. Methodology	It would be useful to show extent of model in a figure The report should show the locations of the cross-sections used for the 1D channel modelling in a figure.
Section 7.3. Flood hazard assessment	Para 8 and Figure 7.4. It would appear that the arrow in Figure 7.4 is pointing to the wrong depression.
Section 8. Conclusion	There needs to be a section here about the uncertainty on the flood hazard assessment, noting the uncertainty in the flood peak and the uncertainty in the flood modelling given the lack of flood levels for calibration of the flood model.
Kuratau River	
Section 3. Flow Characteristics	One of the maps should show the locations of the water-level recorders and the rain gauge.
Section 6.1 Previous flood modelling	Para 3 – It is not clear how the model output levels were judged to be higher than observed if there was no calibration data
Section 6.3. Model calibration	Two water levels over an 18 km^2 domain is not enough to calibrate a model especially when the precise location of one of the calibration sites is unknown. The calibration for location 1 is within acceptable limits but it is overstating accuracy of the model to say that the water level at location 2 was perfectly modelled when its exact location is unknown. This needs to be acknowledged at this point in the text. Para 4, line 2. Would “uncertainty” be a better word than “inaccuracies”?
Section 6.5. Effect of Lake level on Kuratau River Flooding.	Para 3 discussing the back water profile for the 29 February 2004 flood gives the lake level at the time of the flood peak of RL 357.24 m whereas Table 6.1 states the water level at the downstream boundary for the model as being RL 357.35 m (the maximum water level during the whole event). It would be normal practice to run the model with a time varying downstream water level boundary, or if that facility was unavailable, to run the model with the downstream level at the time of the flood peak. While Figure 6 shows that the differences in water level at the calibration site would have been only slightly affected it is not clear why RL 357.35 m was used when it was higher than the level during the flood peak.
Section 6.9. Maximum velocity	Figures 6.7 and 6.8. To allow a better visual comparison of the two maps, the velocity legend and scale should be to the same.
Section 7.4. Summary	Para 1 mentions that the calibration used surveyed flood level data, and a flood map, yet there is no mention in the section on calibration about a flood map. It would be very informative to be able to compare the flood map and the modelled flood extent.

Section	Comment
Tokaanu Stream	
Section 6.1 Methodology	Para 1. There should be a figure to show the extent of the model or a statement that figure x shows the full extent of the model. While the text does mention that a MIKE21 model was used, it is not immediately clear, that unlike the modelling for others rivers in the report series, the channel was not separately modelled.
Section 8.3. Area affected	The text mentions that *"Maps of the combined flood hazard……..are included in the data appendix to this report."* The appendix is missing from the report.
Tongariro River	
Section 6.2 Methodology	Section 6 "MIKE21 flood model" just reports the findings from a model previously reported in Opus 2009, so it is more difficult to review the modelling for this river than for most of the other studies in the series.. Para 1. Since the timing of the LiDAR survey causes issues with the modelling, it would have been useful to have the date of the survey and the dates of other relevant matters.
Section 6.3. Model calibration-February 2004	It appears that there were plenty of levels and a map of flood extent against which the model could be calibrated, however no information is given on the water depths at the calibration points so it is not possible to judge the accuracy of the model, except for a statement about the agreement of the extent between a previous model and the MIKE21 model, but from the scale of the figures it is hard to judge how well they agree. The calibration flood peak is stated to be the average of the oscillating part of the flood peak. Given that the velocities at the recorder site were sufficient to scour the bed and cause enough bed movement for waves of sediment to pass the recorder and affect the flow record, the better option would have been to model the peak flow rather than an average of the oscillating part of the hydrograph peak. Also it is more credible to use a hydrograph to model inundation from a flood than a steady flow, especially if the peak is of short duration, as it will result in a lower volume of water on the flood plain as is shown in Figure 8.1.
Section 7.3. Maximum velocity maps - Figure 7.3.	Figure 7.3 shows the location of high velocity flows and their pattern appears quite credible, but the caption indicates a maximum velocity within the model of 13.4 m/s. Such incredibly high velocities bring into question the quality of the modelling. The area of high velocity should have been focused on and some explanation given.
Section 8.2. Nature of the Tongariro River under flood conditions	The impression from Section 6.2 is that there were many cross-sections available for the modelling and that the inundation was well modelled. However bullet 1 makes it clear that there was a lack of cross-section data for some parts of the model. The report should have been more "upfront" about these shortcomings in Section 6.2.

Section	Comment
Section 8.3 Effect of varying the upstream boundary.	We have already given our opinion that flood plain modelling should be undertaken using hydrographs rather than steady state flows, as steady state flows could put an unrealistic volume of water on the flood plain and exaggerate flooding depths and extent. Figure 8.1 bears that out with the water depths over whole flood plain being covered with up to 0.1 m more water with the steady state model. While this may be within acceptable model uncertainty is certainly biases the whole result. Para 2. In the last sentence there is mention of the lack of accurate and detailed calibration data. This should also have been mentioned in Section 6.2.
Section 10 River flood hazard classification	Point 21 from Section 3.2 applies to the Tongariro River flooding
Tauranga-Taupō River	
General comment	Opus have used a MIKE FLOOD model developed by Waikato Regional Council to run the 100-year and 100-year climate change affected floods. No details of the model are given so no judgement can be made of the adequacy of the MIKE FLOOD model of the Tauranga-Taupō River. As there is no formal or informal report of the model by Waikato Regional Council the OPUS report should have provided details of: ▪ The model boundary conditions. ▪ The number extent and location of the cross-sections for the 1D MIKE 11 part of the model. ▪ The size of the cells in the 2D portion of the model. ▪ The nature of any calibration data and how well the model fitted the calibration.
Section 5. Flood risk for the Tauranga-Taupō River	There are a number of scenarios with different lake levels and river floods described and illustrated in this section. However, it is not very clear from either the text or the figures which lake levels and flood flows apply to each figure. The text and figures need to explicitly state the lake levels for each scenario. Para 1. The lake level for Figure 5.1 should be given in this paragraph and in the caption for Figure 5.1. Para 6. The lake level for Figure 5.3 should be given in this paragraph and in the caption for Figure 5.3 Para 8. It should be made clear that Figure 5.4 is for river flooding and does not include flooding from the lake and the lake level for the model run needs to be stated in both the text and figure.
Section 6.3. Flood hazard assessment	Point 21 from Section 3.2 applies to the Tongariro River flooding
Hinemaiaia Stream	
Section 3. Flow characteristics	One of the maps should show the locations of the water-level recorders and the rain gauge.
Section 6.1. Methodology	Para 1. There should be a figure to show the extent of the model or a statement that the figure comprises the full model extent

Section	Comment
	Para 5. Given the model domain's small size a 2.5 m grid could have been used.
Section 6.3 Model calibration-October 2000 flood event.	Para 3. The calibration point locations should be shown and a table given to show how well the model performed.
	Para 4. While the authors are optimistic about calibration of the model in the future should data become available, their comments in the previous paragraph indicate that future calibration may be difficult given the dynamic nature of the channel.
Section 7.1 Scenarios modelled	Para 2. There are comments here that modelling of the DTM with a 5 m grid might be compromising definition of area flooded by this river.
	Figure 7.4. This figure is for the 100-year ARI event without climate change, but Section 7.3, para 1 refers to Figure 7.4 showing "*the maximum velocities for the 100-year ARI event; adjusted for the potential effects of climate change*".
Section 8.4. Summary	Para 4. This statement does not apply at this site as the bed morphology changes during floods. These bed changes were given as a reason for variable calibration fit, so it is unlikely that the model could quickly recalibrated.

4 Lake Taupō foreshore flooding

4.1 Introduction

This section reviews the report titled “Taupō District flood hazard study – Lake Taupō foreshore”, prepared by Ward, Morrow, and Ferguson from OPUS Wellington, dated June 2014. We begin with an overview of the OPUS study, then provide section-by-section comments around significant aspects of the methodology and issues. A list of relatively minor technical comments and editorial suggestions is included in Table 4.1.

4.2 Overview of OPUS study

The OPUS study aim was to estimate extreme water levels for mapping inundation extents around Lake Taupō at specific recurrence intervals.

The authors recognise that water levels around the shore of the lake are controlled by a number of factors, including inflows, human control on outflows (for HEP generation and flood management down the Waikato River), the characteristics of the lake outlet structure, subsidence and uplift around the lakeshore, seiching, and wave runup. Moreover, they consider that future inflows (and so lake level) have the potential to be influenced by climate change and land use change. They consider these factors independently, then generally combine their effects in a linear way, adding components to the lake level expected for a given return-period event. Often, this results in a conservative estimate of the lake level due to combined effects because at least some of the components are independent. However, during discussion with Jack McConchie (1/10/21014) it was clear that providing conservative results was a deliberate strategy followed by OPUS.

4.3 Section by section comments:

4.3.1 Lake level (Section 3)

The record of measured 3-hourly averaged lake levels from 1980 to 2013 was used to develop a series of annual maxima, which was then fitted with a PE3 distribution, which was used to estimate ‘static’ lake levels for return periods ranging from 2.33 to 1000 years. The 1980-2013 record period was chosen as a compromise: while it was not as long as the full record, it was long enough to estimate lake heights out to a return period of 100 years with reasonable confidence and it covered a period when human control on lake levels has been reasonably stable and is expected to be representative of the foreseeable future.

This approach appears reasonable, and the compromise in period of record appears justified given the importance of having a lake level regime that is as stationary as possible.

4.3.2 Climate change effects and signature (Sections 4 and 5)

Guidance from MfE was used to estimate how the static lake level at a given return period would be increased due to increased inflows associated with rising air temperatures and rainfall. First, the MfE guidance gave a certain percentage increase in rainfall per degree temperature rise for 24-hour storms of given return period, and the same percentage increases were assumed for lake inflows. Second, the record of inflows to the lake was used to generate a record of inflow events wherein inflows exceeded the capacity of the outflow structure (310 m^3/s), the accumulated inflow volumes over these events were converted to equivalent rises in lake level (assuming a vertical walled shore), from which an annual maxima series of lake level rise events was derived and modelled. Third, the same % increases in inflows due to climate change guidance (for given return period and focussing on temperature changes expected by 2090) were applied to the lake level rises by return period – which were then added to the static lake levels (for given return period) to 'boost' the design levels.

The underlying assumptions for this analysis approach are that (1) with climate change all flood inflows to the lake will increase in magnitude and runoff volume, and (2) because the lake is limited in how quickly it can drain then this means that it will fill higher during inflow events in which there is no capacity to boost the outflow. A further assumption (3) is that a given return period lake level occurs as a result of an inflow of the same return interval.

We are concerned that it may be inappropriate to simply add the lake level rise increase for a given return period inflow event to the static lake level for the same return period and expect that the combined level would have the same return period (assumption 3). This is really expecting that, for example, a 100 year annual inflow would coincide with a 100 year annual lake level – but the 100 year inflow event could just as easily occur when the lake is low. Indeed, we consider that antecedent lake levels and inflows should be independent, thus if anything, this climate change factor could be overestimated.

A possible alternative approach would be to develop a model to simulate lake levels, driven by inflows back-calculated from the existing outflow and lake level records and subject to existing outflow constraints and rules. This could then be run with the climate-change boost added to inflow events, with lake level extreme events then re-analysed as has been done for the actual record. However, we recognise the difficulty of simulating the human influence on outflows.

Strangely, after the above analysis some additional analysis was undertaken examining flow records from the Tongariro River (Lake Taupō's main tributary) and temperature records from its catchment. This concluded that there was no local evidence of a link between air temperature and lake inflows and levels. This conflicts with assumption 2 and further suggests that the climate change effects on lake levels are likely to be overestimated.

Our suggestion is that if TDC are satisfied with conservative estimates, then this analysis provided by OPUS is adequate. If not, then the simulation approach we have suggested could be considered.

4.3.3 Tectonics (Section 6)

Tectonic effects on local lakeshore levels were addressed by assuming that the average rates of ground deformation observed over the period 1979-2013 would continue into the foreseeable future. These deformation rates were estimated at 22 stations around the lake, and it was assumed that the rates at each station could be applied to the span of shore half way towards the neighbouring stations. It was recognised that there is significant short-term and spatial variability in the observed deformation rates, but that averaging over this variability is the only pragmatic approach. For the purpose of the flood risk analysis the deformation was included as a spatially-varying effective rise in lake level (for a given design period), added to the static design lake levels. The net level was then projected over the un-deformed digital elevation model derived from the LiDAR survey to derive the extents and flood depths.

We accept the pragmatic approach followed to derive the estimates of future ground deformation, and that the ground deformation accumulated over the design period should be added to the design water level (since this will occur on an incremental basis through the design period).

4.3.4 Seiching (Section 7)

Seiche was analysed using the difference between the 5-minute lake level record and the 3-hourly averaged record. An annual maxima series of seiche amplitude was derived, a PE3 distribution was fitted, and seiche amplitudes of various return periods were extracted from this distribution. It was noted that the seiche maximised at 110 mm at a return period of 50 years. The seiche magnitudes were simply added to the static lake levels at matching return periods.

We have two concerns with the approach used for seiche. Our first concern is that seiche has been termed as a static factor. In our view, it is another dynamic factor, similar to wave runup, since it is a gravity-restored oscillation 'stirred-up' by meteorological forcing (wind stress and atmospheric pressure gradients). Moreover, it can resonate to significantly higher amplitudes than the initiating forcing. Perhaps the term static was used because it has been assumed that its magnitude is uniform around the lake, but if so this is misleading. Secondly, there was no analysis done to search for any relationships between seiche and lake level and between seiche and wave runup. The seiche effect is simply added to the design lake level at a given return period. This assumes, for example, that the 50 year seiche event would coincide with a 50 year lake level event. There is no basis for assuming this, particularly since seiche events are likely to be associated with passing weather systems and the wave analysis indicates no significant relationship between wind-generated wave height and lake level. However, we would expect to see some correlation between seiche and wave height (since both are forced by passing weather systems). The simple addition of seiche effects at matching return periods will overestimate the lake level at each return period.

The analysis could be improved by dealing with seiche as a separate dynamic factor and combining the seiche record with the 3-hourly average lake level record and the wave runup records for the analysis of effective lake level (which is the approach used by OPUS to deal with the joint probability of high lake level and wave runup events). We understand that 5-minute seiche records are available back to the 1990s.

Thus as things stand, seiching has been included on a conservative basis, but since its amplitude is small relative to the static lake level variation and wave runup, we do not consider this to be a significant issue.

4.3.5 Land use impact (Section 8)

The effect of future catchment landuse change on Taupō inflows (and so lake level extremes) was considered by OPUS but was dismissed as likely to be insignificant. The analysis used results from a 2006 study by Environment Waikato that estimated the increase in flood peak discharge and runoff volume (by return period) per square km of forest converted to pasture. These increases were then scaled-up assuming that all of the 628 km^2 of forest lands in the Lake Taupō catchment were converted to pasture, and then converted to a potential increase in lake level (again assuming a vertical-walled shore). The maximum increase in lake level was calculated as 72 mm for a 100 return period inflow event. Based on the size of this potential rise and the expectation that land cover in the catchment was not expected to change significantly in the foreseeable future anyway, it was concluded that the effect of future land use change on lake flooding could be ignored.

We can accept the latter piece of logic, but the approach followed to derive the potential effects has issues. Firstly, it is a puzzle why a different approach was followed from the one used for climate change effects – surely a systematic increase in flood magnitude due to climate change should be analysed in the same way as a systematic increase associated with land cover change – yet the climate change analysis considered only events with inflows beyond the lake outflow capacity (310 m^3/s) while the land use analysis makes no mention of this. Secondly, and as per the climate change case, it is questionable whether it is appropriate to simply add the lake level effects estimated due to land cover change, which assumes that, for example, the 100 year inflow event will coincide with the 100 year lake level.

In summary, based on the expectations of insignificant land use change in the Taupō catchment and the likelihood that the analysis overestimates the effect of the assumed worst case land use change on extreme lake level events (which is relatively small anyway), then the choice to ignore land use change effects is probably reasonable.

4.3.6 Wind waves and combined risk (Section 11)

Wave runup above static water level was recognised by OPUS as another factor influencing lakeshore flooding. It was also noted that this effect varies around the lakeshore due to wind direction, exposure and fetch, and shore characteristics. Wave runup around the lake was hindcast off wind records from Taupō Airport over the period 1992-2013 using the LAKEWAVE model. The shore was then divided into 10 segments of reasonably uniform wave climate, each represented by a single station. Annual maxima from the hindcast runup records at each station were fitted with Gumbel or PE3 distributions, and these were used to interpolate runup height by return period. Also at each station, plots of daily runup vs daily lake level and also of annual runup maxima vs the corresponding lake level were used to demonstrate that runup height was independent of lake level. Predicting the joint probability of high lake levels and high runup was undertaken by generating a series of *effective water levels* that combined the static lake level and runup records, again at each of the 10 representative stations. Annual maxima were then extracted from the effective water level records, distributions were fitted, and design effective water levels were interpolated from these. These design effective water levels were judged to be superior to those estimated using alternative indices (for example, the 100 year effective water level was considered better than adding the 10 year design runup and 10 year design static lake level as derived from their independent analysis).

We accept the general approach followed and the concept of using effective water levels to manage the joint probability issue of wave runup and lake level. However, there are some issues.

First, LAKEWAVE was developed ~ 15 years ago and there are now more sophisticated wave generation models available (such as the SWAN model). One key difference is that LAKEWAVE has no nearshore dissipation of wave energy so if anything it is liable to overestimate wave height on shelving shores (e.g. 5 Mile Bay). Nor does LAKEWAVE formally refract or diffract waves (although it does address this empirically using an exposure weighting on the effective fetch), so it is less reliable in embayments where these processes are important. In particular, the eastern shore of Taupō Bay (Tapuaeharuru Bay) has many small indents and also structures (e.g. revetments, groynes, boat-ramps) that induce significant wave reflections and impose local variation in wave exposure, shore slope, and permeability, all of which will induce considerable local variation in wave runup. These will not be captured in the OPUS LAKEWAVE runup estimates, which represent all of this shore by a single set of representative characteristics. Moreover, it is not at all clear how these characteristics were chosen. This is particularly important because of the value of lakeshore assets along the Taupō Bay foreshore. We would have preferred to have seen a wave model such as SWAN used for this project and applied at finer resolution, at least along the complex segment of shore on the eastern side of Taupō Bay. We note that SWAN is freely available and has become a standard worldwide for coastal engineering analysis.

The technical compendium (McConchie, 2015) acknowledges these issues re use of the LAKEWAVE model but also notes that use of a model such as SWAN was beyond the scope of the Taupō District Flood Study. Thus the strategy adopted was to use LAKEWAVE but to also recognise its limitations when applying the results in any District Plan framework. Quite how this will be done remains unclear. We note that McConchie (2015) incorrectly says that the LAKEWAVE model is "liable to over-estimate nearshore dissipation" (line 13, page 38). In fact, LAKEWAVE assumes no dissipation and so is liable to over-estimate breaker height and runup. Second, the use of the Taupō Airport wind record all around the lake means that the wave predictions will tend to be excessive at the southern end of the lake. Solving this is problematic given the lack of an equivalent wind record for the southern shore, but it remains likely that the runup estimates at the southern shore stations are conservatively high. While this bias was noted in the OPUS report, it was not considered a significant factor on runup levels. McConchie (2015) clarified that the reasons this was not considered to be a significant factor were because of the 'District scale' of the investigation and because it produced conservative results (i.e., overestimating risks) at the southern end of the lake – as, indeed, was demonstrated when he compared the predicted design effective lake levels elevations against field evidence.

McConchie (2015) used levels of features such as the vegetation edge (or trim-line) and beach crest to 'calibrate[2]' the estimates of the design effective lake levels. This drew on observations from NIWA (2000) and Cheal Consultants (2012a-d). McConchie chose not to use information from TDC reports on lakeshore flooding and erosion events (e.g. Grigg 2010, 2011) because they contained no information on levels. However, it is our view that useful levels could have been obtained with a follow-up field survey, since most of the features from the 2010 and 2011 events remain visible, and these were significant events. We suggest that this would still be a worthwhile addition to McConchie's (2015) validation study. Apart from this, the results of McConchie's validation study appear reasonable, allowing for uncertainty in runup estimates, longshore variability in the level of features such as the vegetation edge, and expected overestimates of runup height (such as at the southern end of the lake, as discussed above). We note that the beach ridge at Five Mile Bay – Waitahanui is capped with a low 'dune' of wind-blown pumice, so this explains why the predicted water levels lie 0.4-0.5 m below the beach crest. .

4.3.7 Combined risk (Section 12)

The results from the preceding analyses were combined to define two 100-year return period inundation zones. The first captured the static water level adjusted for seiche, climate change, and tectonic deformation. The second included the effect of wave runup and substituted the design effective water level for the design static water level.

As discussed previously, adding on the matching effects of seiche at a 100 year return period will certainly overestimate the real 100 year lake level height while adding in the effect of climate change will probably overestimate this as well. Also, the use of the effective water level reduces the analysis period to 21 years (1992-2013) compared to the 33 years (1980-2013) used for the analysis of the static lake level on its own – which is another compromise in regard to record stationarity and reliability of design levels predicted beyond ~ 50 years. In this regard, it would be helpful if the uncertainty of the 100-year design lake levels could be estimated. It is stated that storm surge and landslides can both cause wave runup around the shore of Lake Taupō, and they have been included

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[2] We note that this exercise was a validation one, since there was no calibration adjustments made to the LAKEWAVE model to align results with field observations.

in the frequency analysis that has been undertaken. This is largely incorrect. The signal of the 1910 Waihi landslide has not been captured in the lake level analysis because that was limited to the period since 1980. Storm surge is an elevated water level (or setup) against a shore due to the combined effects of wind, waves, and atmospheric pressure gradients. While the runup estimator in the LAKEWAVE model includes the effect of wave setup, it does not include the wind or pressure components. We note that the latter two components were discussed by OPUS in their Section 7.2 on seiching, but were dismissed by OPUS as insignificant since their estimated amplitudes were only of the order of 1-2 cm which was small compared with the estimated wave runup. We note that these are additive factors and are not captured by seiche amplitude (i.e., pressure-gradient and wind setups can both occur at the same time and seiche will occur at higher frequencies on top of these), so it would have been 'tidy' to have included them in the analysis of effective water levels. Not having done so indicates a small underestimate which, we accept, will be within the uncertainty level associated with the wave runup analysis.

4.3.8 Conclusions (Section 13)

The Conclusions section summarises the key results of the previous sections in tables and generally is faithful to the previous sections. Our main issue is with the statement in section 13.3 that the effective water level is at a "slightly" higher elevation than the static lake level. In fact, as a comparison of Tables 13.1 and 13.3 shows, the 100 year effective water level is up to 1.46 m higher than the static level – which is a significant (not slight) difference in the context of the Taupō shore.

4.4 Minor comments by page

Further minor technical comments and editorial suggestions are listed by page and paragraph in Table 4.1.

Table 4-1: Minor technical comments and editorial suggestions. By page and paragraph number as in OPUS Taupō foreshore report.

Page, paragraph	Comment
Pvii, para 2:	There is an issue with terming seiche static, since it is really an oscillation/wave that perturbs the static lake level. Also, what does 'holistic' mean?
P3, para 3:	The last sentence is repeated several times through the report but we are not sure that it is correct in detail. What is really meant is that the same water level can arise from different combinations of factors that occur individually at different frequencies.
P3, last para:	Use precipitation not rainfall?
P5, Fig 1.3:	The hill-shading gives a false toning of the rainfall. We suggest it be removed.
P7, para 2:	The 2.33 year event only corresponds to the mean annual value for the case of the EV Type 1 (Gumbel) distribution – but these lake levels are typically fitted to PE3 distributions. We advise removing this sentence.
P8, last para:	How could the 1947 Act specify a datum that was only established in 1956?

P13, para 2:	Actually, the lake levels differ by up to 1 m, which is more than a slight deviation. This could be reworded.
P15, Table 3.2 caption:	It is important to mention that these are 3-hour average lake levels, not instantaneous levels (and so have had the seiche signal removed).
P16, para 2:	Fig 3.6 only shows the PE3 distributions for the 1906-2013 record.
P19, para 1:	This is too bold a statement to be made from simple visual assessment of the plot, and no statistical analysis has been done to back it up.
P19, bullet 1:	Both the natural and actual records are discussed, so it would be useful to include both on Fig 3.7.
P21, 1st para, last sentence:	The 0.39 m range is between once per thousand and once every 2.33 years, not once each year.
P24, para 5:	This is the only useful information of the last 2.5 pages. It is suggested that this section could all be summarised down to a few sentences. Similarly, section 4.3 takes a long time to get to the point.
P31, para 2.	The MfE guidance is for % change in rainfall per degree increase in temperature, not by average % increase in temperature. Hopefully this is just a typo and was not actually done in the analysis.
P31, para 2.	From table 4.3, the 7.2% and 16.8% increases pertain only to 50 and 100 year events but it reads like these were applied to all return periods?
P34:	Given that the MfE guidance is for 24-hour duration events, how relevant is this to the multi-day net inflow events being simulated?
P34, Table 4.7:	Caption should read 2010 flood, not 2004 flood.
P 38, para 2:	It is inappropriate to conclude that the frequency of flood activity is random from a plot of a regular annual series. Also, this is only a visual assessment, not based on any statistics.
P 38, last para:	This is contradictory – first it is said that there is no significant trend, then it is said that the annual flood may have increased slightly. Also Figure 5.4 simply repeats Fig 5.3.
P 39: last para:	How can it be claimed that flood activity only weakly relates to temperature when there is such a marked summer high in Table 5.5?
P 41, para 9:	It appears illogical that this discussion follows the analysis done in the preceding section. It comes across as if material has been merged from two separate reports.
P46, para 1:	Not fully correct. Fig 5.11 shows that the temperature range is trending up.
P51, para 2:	It would be useful to explain briefly why the lake dropped by 34 m to leave the terrace.

P54, para 1:	Whangamata Bay is not located on any map figure.
P64, last para:	For consistency, it would be useful to show a magnitude-frequency plot from the seiche annual maxima analysis. Also, it would be useful to correlate seiche with wave runup to explore the degree of dependence.
P72-75, Risk assessment section:	This section appears out of place (it would be more logical to have it at the end of the report?), is mainly relevant to river flooding, and it takes a long time to cut to the chase. The essential point is that foreshore flooding collapses onto the y-axis of Fig 10.1 (zero flood speed) and so there should be only low and high risk flood classes (< 1 and > 1 m depth) around the foreshore.
P77, para 3:	This comes across pretty muddled – is it the same instrument but TDC are now distributing the data and in the process they alter the numbers somehow?
P 78, para 2:	It is not clear why the magnitude/frequency estimates will be realistic even if the wave energy is over-predicted.
P 83, Fig 11.6:	What are the frequency units? Days?
P 84, last para:	The information on Figs 11.9 and 11.10 is already apparent on Fig 11.8, so 11.9 and 11.10 are not needed?
P 85, Table 11.5:	Caption should read. .. Statistics of 2% exceedance …
P93, paras 1 and 2:	This study is all about flooding, not erosion, so we suggest that references to erosion should be removed.
P94, para 4:	We suspect that the round-the-lake variation in return-period of the maximum estimated value stems from the goodness-of-fit at the top end of the distribution, particularly since the records are all of the same length and period. Indeed, this round-the-lake scatter is more indicative of the error in the distribution fitting.
P94, last para:	Surely the large range in ARIs produced by this analysis are an artefact of the independence of the wave and lake-level records and the directional variability of the waves (which determines whether a shore station will have high runup or not)?
P100, first para and Table 12.7:	It is not clear where the selection of possible indices comes from. Were they guesses or based on some previous analysis?

5 Discussion

In our review and in discussion with Opus, we have noticed that the sequence of estimation necessary in a project of this nature has tended to gradually increase the overall risk being assessed. This is because at each step of the way, ‘conservative’ assumptions are used and their effect is generally additive. We recognise that this provides a higher level of protection, or conversely a larger area considered to be at risk and thus subject to planning control. However we believe that this approach can be carried too far, as the actual level of protection is difficult to assess and may in fact be at a very high level, or very low aep.

If these studies were to be used for major capital works for protection of assets or for denying planning approval to large projects, we suggest that our recommendations regarding alternative frequency analysis methods, dealing with uncertainty, potential compounding of probabilities, and aspects hydraulic model calibration of data collection, be addressed.

6 Acknowledgements

Jack McConchie of Opus International Consultants for providing valuable insight to the background of these studies, and the overall client focus, as well as clarifying a number of matters throughout the report series.

7 References

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