Peer Review Discussion

Taupō District Flood Hazard Studies

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1 Background

Taupō District Council (TDC) engaged Opus International Consultants Ltd to provide a preliminary assessment of the flood hazard posed by Lake Taupō and its six major tributaries. While there are a number of editions of some of these flood studies, the latest iterations are presented in the following reports:

- Knight, J. & McConchie, J. 2010: Taupō District Flood Hazard Study: Tauranga Taupō River. Report prepared by Opus International Consultants for Environment Waikato and Taupō District Council. July 2010. 48p.

- Maas, F. & McConchie, J. 2011. Taupō District Flood Hazard Study: Tongariro River. Report prepared by Opus International Consultants for Environment Waikato and Taupō District Council. July 2011. 59p.

- Smith, H. Paine S. & Ward, H. 2011: Taupō District Flood Hazard Study: Kuratau River. Report prepared by Opus International Consultants for Environment Waikato and Taupō District Council. July 2011. 52p.

- Paine, S. & Smith, H. 2012: Taupō District Flood Hazard Study: Hinemaiaia River. Report prepared by Opus International Consultants for Environment Waikato and Taupō District Council. June 2012. 46p

- Paine, S. & Smith, H. 2012: Taupō District Flood Hazard Study: Whareroa Stream. Report prepared by Opus International Consultants for Environment Waikato and Taupō District Council. June 2012. 48p.

- Paine, S. & Smith, H. 2012: Taupō District Flood Hazard Study: Tokaanu Stream. Report prepared by Opus International Consultants for Environment Waikato and Taupō District Council. June 2012. 50p.

- Ward, H., Morrow, F. & Ferguson, R. 2014: Taupō District Flood Hazard Study: Lake Taupō. Report prepared by Opus International Consultants. Draft for internal review. June 2014. 108p.

These reports were written largely for a 'lay' audience. Therefore while the reports present the results of robust analysis and modelling, the technical detail relating to the hydrological analysis and hydraulic modelling was deliberately kept to a minimum. The only difference to this approach was the detailed technical report prepared for Waikato Regional Council relating to the Tongariro River 2D hydraulic modelling (Maas & McConchie, 2011). That report was prepared for a very different audience. The detail in that report was required because the modelling and results were a significant departure from the hydraulic modelling which had been done previously on the Tongariro River i.e., 2-D as opposed to 1-D.

Following a comprehensive peer review of these reports it was suggested that some additional technical information, implicit in the various flood studies, might be useful to facilitate discussions, and inform hearings, relating to any proposed District Plan changes to recognise the flood hazard.

Rather than modifying each individual report, a *Technical Compendium* (McConchie, 2015) was prepared which provides the background, some technical detail, and the analyses which underpin all the individual reports. It was considered that this approach:

- Provides the level of technical detail necessary so that confidence can be placed in the findings and conclusions of the various individual reports; while
- Allowing the individual reports to be easily read and understood by a 'lay' audience, without a considerable amount of repetitive and potentially confusing scientific and statistical detail.

The *Technical Compendium* addresses issues of background, approach, philosophy, assumptions and limitations, hydrology and data reliability, principles and constraints of hydraulic modelling, wave run-up analysis, combined probabilities, and the residual uncertainty of the results and conclusions inherent in the studies.

2 Purpose

The purpose of the various flood studies was to provide a District-scale assessment of the potential flood risk over the longer term. The studies were never intended to provide precise flood risk assessments at the level of individual sites or building platforms. In effect, the studies were developed largely as a screening tool to identify those areas where flood risk is not a consideration, and those where some further investigation may be warranted. The uncertainty inherent in both flood modelling of extreme design events, and a District-scale assessment, mean that the resulting flood maps should not be regarded as 'definitive' or having a high level of precision. While confidence can be placed in the maps, given the various assumptions and the present situation, should either of these change then so too might the flood hazard.

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

The various flood hazard maps should therefore be regarded as a planning tool and a guide for further investigation rather than necessarily providing a single 'answer' to the nature and magnitude of the flood risk throughout Taupō District.

3 Study constraints

3.1 Scale

It is necessary that natural hazards and associated information are mapped at a scale appropriate for the end-use, in this case allowing planners to provide guidance regarding land use on or close to areas potentially at risk from flooding. However, while generally the larger the scale the better the resolution and detail available, cost acts as a major constraint. Decisions therefore need to be made regarding the scale and cost of any hazard investigation, and where any costs should lie. For example, which costs should be borne by the wider rating base (i.e., the Council) and which should be borne by a developer and individual landowner?

It has been suggested that local authorities should map hazard information to an appropriate planning-level scale of approximately 1:10,000 to 1:20,000; with a larger scale being appropriate for 'urban' as opposed to 'rural' areas (GNS, 2015). Such an approach has been adopted in the Taupō District flood studies.

While the highest resolution data has been used in all the modelling, including LiDAR topographic information for defining the terrain, there remains some inherent uncertainty which is difficult to define without robust calibration. However, flood calibration data only exists for the Tongariro and Tauranga Taupō Rivers; with some qualitative data also available for the Kuratau River. Even in those cases where calibration data are available, this tends to be for relatively small events when compared to the large design events used in the flood studies (i.e. the 1% AEP event plus an allowance for the effects of climate change). Since the scenarios modelled in the Taupō District flood studies are relatively 'extreme', precise calibration has not been possible.

It must be recognised therefore that even at the relatively large scale used in the various flood studies there remains some uncertainty regarding the flood hazard at the 'site level'. This uncertainty is a function of the resolution of the data used in any model, its calibration, changes which have occurred since the model was developed, and the constraints of the actual modelling. In addition it must be recognised that any hydraulic model will always be a simplification of reality.

It is important to note, however, that the scale of the mapping and resolution of the various flood hazard zones tend to 'moderate' and 'smooth' the inherent uncertainties in some of the input data. For example, at the scale of the analysis the effect of a 10-20% change in the peak discharge of a design flood event, or consideration of the effect of climate change, has been shown to have a relatively minor effect on the extent and depth of inundation. While the absolute numbers may be different, the pattern of flooding is the same.

The potential effects of uncertainty of the input data are also moderated by the major influence of topography on the extent and depth of inundation. Rather than topography increasing gradually and evenly away from the lake or rivers, the landscape is often comprised of a series of terraces, or distinct 'breaks in slope'. These 'steps' in the landscape tend to constrain the extent of any inundation until the threshold of the 'step's' elevation is exceeded by the water surface and water can start to flood over the next level.

Therefore, while every endeavour was made to use the highest resolution data during the Taupō District flood studies, there remains some residual uncertainty at the specific site or property level. This uncertainty is likely to be greatest at the boundaries of any mapped inundation zone.

3.2 Hydrometric information

The quality of the hydrological inputs to any computational hydraulic model are critical to the reliability and accuracy of the results, and any assessment of the flood hazard.

All the hydrometric data used in the various Taupō District flood studies were obtained from either the National Hydrological Archive maintained and managed by NIWA, or the Waikato Regional Council. Both of these organisations collect and maintain their hydrometric databases to strict standards of quality control and externally audited quality assurance procedures. While there will always be some inherent uncertainty regarding hydrometric data, because of natural variability and the manner in which it is recorded, all the data used in the flood studies has been collected using industry 'best practice'.

While the various factors which affect the reliability of estimates of the design flood hydrographs were reviewed, it has been assumed that the 'raw' water level and flow data from which these estimates are derived are the best available.

Likewise, despite some uncertainty over the accuracy of the rating curves used during the flood studies to convert measurements of water level to flow, it has been assumed that the annual flood maxima series are the 'best available'.

The reliability of estimates of design lake levels and flood discharges is largely a function of the length of flow record used in the analysis, and the appropriateness of the flow record to the particular flood model. Uncertainty of design flood estimates increases rapidly for more extreme events. Given the moderate duration of the majority of flow records used in the flood studies, especially with respect to the magnitude of the design flows of interest (i.e. 100-year ARI or 1%AEP), there will always be uncertainty over design flow estimates.

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

4 Peer review

Prior to commencing a review of the provisions within the District Plan relating to land prone to flooding, Taupō District Council engaged NIWA to provide a peer review of the various flood study reports.

The peer review was to:

- 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.

Three technical experts undertook the review: Mr Roddy Henderson reviewed the flood hydrology aspects of the six river flood hazard reports; Mr Maurice Duncan reviewed the hydraulic modelling aspects of the six river flood hazard reports; and Dr Murray Hicks reviewed the Lake Taupō Foreshore Hazard report.

4.1 Executive summary

The Executive Summary from the NIWA Peer Review (Henderson *et al.*, 2015) is provided below, together with comments and discussion when particular issues are raised or questions asked.

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 peer review suggests that in general terms an individual flow record should not be used to estimate the magnitude of events with an annual exceedance probability (i.e. AEP) for a period longer than about 5 times the record length.

The record lengths from which the annual flood maxima series were drawn for the various the Taupō flood studies are shown in Table 4.1. In all cases, except for Whareroa and Tokaanu Streams, the annual flood maxima series exceed 20-years; in the case of the Tongariro almost 60-years. Consequently it is considered that the design flood estimates for these rivers, based on an analysis of the annual flood maxima series are likely to be realistic.

There will always be some uncertainty as to the most appropriate statistical distribution to adopt when modelling the annual flood maxima series, and the assumption that the annual flood maxima will continue to conform to this distribution into the future. However, as shown in McConchie (2015) the choice of the statistical distribution generally makes only a relatively minor difference to the extrapolated design flood maxima.

Table 4.1: Duration of hydrometric series used in the analyses.

Hydrometric site	Duration of record
Lake Taupō	~35 years
Tongariro @ Turangi	~57 years
Tauranga Taupō @ Te Kono	~38 years
Kuratau @ SH41	~36 years
Whareroa @ Fishtrap	~16 years
Hinemaiaia @ DS Dam	~28 years

Any estimate of the magnitude of the design flood will only ever be an estimate. There is no way of determining the exact magnitude of any potential event; even after the event. This issue of uncertainty of the design flood estimate is problematic. The uncertainty is actually a function of a wide range of variables, including: the accuracy of water level measurement; flow gaugings; the rating curve, especially for high magnitude flows; the length of record; the appropriateness of the statistical distribution; how well the chosen distribution models the annual maxima series;

and the appropriateness of the flow record in representing the future rainfall-runoff relationship. Therefore while recognising the uncertainty is relatively easy, quantifying it is not.

With respect to the various flood studies this uncertainty was accommodated by adopting conservative, but still realistic and reasonable, estimates for the magnitudes of the various design flood events. The inherent uncertainty is certainly recognised.

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

With respect to both the Whareroa and Tokaanu Streams, the magnitude of the design flood hydrographs had to be 'modelled' rather than interpolated from an appropriate annual maxima series. In the case of Whareroa Stream the annual flood maxima series covers only about 16 years, while for Tokaanu Stream there are essentially no useful in-stream flow measurements or annual flood maxima.

In both these situations, regional flood estimation could have been used to provide additional support for the likely magnitude of the design floods. The scaling of the annual flood maxima from adjacent catchments provides a useful 'first approximation' of the magnitudes of design floods. These estimates would certainly have benefited from consideration within the framework of the regional flood procedure (Pearson & McKerchar, 1989).

It would appear from the preliminary discussion provided in the peer review that the design flood estimates for the Whareroa and Tokaanu Streams are likely to be very conservative i.e. higher flows are modelled than will likely be experienced.

Given the preliminary and 'screening' nature of these flood studies, and the fact that neither the Whareroa or Tokaanu flood models could be calibrated, it is considered that conservative flood estimates, and consequently flood extents, velocities and depth, are reasonable. For example, it will be easier to 'retract' or 'reduce' flood hazard areas as more information becomes available than to try to 'expand' them once development has taken place.

The regional flood frequency indices are currently being revised and updated to include all information collected since the original report (i.e. since 1985). Once these new indices are available it would be appropriate to undertake a revision of the design flood estimates for at least the Whareroa and Tokaanu Streams. This would, as suggested in the peer review, add significantly to the robustness and consistency of design flood estimates from either short records (i.e. Whareroa Stream) or when flood information has to be translated from adjacent catchments (i.e. Tokaanu Stream).

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.*

It is recognised that a scenario which includes a 100-year lake level and a 100-year flood is potentially extreme, at least in statistical terms. However, it was necessary to adopt a consistent scenario for all the various flood modelling. It should also be noted that the 100-year lake level adopted was that defined simply from the 1980-2014 lake level record. It does not include any of the various factors which are also likely to affect water levels e.g. seiche, subsidence, climate change, waves etc. Consequently the lake level adopted is actually not likely to be 'extreme', at least over the 100-year design period. However, the aim was to be slightly conservative rather than potentially under-estimating the potential flood risk. The difference in lake level between a 10%AEP and 1%AEP scenario (i.e. 14cm) is likely to be within the resolution of the various hydraulic models.

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 lack of calibration and validation data for any of the models, other than that for the Tongariro, is certainly a significant constraint. However, the model calibration for the Tongariro River is considered robust. Calibration showed an excellent match between the modelled and actual flood extents during the 2004 flood. Information gained from calibrating that model, with regard to building the bathymetry from LiDAR, model cell size, and roughness factors were used to inform the other models. Consequently there is a high level of consistency across all the various flood models used in the Taupō flood studies.

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.

As mentioned, the lack of calibration and validation data for the various flood models is a major constraint. The peer reviewer's suggestion that priority needs to be given to recording water levels and flood extents during any large event is endorsed. While there are obviously a number of priorities during large floods, the value of accurate information regarding the extent and depth of flooding cannot be over-estimated.

The 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.

The Taupō flood studies was a combined project involving both the Taupō District and Waikato Regional Councils. Consequently there was a need to retain a consistency of approach when defining flood hazard. The hazard matrix, and definition of various hazard categories, adopted were those already used extensively throughout the region.

It is recognised that a 'low hazard' defined largely on 'structural criteria' may not recognise the economic and social costs once flood waters get above floor level. There is also an assumption that all affected persons are able bodied and mobile which may not be the case. In addition, a low hazard does not indicate no hazard which may be a possible interpretation.

In the Taupō flood studies the standard flood hazard matrix needs to be modified when assessing the flood hazard as a result of high lake levels. This is because lake flooding does not generally have a velocity component and hence information exists for only one variable in the matrix i.e. water depth.

As a result of recent flooding in Christchurch, and the consequences and effects of this flooding on people and property, it might be appropriate to re-assess the current regional flood hazard matrix. The significance of floor levels might provide one basis for subdividing the low hazard category. This could result in finer definition of the 'low hazard' zone, and a recognition of various consequences and impacts of flooding other than simply structural failure.

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 run-up. 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 run-up 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 run-up 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.

As discussed in the peer review, the use of 'static' water level is not strictly correct. However, the term was adopted to describe the water level across the entire lake, independent of any waves, wave run-up, or tectonic deformation around the shoreline.

The general approach followed and the concept of using effective water levels to manage the joint probability issue of wave run-up 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 run-up 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.

Further refinement and calibration of the wave environment of Lake Taupō should be based on a more modern wave hindcast model, such as SWAN 2D. However, the development of a new model, and its calibration, was beyond the constraints of this project. Consequently it was decided to use an existing model (i.e. LAKEWAVE (Hicks *et al.*, 2000; Hicks, 2006)). This had the advantage of retaining consistency when modelling wave run-up across the various studies which have investigated the wave regime, and its effects, on Lake Taupō.

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 run-up. However, *since the extreme seiche amplitude is small relative to the static lake level and wave run-up 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).

The purpose of the various flood studies was to provide a District-scale assessment of the potential flood risk over the longer term. Both the scale of the studies, and the long time frame considered, meant that a conservative approach had to be taken. It is recognised that when applying a conservative approach to a multi-parameter situation might result in an 'overly conservative' outcome.

However, in most situations many of the parameters which affect flooding have only a very small effect on the final water level or flood risk e.g. seiche, climate change etc. Consequently even adopting a conservative approach to these parameters actually has only a minor effect on the outcome. In addition, it is also possible that a particular combination of parameters could occur over the longer term. Likewise, while it is likely that some parameters have been slightly over-estimated it is also possible that some have been under-estimated. This uncertainty is usually accommodated in some 'free-board' level, which has not been included in the Taupō flood studies.

Furthermore, the studies were never intended to provide precise flood risk assessments at the level of individual sites or building platforms. In effect, the studies were developed largely as a screening tool to identify those areas where flood risk is not a consideration, and those where some further investigation may be warranted. The uncertainty inherent in both flood modelling of extreme design events, and a District-scale assessment, mean that the resulting flood maps should not be regarded as 'definitive' or having a high level of precision. While confidence can be placed in the maps, given the various assumptions and the present situation, should either of these change then so too might the flood hazard.

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

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.*

One of the outcomes of this study could be a recommendation as to the kinds of modelling, and scale of modelling, which should be used to better define the risk from flooding or wave run-up in particular locations. These recommendations would include discussion of those elements identified by the peer review team.

The costs associated with the detailed assessment of the risk at particular locations should perhaps be borne by those who will benefit from the development rather than by Council. Providing this level of detailed investigation is potentially beyond both the 'District's capacity to pay' and the 'District's responsibility'.

5 Editorial comments

The peer reviewers provided a number of comments relating to either all the reports or specific sections of each report. These comments included 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. A number of typographical and other errors or points of confusion were also identified. Wherever possible the final versions of the various reports have been amended to include the suggested information, corrections, or clarification.

6 Conclusions

The various flood studies provide a District-scale assessment of the potential flood risk over the longer term. There will always be some residual uncertainty in any flood modelling, particularly of more extreme design events. Consequently, a slightly conservative approach has been adopted. Given the District-scale nature of the studies they may not provide precise flood assessments for individual sites or building platforms.

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

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

The limited flow information available for both Whareroa and Tokaanu Streams is particularly problematic. Following the release of the updated regional flood estimation parameters the design flows for these two catchments should be reviewed, and if necessary the hydraulic models re-run using any revised hydrographs.

The studies provide a consistent assessment of the flood hazard posed by Lake Taupō and its various tributaries given the current state of knowledge. However, should a large flood event occur, and calibration data become available, consideration should be given to updating the particular flood model and its results.

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