SUPPORTING TAURANGA CITY COUNCIL'S INTEGRATED STORMWATER PROJECT

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ABSTRACT

A large storm event occurred in Tauranga in April 2013. Consequently, Tauranga City Council (TCC) came under significant pressure to remedy the flood hazards apparent to the public. The first step in the flood mitigation efforts that were part of TCC's Integrated Stormwater Project (ISP) was to develop computer-based models of all catchments across the city for flood-hazard assessment and mitigation-option testing. DHI was engaged by TCC to assist in the field of stormwater modelling.

At the beginning of the ISP, initiated in 2013, TCC had seven flood models already constructed by a number of different consultants based on a variety of approaches. As part of the ISP, four engineering consultants were selected to construct the twelve remaining stormwater catchment models. A significant effort was made to standardise the model-build approach, to ensure some degree of consistency between models.

DHI provided simulation technology, produced technical components of the tender briefs, undertook the technical peer review, and provided software and flood-modelling assistance to both TCC and the consultants.

Technical aspects that set the models constructed for TCC apart from previous studies include: explicit representation of all council-owned sumps, rain-on-grid hydrological approach, and the combination of raised footprints and high roughness to represent building blockage. Each of these approaches are justified by practical model-build experience and the intended use of the results.

A wide range of documents have been produced to support the ISP, including flood-modelling guidelines, largely-standardised technical tender briefs, a tested peer-review schedule, peer-review checklists and peer review reporting.

As a result of the ISP, Tauranga City Council has moved from providing an indicative level of service (too costly) to focusing on flooding that directly threatens life. Many of the flood models, developed as part of the ISP, have already been used successfully in options assessments.

KEYWORDS

Tauranga City Council, flood, modelling

PRESENTER PROFILE

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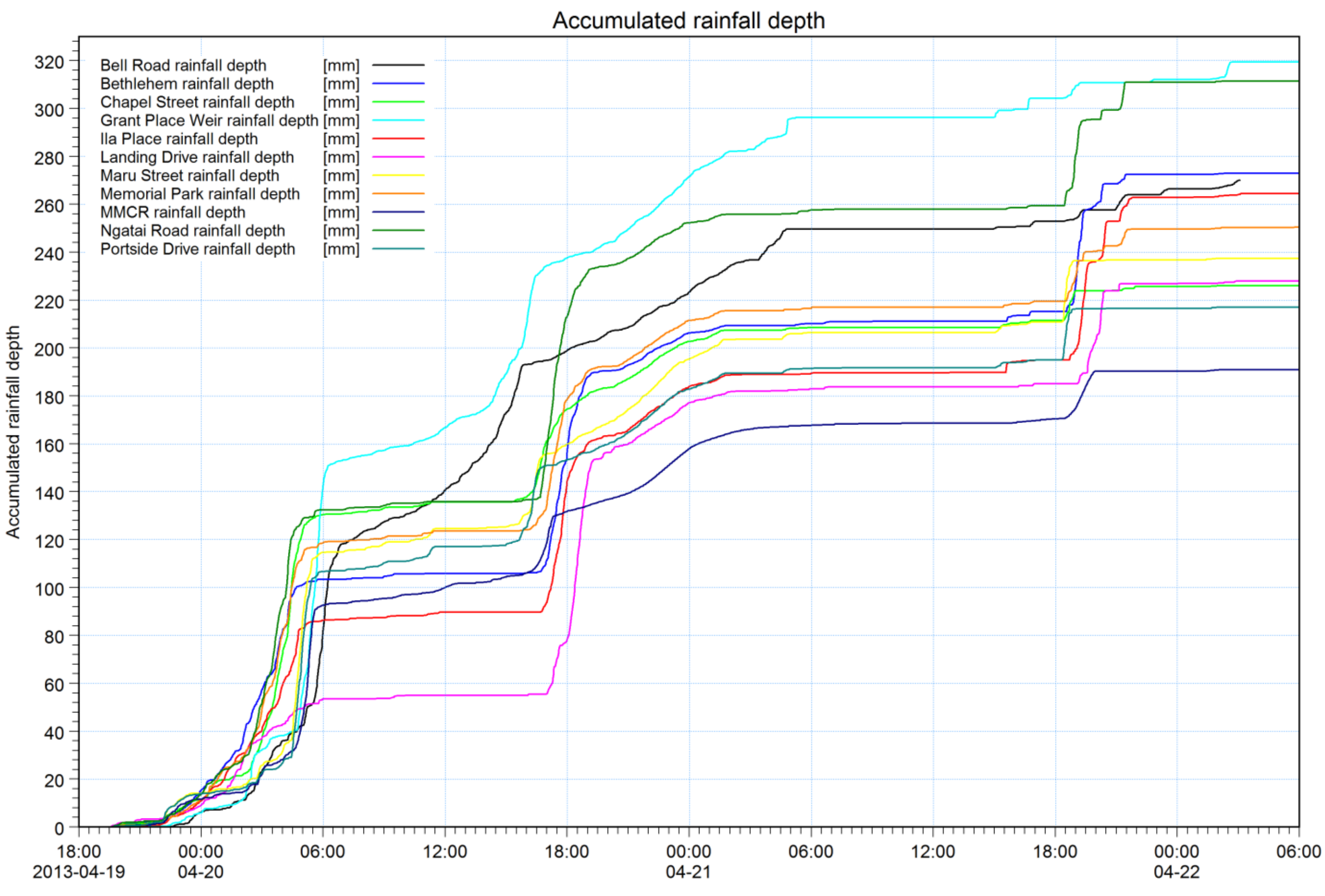
1 INTRODUCTION

1.1 THE APRIL 2013 STORM

The April 2013 storm event in Tauranga resulted in $11.5 million in insurance costs, $7.3 million of which were due to damage to residential property (Insurance Council of New Zealand, 2013). Rainfall varied in depth and timing across Tauranga: Figure 1 presents accumulated rainfall depth at eleven raingauge locations. The majority of the rainfall was delivered in three peaks, which are indicated by steep increases in the plotted lines in Figure 1, at around 5:00 20th April, 18:00 20th April and 20:00 21st April. The relative intensities of the three peaks was different for each raingauge, but generally the second peak delivered the most rainfall. Analysis of storm return periods, carried out by TCC for ten of the locations presented in Figure 1, suggests that across all raingauges and peaks, a 1 in 20 year event was only produced by the first peak at the Grant Place raingauge and events slightly greater than 1 in 5 year were produced at only five other gauges. The second and third peaks contained storm events lesser than 1 in 3 year, with the exception of a 1 in 5 year event at the Bethlehem raingauge (Dohnt and Groves, 2013). At the time, TCC's Infrastructure Development Code (IDC) required that the stormwater system provide protection for building floor levels from flooding in a 1 in 50 year event, with a 300-500 mm freeboard. In short, the IDC suggests that the April 2013 storm event should have caused no damage.

Figure 1: Accumulated rainfall depth measurements for the April 2013 storm event at eleven raingauges across Tauranga.



1.2 THE RESPONSE TO THE STORM

Prior to the April 2013 storm event TCC had commissioned the construction of seven flood models. Plans made subsequent to the storm allotted budget for the construction of nine more stormwater catchment models over two years at an estimated cost of $200 000 each (Dohnt and Groves, 2013). This work was to come under the Integrated Stormwater Project (ISP). Another three models were commissioned beyond this timeframe. Time frames for completion of each model was estimated to be 6 – 8 months. Figure 2 provides an overview of the stormwater catchment boundaries and Table 1 presents their priority and actual time taken to complete. Note that the models for the seven highest priority catchments were either constructed or construction was initiated prior to the April 2013 storm event and so were not part of the ISP.

Figure 2: Map of stormwater catchment boundaries in Tauranga, where completed catchments are those that were comissioned prior to the ISP.

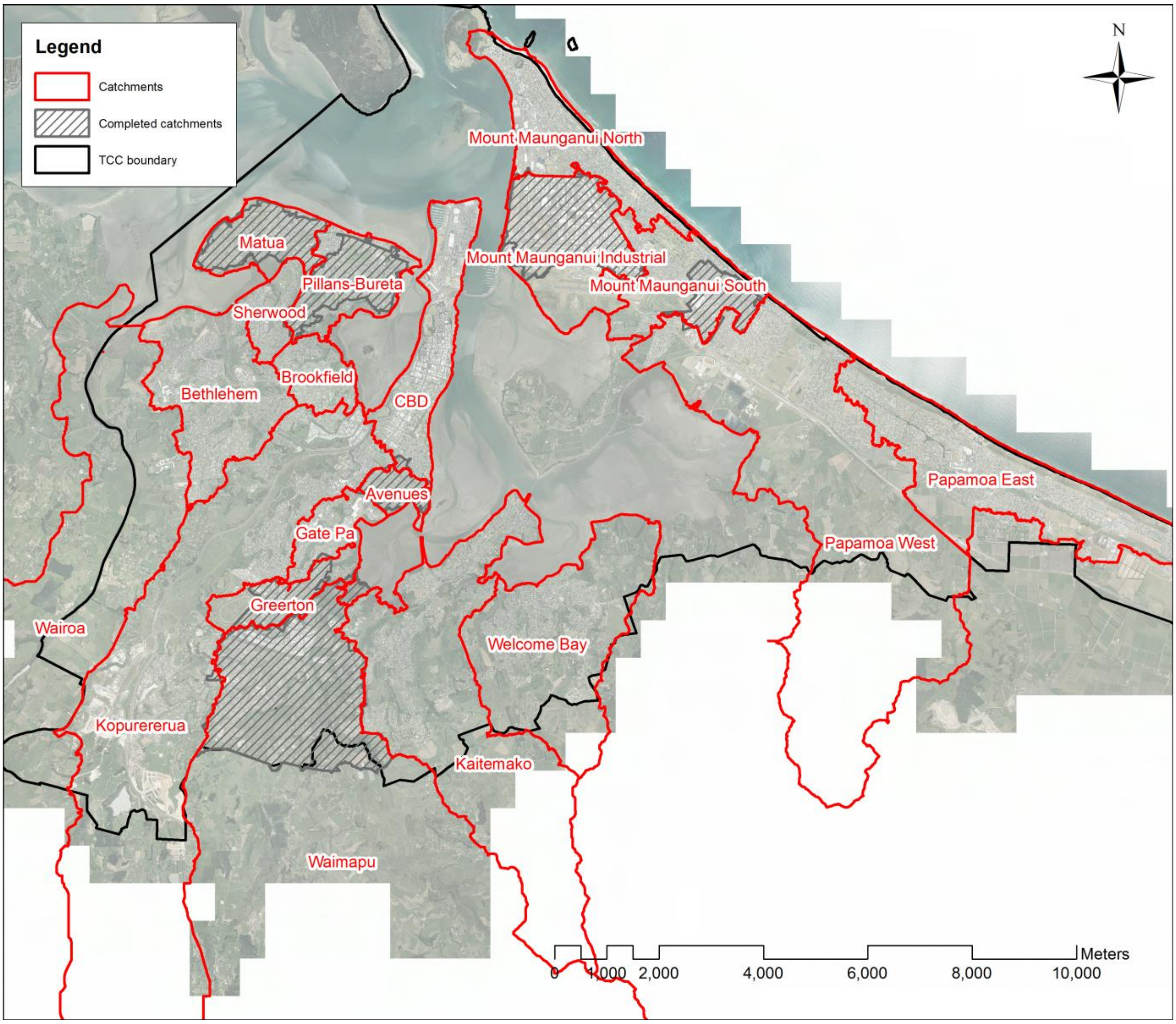


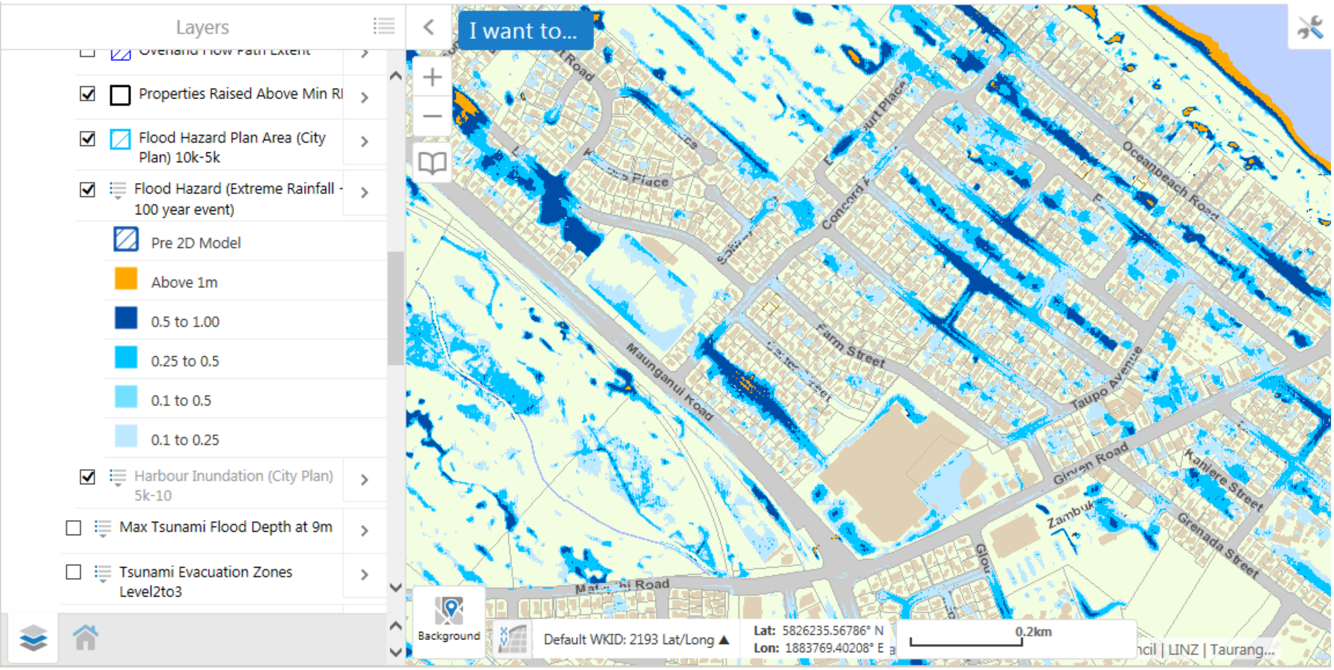
Table 1: Stormwater catchment priority order, site visit date and estimated and actual time taken to complete.

Priority	Catchment	Area (ha)	Site visit date (start of project)	Approx. time to complete (months)	
				Estimated	Actual
1	Greerton	198	-	Prior to ISP	Prior to ISP
2	Mount Maunganui Industrial	560	-	Prior to ISP	Prior to ISP
3	Pillans-Bureta	317	-	Prior to ISP	Prior to ISP
4	Matua	253	-	Prior to ISP	Prior to ISP
5	Avenues	87	-	Prior to ISP	Prior to ISP
6	Waimapu	10447	-	Prior to ISP	Prior to ISP
7	Mount Maunganui South	436	-	Pilot study	Pilot study
8	Mount Maunganui North	437	10th December 2013	7	10
9	Kopurererua	7378	11th December 2013	8	26
10	Sherwood	141	12th December 2013	6	23
11	Papamoa East	1334	9th December 2013	8	31
12	Gate Pa	157	9th October 2014	6	13
13	CBD	436	11th September 2014	6	20
14	Papamoa West	2534	27th November 2014	6	21
15	Brookfield	168	20th November 2014	6	13
16	Wairoa	44635	17th November 2015	8	Work in progress
17	Bethlehem	639	16th July 2015	8	15
18	Kaitemako	1644	20th October 2015	6	13
19	Welcome Bay	1010	8th December 2015	6	Work in progress

In order to expedite the tendering process, TCC short-listed four engineering consultancies and engaged DHI in an assistance role to oversee the technical aspects of the modelling work. The existing Mt Maunganui South stormwater catchment model was revised and the domain enlarged (see difference in completed vs. catchment extents in Figure 2) by DHI and used as a pilot model to test some unfamiliar modelling approaches to be used for all future modelling work. A one-day workshop was held in Auckland with the modelling teams from the short-listed consultancies and the methodology applied to the Mt Maunganui South model was presented as an exemplar: parameters and an outline of the construction process were provided. The intention was to standardise the methodology used across Tauranga, so that TCC staff need not familiarise themselves with methodologies specific to different catchment models.

At the beginning of each model-build project a kick off and schematisation meeting and site visit was held in Tauranga, attended by the consultant's lead modellers, the DHI peer reviewer and TCC staff. The first schematisation meetings took place over four days beginning on Tuesday 10th December 2013. While there were many factors that contributed to delays in delivery of the models, by the close of 2016 (3.5 years after the April 2013 storm event) ten models had been completed and peer reviewed and flood hazard maps had been produced. Flood hazard maps have been produced using design storms, both specific duration and Chicago-temporal-pattern based. TCC has presented these maps to the public by means of a viewer on the TCC website. A screen shot of maximum flood depth map, available through the TCC website, is shown in Figure 3.

Figure 3: Screen shot of flood hazard maps available through the TCC website.



In addition to maximum flood depth, TCC have used a hazard classification based on the maximum value during a flood event of instantaneous current speed multiplied by instantaneous depth. In light of the ISP results, TCC has adopted an approach to flood risk management that focuses on "safety to persons". Priority of future works is based on lessening flood hazards to the greatest number of affected properties: top priority is to residential properties with habitable floor areas within 8 m of flood hazards above specific thresholds (Tauranga City Council, 2016). Several of the catchment models have already been used for testing future development and mitigation options.

2 TECHNICAL OVERSIGHT

2.1 OVERVIEW OF SERVICES PROVIDED

DHI has proved modelling services to TCC in the stormwater field since 2010. Involvement in the ISP for DHI was not only an intensification, but also an extension of these services. Tasks related to all catchments, or to specific catchments. The following is a list of tasks undertaken that had a bearing on all catchments.

1. Update of TCC's *Guidelines for Stormwater Modelling using MIKE FLOOD*, which formed the basis for the ISP model builds: this revision was finalised in November 2013 in time for the first round of models.

2. Revision and extension of the Mt Maunganui South stormwater catchment model, which provided the opportunity to locally test software functionality and newly-developed methodology. The experience gained in this pilot model work was indispensable, particularly in identifying gaps in methodology and bottlenecks in the model-build procedure ahead of presenting to professionals from four different consultancies.

3. Refinement of stormwater catchment boundaries based on TCC's stormwater asset data: these were used for TCC maps of all catchments involved in the ISP, but also in the production of tender briefs. Amalgamated watersheds generated through a

drainage analysis of TCC's LiDAR-based surface model, using sump locations as sinks, formed the basis of the catchments presented in Figure 2.

4. Compilation of local data relevant to soakage and infiltration and the estimation of model parameters to be used in all catchments as defaults. This analysis touched on important characteristics influencing soil drainage in both the coastal strip (sandy, flat) and mainland (loamy, steep) areas.

5. Development of techniques for upgrading MIKE FLOOD models that use MIKE 21 Classic for the overland flow component, to use a MIKE 21 Flexible Mesh component. This effort was brought about by the need to reduce the simulation run times, especially during the validation stage of the model builds. The use of MIKE 21 Flexible Mesh was only considered after the first round of models had been commissioned, so the conversion contributed to delayed deliveries.

6. Provision of a technical methodology workshop at the inception of the modelling component of the ISP. At this one-day workshop, team members from all short-listed consultancies were invited and an outline of unfamiliar methodology to be used for the modelling was covered. At this point parameter sets, such as floodplain roughness, were agreed upon. While determining many parameters as a group and prescribing methodologies may reduce consultants' freedom, most were keen to be relieved of the burden of justifying decisions concerning parameters.

7. Provision of assistance to consultants during the model build stage and technical problem solving. When issues arose in individual models, solutions were sought that would be applicable across all stormwater models across Tauranga. These solutions informed changes to the methodology throughout the ISP and will be included in the next revision of TCC's *Guidelines for Stormwater Modelling using MIKE FLOOD*. Because of the evolution of the methodology, models built towards the end of the project differ in subtle ways from those built at the beginning.

For each stormwater catchment model DHI provided the following assistance to TCC staff and the consultant.

1. Development of the technical component of the tender brief.

2. Review of the non-financial component of the tender provided by the consultant to ensure adherence to the tender brief.

3. Attendance at the schematisation meeting and site visit as well as all technical meeting regarding the catchment model.

4. Peer review of the model, results and associated documentation and the provision of comments and formal recommendations to TCC concerning the state of the model and results.

5. Response to software and model-build procedure queries from the consultant. Acting as the peer reviewer, DHI was frequently relied upon by consultants to provide precise guidance on parameter sets and model build procedures, which would otherwise be sought in-house. While this was demanding and somewhat compromising from an impartiality perspective as peer reviewer, this approach produced a high degree of coherency between models built by different consultants.

2.2 UNFORESEEN ISSUES

Several unforeseen issues caused delays in many of the model-build projects. The following are a list of some of the most significant issues encountered.

1. Lack of human resources on the model build side. Whether the modeller leaves the consultancy, goes on leave or is diverted to another urgent task, model build efforts stall. The ISP flood models are sufficiently complex that it is very difficult for another modeller to pick up a model built by someone else, particularly part way through a model build, without repeating work already carried out.

2. Lack of human resources on the peer review side. As it was never the case that models, results and documentation were ready precisely to programme, scheduling the peer review work was difficult and often peer reviews would be delayed due to other commitments. This is particularly true when one staff member was peer reviewing more than one model. The level of engagement, required of the peer reviewer, was much greater than usual.

3. Interaction between neighbouring catchments. For example, finalisation of the flood hazard mapping for Papamoa East had to be delayed to incorporate highway-overtopping flows from the Papamoa West catchment. As Papamoa West was viewed as a lower priority, work on this catchment was commissioned a year after work on the Papamoa East model.

4. Runtime delays. The requirement that a 2 m x 2 m cell size be used uniformly across all catchments caused runtimes for MIKE 21 Classic models to become unacceptable. Solutions to remedy this issue included increasing the cell size to 4 m x 4 m in the largest models, Papamoa East and Kopurererua, and converting models to use MIKE 21 Flexible Mesh (FM), which can make use of Graphics Processing Units (GPU). Delays were particularly severe in the case of conversion to MIKE 21 FM as this platform was uncommon in flood modelling at the time and there was little experience with it both among the consultants and DHI staff.

5. Difficulties in representing infiltration in the Papamoa East catchment. The Wairakei Main Drain is a prominent feature in the Papamoa East catchment and coincides mostly with peat, which lines the bed of a pre-existing stream. The drain has four level gauges which proved difficult to match for the April 2013 storm event without tuning local infiltration rates. Flooding elsewhere in the catchment, which was overpredicted by the model, indicate that the surface infiltration does vary spatially, but insufficient data or measurements exist to justify locally tuning infiltration, especially when there is uncertainty about the spatial variation of the rainfall.

2.3 DISCUSSION

The technical assistance provided by DHI to TCC staff was crucial in the successful undertaking of the ISP. A number of MIKE FLOOD models, which differed significantly in size and prominent hydraulic features, were produced by a range of consultants and modellers to a reasonably consistent set of guidelines. The role of overseeing the technical methodology was challenging and exhausting. A large part of the challenge was the massive responsibility of the role: software issues, model-build procedures, methodology decisions and judgements of the quality of peers' work. All matters were urgent as they could potentially stall progress on multiple model builds. The pilot model study certainly reduced this pressure, however it did not resolve all issues. Having all project management tasks taken care of by someone who is not involved in deciding on technical aspects was extremely important.

The fact that models follow the modellers that built them is something that happens outside of the ISP, but this phenomenon was highlighted during this project. Although consultancies are engaged to construct flood models, the number of people capable of leading a flooding model build in NZ is so small that all consultancies struggle to maintain sufficient depth in their modelling teams. High staff turnover in these teams disrupts model builds and lowers the quality of the final product. It is advised that clients consider the individuals that will be directly involved in the modelling work and not the organisation's credibility or past performance.

3 MODEL FEATURES

3.1 INTRODUCTION

Several flood modelling methodologies uncommon in New Zealand prior to the ISP were incorporated into the models built in this project. These items include the following, which will be described in further detail in the subsections below.

1. Explicit representation of council-owned sumps.

2. Rain-on-grid hydrological approach.

3. Building footprint treatment for flow blockage.

3.2 EXPLICIT REPRESENTATION OF COUNCIL-OWNED SUMPS

Prior urban flood modelling work in Tauranga relied on estimates of upper-limit inflow capacities developed for a range of different types of sumps found in Tauranga. The inflow-depth capacity curves were simply composed of a default orifice flow curve and an upper limit specific to the sump type. In the model, a link from the surface to each stormwater main line manhole was made and the parameters controlling the inflow were based on a sum of the capacities of the sumps connected to the manhole. This approach suffered from the following limitations: the capacity curve was not based on empirical evidence; the inlet area was often constrained by the manhole area; inflow into the stormwater main line system would only begin when the flooding reached the link location, not the locations of the sumps, which are often 100-300 mm lower; and as manholes are often placed in the middle of roads, water below the crest level of the road would not drain when the flooding had resided. This last point had particular significance for the April 2013 storm event as the storm was composed of three peaks in rainfall spread across two days.

To improve the sump capacity estimates for sag inlet conditions, the following steps were undertaken.

1. The GIS data set for Tauranga's almost 14,000 council-owned sumps was analysed and a simplified set of 19 different sump sizes and configurations was decided on.

2. A simple mathematical model was developed from approaches specified in Brown et al. (2009) and Guo and MacKenzie (2012).

3. The sump sag-inlet model parameters were tuned with the little sump inflow performance information that was freely available. The Colorado Department of Transport (Guo and MacKenzie, 2012) was an important source of information as

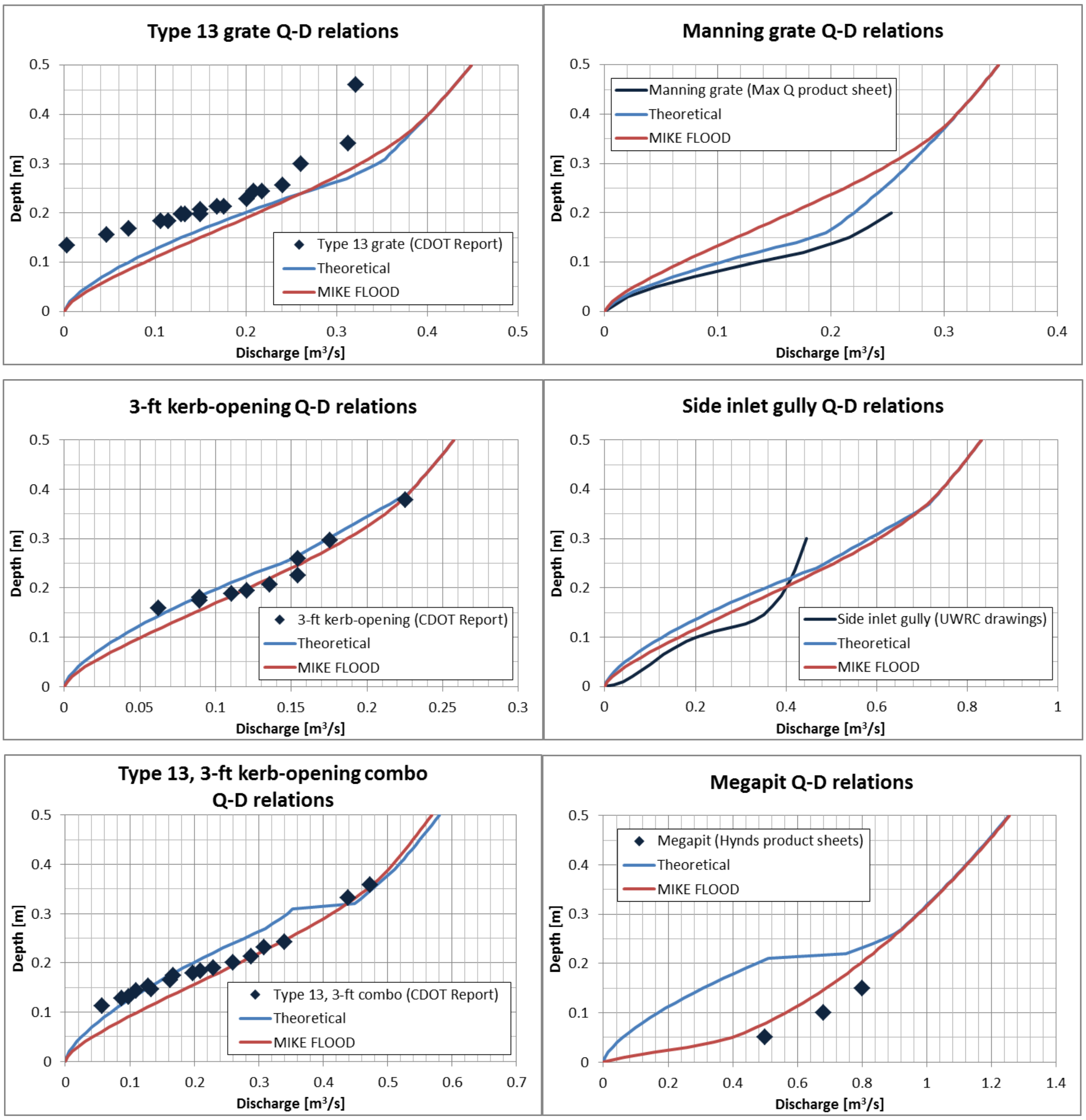
they have published physical model study results for grates of a similar size to those common in New Zealand.

4. The sump sag-inlet model parameters were modified to suit the 19 sump configurations found in Tauranga and then MIKE FLOOD model parameters that best approximated the sump sag-inlet model curves were found.

5. Look-up tables that linked combinations of TCC GIS asset data table entries to MIKE FLOOD parameter sets were developed and provided to consultants.

Figure 4 presents sump capacity curves produced through the process described above, both theoretical and modelled in MIKE FLOOD, compared to empirical data: the top two are for grate-only sumps; the middle two are for kerb-opening-only sumps; and the bottom two are for combination grate and kerb-opening sumps. Although the fit with empirical data is not particularly good in any one case, a common set of parameters that produced the best fits across the board was adopted as this was deemed to be the most appropriate for extending to sumps that empirical data is not available for.

Figure 4: Example Sump sag-inlet capacity curves (Q-D).



With look-up tables and TCC's extensive GIS data coverage, it was possible for model builders to quickly import all sumps in each catchment and assign appropriate parameters. By incorporating the sumps explicitly, simulated drainage is more accurate and reliable and this approach actually requires less modelling effort and conceptualisation, although there will be small simulation runtime penalties. Results from the simulations also show that distributing flow across many sumps has a noticeable stabilising effect on the hydraulic pipe models.

All sumps were modelled in all models whether the hydrology was represented by rain-on-grid or traditional lumped subcatchment models: in the latter case subcatchment discharge was dumped directly onto the MIKE 21 overland flow model surface next to the sump location to allow ponding on the surface before the water entered the inlet. Thus it would be possible to change hydrological model type without modifying the sumps. This allows greater flexibility in hydrological model choice and minimises the work required if the decision is revised at a later point.

3.3 RAIN-ON-GRID HYDROLOGY

3.3.1 THE APPROACH AND ITS ADVANTAGES

The rain-on-grid hydrological approach dispenses with traditional subcatchments, which prior modelling work had relied upon, and applies rainfall volume directly onto each cell in the flood model. In the ISP, traditional lumped subcatchment hydrological models were used for the steep, highly-impervious mainland urban subcatchments and rain-on-grid was used for the CBD and the catchments on the coastal-strip. Rain-on-grid was preferred for the coastal-strip models because the sandy soil is highly pervious and so ponding trapped in the naturally occurring troughs between historic dunes will drain very quickly into the ground: there was concern that the catchments would not respond correctly to the April 2013 storm event, used for validation, if hydrological losses were only accounted for before the water reached the overland-flow surface model, as is the case for lumped subcatchments models. In implementing a rain-on-grid approach in a flood model, maps of infiltration rates and spatially-distributed rainfall are preferred, but not necessary: uniform rainfall was assumed for all models in the ISP. All consultants were given assistance in setting up maps of infiltration and leakage parameters that reproduced storage and constant continuing losses based on building and road footprints and remote-sensing of impervious ground coverage, see Figure 5.

Figure 5: Example of land cover estimates based on TCC building and road footprints and remote-sensing.

A theoretical benefit of the rain-on-grid approach is that the boundary between the hydrological model and the hydraulic model is moved upstream of the area of interest, in TCC's case this is flooding in public spaces, including streets. In traditional lumped subcatchment models the boundary is where the runoff discharge from the subcatchments is loaded into the pipes or channels or onto the surface of the hydraulic model; in the rain-on-grid model the boundary is where rainfall contributes water volume to each cell. Model-build best practice dictates that boundaries should be distanced from the area of interest so as not to influence the results: in ocean models this is possible by extending the expanse of the domain outward in a horizontal direction or in river models upstream (for inflow) and downstream (for outflow); this approach is not applicable in two-dimensional flood modelling as the boundary is directly above the area of interest, so an alternative is to include more of the processes, traditionally viewed as hydrological, in the hydraulic model. The rain-on-grid approach allows estimates of flooding to be made at every point in the domain, the accuracy of these estimates is another matter that will be better understood in the future, whereas in lumped subcatchment models flooding estimates can only be made for areas touched by flooding extents, which are heavily influenced by choices made by the model builder in locating subcatchment discharges. To limit the impact of variability in model builder decisions with regard to subcatchment delineation in mainland catchments where subcatchments were used, subcatchments were consistently delineated at the sump level, although this is not a completely satisfactory solution.

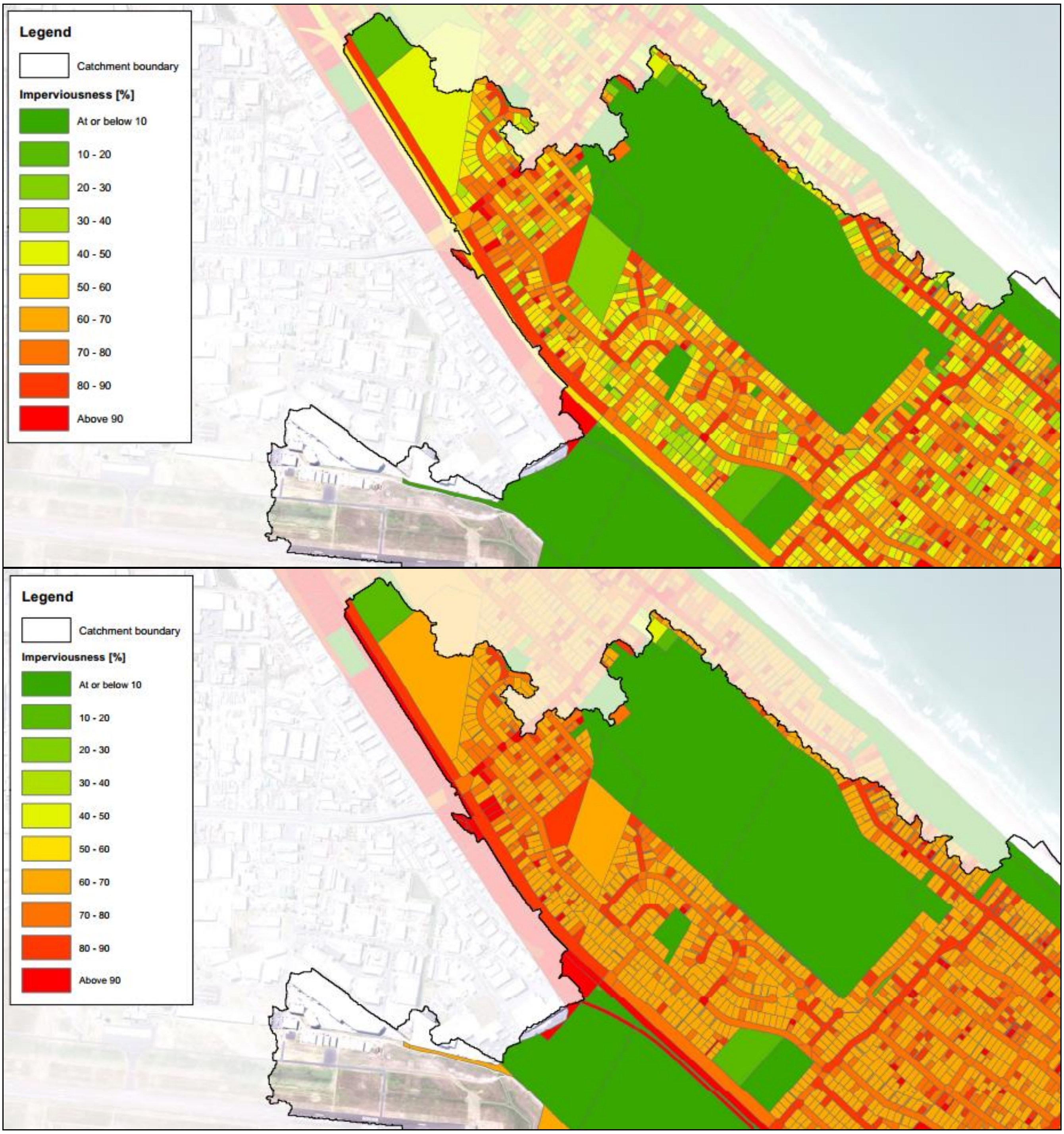
3.3.2 HYDROLOGICAL LOSSES

The pre-existing approach for updating lumped catchment imperviousness estimates for future development scenarios was extended to account for the greater resolution of spatially-distributed parameters in the rain-on-grid approach. Where, in the past, each subcatchment was intersected with future planning zones, each with their own imperviousness estimate, and assigned weighted averages of imperviousness, in the new approach averaged imperviousness estimate increases are not straight-forward due to the uneven distribution of existing imperviousness across property parcels within each planning zone. The solution devised was as follows.

1. Estimate existing imperviousness in every property parcel.
2. Compare existing to future estimates of imperviousness for each property parcel based on future planning zones.
3. Calculate the increase in imperviousness for each property parcel.
4. Reduce the infiltration losses in the pervious cells in each property parcel accordingly.

This analysis was useful in itself as it provides a property-parcel-resolution map of where in the catchment increases in runoff are likely to occur. Figure 6 presents portions of maps of existing and future imperviousness in the Mt Maunganui South catchment.

Figure 6: Existing (top) and future (bottom) estimates of imperviousness.



Private soakage is wide spread in Tauranga, particularly on the coastal strip. In order to account for this in the rain-on-grid approach, soakage capacity was approximated by initial and continuing loss per square metre of roof area and applied to the building footprints. Examples of initial and continuing loss rates used for roofs and other land cover classifications are given in Table 2. The large value of initial loss used for the roof reflects the relatively large storage available in soak holes. Different soakhole-to-roof area ratios will yield different combinations of initial and continuing losses.

Table 2: Examples of initial and continuing loss parameters used for different land cover classifications.

Land cover classification	MIKE FLOOD Parameters	
	Initial loss (mm)	Continuing loss (mm/hr)
Roof	27.2	16.6
Impervious	0.05	0.0083333
Residential pervious	10	23
Open area pervious	10	23

3.4 BUILDING FOOTPRINT TREATMENT FOR FLOW BLOCKAGE

The representation of flow blockage caused by buildings initially consisted of an extremely high roughness (Manning's M of 0.2, Manning's n of 5) applied to cells within building footprints. Results from the first round of models indicated that for commercial buildings, roughness was not sufficient to reproduce the blocking effect of solid walls and for residential buildings false LiDAR readings inside building footprints often caused ponds to form, which were not realistic. A one-size fits all approach was not appropriate, so the following was devised.

1. Residential building footprints: the elevation of all cells/elements are set to the same value, 100 mm above the maximum surface elevation inside the footprint and the roughness (Manning's M) should be set to 0.2. The intention of this arrangement is to divert shallow flows around the building footprint, while also allowing deeper flows to inundate the building footprint. It has been assumed that the majority of residential buildings in Tauranga are built on piles.

2. Commercial building footprints: the elevation of all mesh elements are raised 1.0 – 2.0 m above the maximum surface elevation inside the footprint and the roughness set to any reasonable value as it is largely irrelevant. It is assumed that flooding will not overtop the raised building cells/elements. The intention of this arrangement is to divert all flood flows around the building footprint, to exclude the storage area in the footprint from the floodplain. It has been assumed that the majority of commercial buildings in Tauranga have concrete slab or block foundations.

It should be noted that industrial buildings may be modelled according to either of the approaches suggested above, depending on specific building characteristics. In cases where the step in elevation from the building footprint to ground was large, dikes were added to pass water, predominantly rain falling on the footprint, in a stable manner. For buildings that had private soakage, the flat footprint, combined with high roughness resulted in most of the rain water falling directly on the footprint to be absorbed by the infiltration rates that were designed to account for soakage.

3.5 DISCUSSION

The modelling approaches described here are departures from traditional flood modelling practices and signal a move from small, simple models that are hand-crafted by expert engineers and have a well-defined purpose, to large, complex models that are more closely tied to data and may be appropriate for purposes not conceived by the model builder. It was intended that robust model build procedures and GIS-based techniques would allow large numbers of model components to be included without direct supervision of the model builder. The focus in the future will continue to move from the quality of the final product to the quality of the processes used to build the final product.

The author has noted that dispensing with subcatchments greatly simplifies options analysis for the modeller, however design engineers, for whom subcatchments are a familiar concept, can struggle to correlate model changes to design outcomes, so more work in the future will be required to improve this.

4 DOCUMENTATION AND PROCEDURES

4.1 INTRODUCTION

A range of documents and procedures associated with the flood modelling work were developed during the years that the ISP has been undertaken. The descriptions of these items are given in this section in order to give the reader some indication of the level of effort involved in overseeing a campaign of flood studies across an entire city.

4.2 TECHNICAL TENDER BRIEF

DHI produced technical tender briefs, of approximately 20 pages, for the twelve catchments modelled in the ISP. These tender briefs evolved during the project, but contained the following basic elements.

1. Introduction to the catchment with brief descriptions of size, extent, dominant terrain features and land use.

2. Description of pre-existing models.

3. Summary of the April 2013 flood event, including the rainfall from the closest rain gauge.

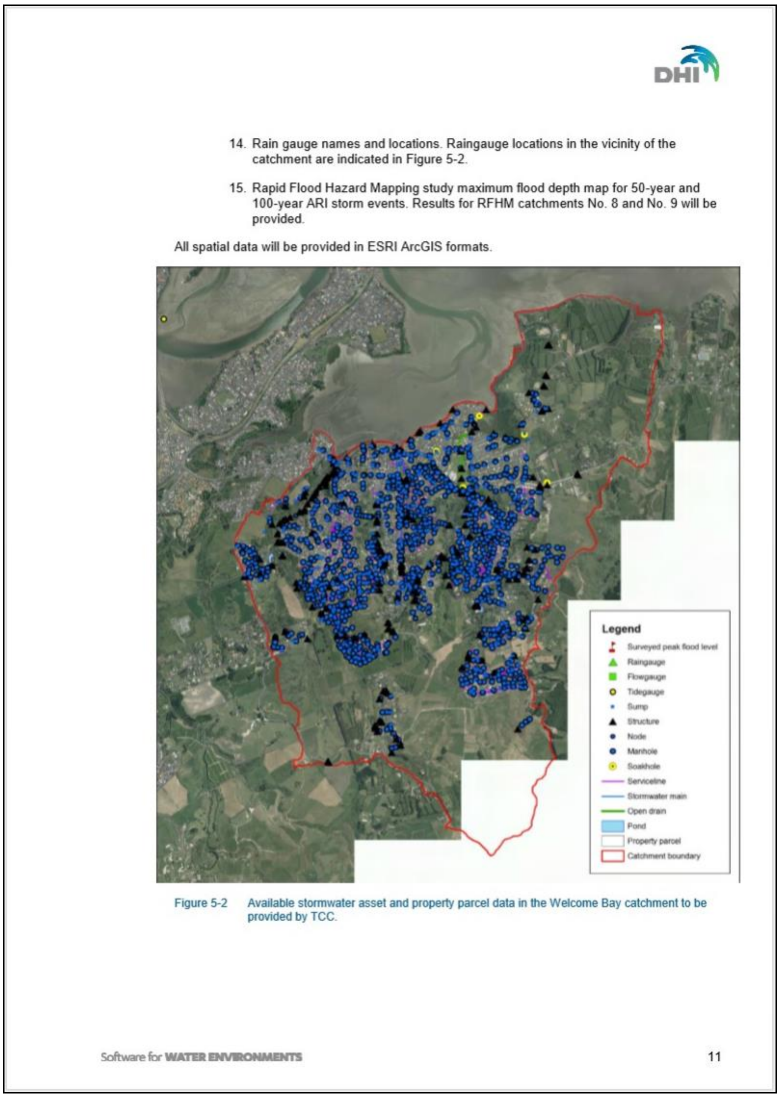
4. Summary of the scope of works, including the modelling platform to use, specific model-build techniques and features required to ensure the final model is consistent with other ISP models, and deliverables. In many cases where a model-build approach was deemed to be non-standard, a high level of detail was included.

5. Description of design-event scenarios to be simulated, the results of which will inform the flood-hazard maps.

6. Summary of available data, both spatial and non-spatial, and counts of TCC assets within the catchment (Figure 7 presents a page from the Welcome Bay tender brief with a map of TCC assets).

7. Description of the hydrology model approach to be applied.

Figure 7: Page from technical tender for the Welcome Bay tender brief with a map of TCC assets.



14. Rain gauge names and locations. Raingauge locations in the vicinity of the catchment are indicated in Figure 5-2.

15. Rapid Flood Hazard Mapping study maximum flood depth map for 50-year and 100-year ARI storm events. Results for RFHM catchments No. 8 and No. 9 will be provided.

All spatial data will be provided in ESRI ArcGIS formats.

Figure 5-2 Available stormwater asset and property parcel data in the Welcome Bay catchment to be provided by TCC.

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The intention of all these items is to allow the consultant to fairly judge the size of the model-build effort and the required standard and level of detail. Each technical tender brief was included in the request for tender material provided to short-listed consultancies.

4.3 PEER-REVIEW SCHEDULE

The precise peer-review schedule developed as the ISP progressed. Various changes in methodology, the most significant of which was the move from MIKE 21 Classic to MIKE 21 Flexible Mesh (FM), necessitated revisions. Table 3 provides an overview of the stages of the peer review process.

Table 3: Outline of the stages of the peer review process.

Stage no.	Description	Scope
1	Site visit and schematisation meeting	Broad-scale schematisation that includes division of the catchment into appropriate domains for the various model components (MIKE 21, MIKE 11 and MIKE URBAN); and conceptualisation of important hydraulic structures included in the site visit on the day.
2	Model build peer review	Confirmation that the model has been constructed according to the agreed schematisation, the guidelines and any agreed refinements in the methodology; and spot-checks of the implemented setup for each of the model components starting from the asset representation, land characteristics and use information and concluding in the computational stability of the preliminary validation simulation.
3	Validation and report peer review	Depending on the validation data available, several rounds of model-parameter adjustments are often required to achieve satisfactory agreement between simulated and observed flooding behaviour; and in addition to the final validated model, several sensitivity simulations were carried out for infiltration and computational scheme parameters.
4	Flood-hazard mapping and report peer review	Confirmation that the models used for flood assessment are correctly configured with appropriate representation of land use and drainage in the catchment and relevant model forcing (boundaries, joint design event composition etc.).

Figure 8 presents the more detailed schedule that consultants were provided towards the end of the ISP. This schedule includes 15 stages with specific details on how many simulations may be expected and arrows on the right-hand side indicating where failing to meet the peer review criteria would require returning to earlier stages.

Figure 8: Detailed schedule used in the peer review process.

	Stage	Responsible	Comments	Simulations
1.	Site visit and schematisation meeting	TCC and Consultant	A day meeting will be held between representatives from TCC, DHI and the Consultant. The Consultant shall ensure that the technical lead for the project is present; however it is preferred that the team member that will carry out the work is also present. The Consultant shall present a preliminary schematisation of the model domain and shall revise the schematisation based on comments from both DHI and TCC representatives. TCC shall arrange for a site visit of key locations within the model domain. DHI shall provide a spreadsheet outlining the items that will be covered in the Model build peer review stage.	
2.	Model build	Consultant	The overland-flow component of the final MIKE FLOOD model will be MIKE 21 FM. The Consultant may choose to use Classic grids (DFS2) to aid the development of the mesh and other model components, or it is possible to build the MIKE FLOOD model with a MIKE 21 Classic component and convert this model to FM. The "high-order" scheme for both the spatial and temporal domains and double-precision calculations shall be used in the simulaton provided at the peer-review stage. A depth correction grid and a mesh using square elements that correspond to grid cells must be used in the final MIKE 21 FM component.	Any number of simulations may be run: this is entirely at the Consultant's discretion. A simulation of the entire validation event shall be undertaken at the end of this stage to provide input to the Model build peer review.
3.	Model build peer review	DHI	The MIKE FLOOD model will be checked for major schematisation issues, conformance with the tender brief, modelling guidelines and other methodology directions, and general agreement with input data. The associated documentation will also be reviewed. The Consultant shall provide the model and associated validation-event simulation results and log files as well as the model-build documentation section of the final report. If the model, reporting or results are not deemed to be acceptable, the project shall return to the Model-build stage.	
4.	Model build approval	TCC	TCC staff will approve the completion of the Model-build stage based on DHI's recommendations.	
5.	Numerical-scheme sensitivity analysis	Consultant	The results from a simulation using the "low-order" scheme for both the spatial and temporal domains and double-precision calculations for the validation event will be compared to the results of the simulation that was peer-reviewed. The Consultant will produce an analysis of the sensitivity of the model to the numerical scheme.	One simulation simulation of the entire validation event will be required.
6.	Numerical-scheme sensitivity analysis approval	DHI and Consultant	The Consultant's numerical-scheme sensitivity analysis will be reviewed and the scheme to use in future simulations will be decided between DHI and the Consultant.	
7.	Validation	Consultant	For each iteration at this stage, the Consultant shall update the model where necessary, simulate the validation event and compare the results to the available flood incident information. The Consultant shall provide a unit price , as part of their tender, for updating the model, simulating the validation event and analysing and presenting the results of the simulation. A single variation shall be raised at the end of the validation stage to cover the costs of all the validation iterations. DHI and TCC shall confirm the need for another validation iteration, should specific changes to the model that are beyond the scope of the input data be recommended in order to improve the match of the model's predictions with validation information; however, model-build issues uncovered at this stage shall be remedied at the Consultant's expense and the subsequent simulation will not count towards the final variation. Technical meetings may be called by the Consultant to discuss results and model modifications. Every iteration at the validation stage shall be approved by TCC.	Any number of simulations may be required to achieve a satisfactory validation. The most-suitable simulation decided upon at the Numerical-scheme sensitivity analysis approval stage will serve as the first validation simulation.
8.	Preliminary validation approval	TCC and DHI	When the Consultant deems that the validation simulation sufficiently reproduces the flood incident information, a meeting will be called in which the Consultant will briefly present the validation results and TCC and DHI will decide whether to approve moving to the next stage.	
9.	Imperviousness sensitivity analysis	Consultant	The Consultant shall simulate a 20 % reduction and 20 % increase in surface imperviousness across the entire model domain. The sensitivity analysis shall be included in the reporting of the validation event simulation.	Two simulations will be required.
10.	Validation and report peer review	DHI	The MIKE FLOOD validation-event model, imperviousness-sensitivity models and results will be checked for major issues, the validity of the model validation will be investigated and the associated documentation will be reviewed. The Consultant shall provide the validation model, sensitivity-analysis models and associated results and log files as well as the validation documentation section of the final report and supporting maps and appendices. If model-build or configuration issues, including non-conformance with the tender brief or modelling guidelines, are uncovered during the review of the validation simulation results and associated documentation, then the Consultant shall, at their expense, update the validation model and simulate the validation event and the two imperviousness-sensitivity scenarios again. The Consultant shall then make a full peer-review submission again. If issues pertaining to data availability or methodology are uncovered during the review of the validation simulation results and associated documentation, then TCC shall authorise the Consultant to raise a variation to cover the costs of updating the validation model and simulate the validation event and the two imperviousness-sensitivity scenarios again. The project shall return to the Validation stage again.	
11.	Validation approval	TCC	TCC staff will approve the completion of the Validation stage based on DHI's recommendations.	
12.	Existing-development flood-hazard mapping	Consultant	The Consultant will simulate the Existing-development (ED), 2005-climate design event and post-process the results. Reporting will include flood-hazard maps and report documentation.	Two simulations will be required.
13.	Maximum-probable-development flood-hazard mapping	Consultant	The Consultant will simulate the Maximum-probable-development (MPD), 2055-climate design event and post-process the results. Reporting will include flood-hazard maps and report documentation.	Two simulations will be required.
14.	Flood-hazard mapping and report peer review	DHI	The MIKE FLOOD flood-hazard-mapping design-event models and results will be checked for major issues and the associated documentation will be reviewed. The Consultant shall provide the flood-hazard-mapping models and associated results and log files as well as the full final report and supporting maps and appendices. The final report including the documentation of the model-build, validation and flood-hazard mapping stages will be submitted by the Consultant. If issues, concerning the design-event simulations, are uncovered during the review of the flood-hazard-mapping simulation results and associated documentation, then the Consultant shall, at their expense, update the flood-hazard-mapping models and simulate the ED and MPD flood-hazard-mapping design events again. The project shall return to the appropriate flood-hazard-mapping stage.	
15.	Project completion approval	TCC	TCC staff will approve the completion of the project based on DHI's recommendations.	

4.4 PEER-REVIEW REPORTING

Documentation was produced by DHI at the model-build and validation stages and at the end of the project to serve as official confirmation for both TCC staff and the consultants that the modelling work has reached the required standards as well as evidence of the scope of the checks undertaken on the models.

At the end of the model-build and validation stages either an email or a brief memo was provided to TCC and the consultant, providing the recommendation that TCC allow the consultant to progress to the next stage. At the very end of the project DHI provided a more detailed peer review report that summarised the stages of the review and significant, agreed-upon deviations to standard methodologies. Other documentation from the earlier stages was compiled into appendices so that this report could stand as the first point of reference in the future for matters pertaining to the peer review. It was not the intention of this report to reproduce the detail of the consultants' reports, which focused on the modelling work and flood-map production.

At the model-build and flood-hazard mapping review stages a spreadsheet-based checklist was used by the peer reviewer to provide greater consistency between models. An example of the MIKE URBAN tab of such a spreadsheet is provided in Figure 9. Items requiring attention were highlighted and the consultant would subsequently revise the model and provide comments to the peer reviewer summarising the action taken. This was an effective way to track changes made to the models, which consist of a huge number of configurable parts, over what could be several iterations of reviews and revisions.

Figure 9: Example of MIKE URBAN tab of review checklist spreadsheet.

Model domain:	XXXXXX		Colour legend:	
Peer review stage:	Model-build and draft report peer review		Not done at all or still not at a satisfactory level	
Software used:	MIKE FLOOD (MIKE 21/MIKE 11/MIKE URBAN)		Addressed partially, still room for improvements but not critical	
Objective of review	Peer review of validation model configuration and associated documentation		Recommendation implemented fully and correctly	
Peer reviewer:	DHI/YYY			

Item	Description	DHI Comments Existing-design, Major	DHI Comments Existing-design, Minor	DHI Comments Future-design, Major	DHI Comments Future-design, Minor	DHI suggestion	TCC comment	onsultant comme	DHI Reply
Model set up: MIKE URBAN									
1	**General**								
1.1	Project check tool	Minor issue with catchment connections.	<-	No significant issues reported.	Minor issue with catchment connections "SC_60203" and "SC_60288" where connected subcatchments appear to have been deleted.				
1.2	Warning.html	Many warnings, but they all refer to minimum pipe lengths. The default of 10 m has been used, which is satisfactory.	<-	<-	<-				
1.3	Corrdinate system	Correct: "NZGD_2000_New_Zealand_Transverse_Mercator"	<-	<-	<-				
2	**Network model**								
2.1	Overview	Not checked as assumed mostly unchanged from model build stage.	<-	<-	<-				
2.2	Nodes	Not checked as assumed mostly unchanged from model build stage.	<-	<-	<-				
2.3	Links	Not checked as assumed mostly unchanged from model build stage.	<-	<-	<-				
2.4	Soakage	Not checked as assumed mostly unchanged from model build stage.	<-	<-	<-				
3	**Rainfall runoff model**								
3.1	Catchment	Not checked as assumed unchanged from model build stage.	<-	<-	<-				
3.2	Rainfall runoff model	ED estimates for initial and continuing losses are reproducible (with some differences in less significant digits).	<-	There are a number (>20) of subcatchments for which the initial and constant losses increase in the MPD scenario.	<-	Please investigate the initial and continuing loss parameters and provide a more comprehensive description of the process of developing MPD parameters.			
4	**Boundary conditions**								
4.1	Catchment loads	Not checked as assumed unchanged from model build stage.	<-	Catchment load item name has not been updated correctly. There is no impact on the simulation.	<-				
4.2	Network loads	-	-	-	-				
4.3	External Water Levels	Tidal timeseries connected correctly.	Tidal timeseries connected correctly.	The "80811_tide" boundary condition is connected to the existing tide level, which is 300 mm lower. This most likely will not have a significant impact on the results as the area drained is isolated and there is spare capacity in the pipe.	Tidal timeseries connected correctly.				
4.4	Soakhole losses	Soakhole values do not correspond to values used in other models. Value is conservative and will most likely not make much difference to the final water flood levels.	<-	<-	<-				
5	**Simulation settings**	Simulation period of 2 day 5 hours with 30 s save step.	<-	<-	<-				
6	**Results**								
6.1	General	Continuity imbalance and water generated in empty parts of the system are very small. Spot checks have been made, but results have not been inspected thoroughly. Water levels and discharges stabilise in the lead up to peak values, which suggests that the simulation period length is appropriate.	<-	<-	<-				
6.2	Instabilities in WL	In many low-lying pipes there is significant back flow at the start of the simulation.	There are instabilities throughout the system, but they don't generally affect peak values.	<-	<-				
6.3	Instabilities in Q	Overall the model is stable with minor oscillations in discharge throughout and generally during periods of low flows, so the peak values are mostly unaffected.	<-	<-	<-				
6.4	Instabilities in M21-MU	Flow exchange appears to be sufficiently	<-	<-	<-				

4.5 DISCUSSION

The large amount of documentation produced during the model peer review portion of the ISP could be considered by many as excessive. However, the author believes that it is necessary when multiple staff from the consultant, the peer reviewer and client are involved, in order to protect the significant investment that TCC has made in each of the catchment models. While this does add a burden, once exemplars have been developed and tested, on-going effort reduces. The checklist spreadsheets have assisted greatly in improving consistency in level of detail and model build methodologies across different models. It is hoped that the documentation will be of benefit to staff of TCC in the future.

The peer-review schedule, shown in Figure 8, is very detailed. This was found to be necessary so that everyone could understand exactly where in the process the modelling work was. It was useful to be able to physically point to a specific point on this schedule and agree on the next steps precisely. On many occasions, before the schedule was developed, there was some confusion during the validation stage as to exactly which simulations should be run and in which order. In some cases, where agreed by all parties, entire steps could be ignored, but all projects still progressed in a linear fashion from the top of the schedule, down.

5 CONCLUSIONS

1. Even relatively small flood events, when compared to those that are used in design scenarios, can have large political impacts for councils.

2. The flood modelling component of Tauranga City Council's Integrated Stormwater Project has been a success. The models produced are of a high and consistent level of quality. Flood maps are available on the council's website and some of the models already being used in options analysis.

3. Flood model builds take much longer than estimated, often for reasons out of control of the consultant. In general, it is unlikely that a model can be completed within a year's period. The longer a model takes to build, the greater the chance that staffing of the project team will change.

4. It is possible to include a high level of detail in flood models without significant increases in model build effort. Indeed, with the right procedures in place data entry effort and reliance on on-the-spot decision making can be reduced. Flood models will become more data-intensive in the future.

5. Maintaining a consistent technical methodology in projects such as the Integrated Stormwater Project is difficult because of the number of people involved from all parties (many being non-technical), the multi-year duration, and attending staff movements. This problem is exacerbated by the difficulty of handing over models of this complexity. By and large, these issues have been successfully managed by the various techniques outlined in this paper.

6. The relatively small pool of flood modellers in New Zealand means that consultancies struggle to maintain modelling teams and experience, so clients must be aware that the success of a modelling project often comes down to the individuals involved and not the reputation of the consultancy.

7. In order to maintain consistency across models, the peer review process was extensive and fine-grained, almost to the point where the reviewer was part of the model-build team.

8. A large body of documentation resulted from the Integrated Stormwater Project: this is necessary to protect Tauranga City Council's investment in the flood models.

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