TAUPO URBAN STORMWATER

Hydraulic Modelling Report

Taupo District Council

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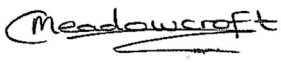
REVIEWED	 Colin Meadowcroft - Project Manager CDM Consultants Ltd
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1.0 EXECUTIVE SUMMARY

Taupo District Council (TDC) commissioned CDM Consultants Ltd (CDM) during late 2017 to develop two-dimensional (2D) Rain-on-Grid (ROG) stormwater models for their urban areas in order to better understand overland flow-paths affecting properties. The models included the best information made available by TDC at the time, with improvements and field validation undertaken by various summer students with CDM guidance.

A ROG hydraulic model is in its simplest form rainfall placed onto a Digital Elevation Model (DEM), otherwise called the 'Grid' or 'ground model'. The ground model is the contour of the land, normally measured by means of LIDAR (Light Detection And Ranging), which uses pulsed laser beams to measure distances to earth, typically from an aeroplane.

InfoWorks ICM (Integrated Catchment Management) software was utilised to undertake this hydraulic modelling for TDC. ICM is reputable software, known to be one of the best packages available for this purpose. TDC has historically preferred InfoWorks software and holds similar licences for wastewater and water supply modelling. TDC has also commissioned WSP to develop water supply models in InfoWorks WS Pro software.

The original ROG modelling was developed for a different scope and purpose from the subsequent proposal for inclusion within the Natural Hazards section of TDC's District Plan Review process. Further model development was necessary to ensure that the final models are more robust for this.

As intended, it is believed that the existing models have defined the general hazard areas within overland flow paths. These flow-paths are often defined with steep sided gulley's in the Taupo Region and can be relatively easily validated as such. The resulting overland flow-paths also compare well to previous work completed by AWT (now Mott MacDonald) several years ago.

The models did not generally have stormwater pipes well represented but were included around properties at flood risk, where pipes were added to better determine their effect on property flooding. Stormwater pipe invert levels generally had to be assumed with lacking asset data and no survey budget. However, for the extreme 100-year rainfall (1% AEP) events under consideration, the pipes generally have minimal influence on flooding as they typically may be designed to convey only a 2-5 year rainfall flow.

Taupo has been affected by relatively few severe urban stormwater floods in recent years with the most significant being January 2011. This event was estimated to be in the order of a 100-year return period event of 24-hours duration (not a critical duration). The models have not been calibrated or validated against known rainfall events as TDC does not collect measurable data for this purpose.

The models are a valuable tool if used with the understanding that a hydraulic model is never absolutely correct but is likely the best available tool to better understand the operation of the stormwater network during extreme rainfall events. The models are certainly useful for the purpose of understanding hazards and can easily define flow velocities, flood depths and therefore hazards. The challenge is being sure as to whether the absolute extent of predicted flooding is accurate.

It is expected that the existing flow-path locations are accurate but conservative with slightly wider extents and greater depths than reality. This confidence could be modified and improved further with reduction of rainfall-runoff and more understanding of groundwater infiltration. Survey of critical asset data, such as all larger culverts would also be a worthwhile improvement where possible.

2.0 INTRODUCTION

2.1 MODEL HISTORY & PURPOSE

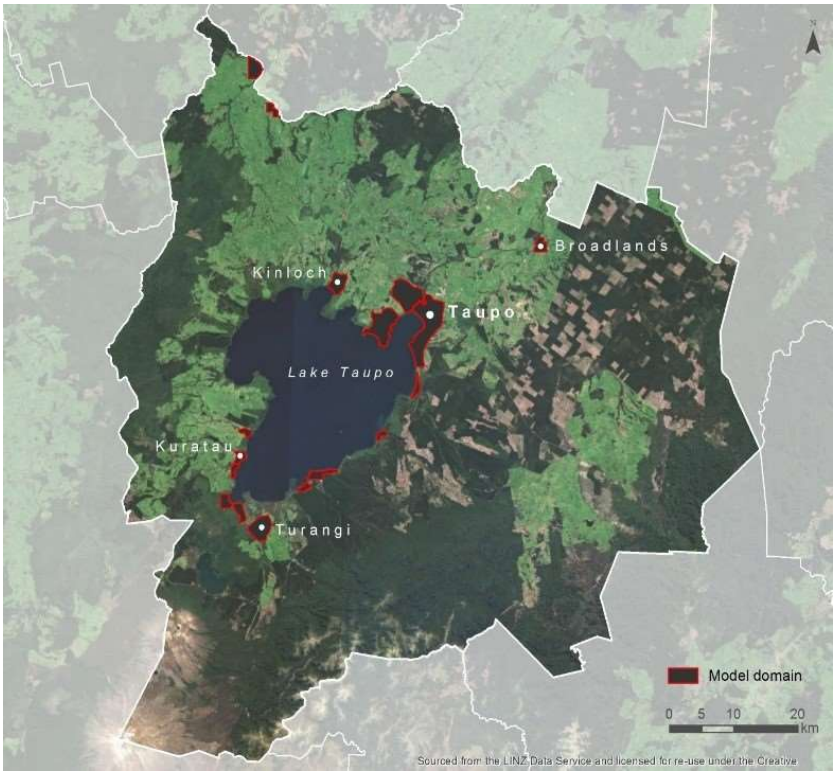
The urban stormwater models were initially developed simplistically with limited budgets to better understand residential properties at risk of stormwater flooding. The models are a valuable tool to develop solutions to mitigate stormwater flooding. The hydrology cannot be represented with absolute certainty given lack of historical flood flows or flood depths/damage. Therefore, the models were initially developed with a conservative approach with no groundwater infiltration and 100% rainfall runoff (not an unreasonable assumption for a highly urbanised area).

The model inputs include design rainfall, ground models based on latest available LIDAR, and limited pipe asset data. The models can provide various outputs however it is expected that flood hazard maps will be the most useful output to convey extreme rainfall event flood hazard information.

With a view to including the modelled flood hazard maps within the District Plan review, the existing models were reviewed by Tonkin & Taylor (T&T) to suggest improvements in order to improve the models accuracy for this purpose. Section 4 describes the model build in technical detail and section 7 describes CDM response to T&T model audit comments.

3.0 CATCHMENT DESCRIPTION

3.1 CATCHMENT EXTENT



The Taupo urban stormwater models include the full urban catchment extents where LIDAR was available in the following urban areas within Taupo Region:

Taupo	Omori	Broadlands
Nukuhau	Whakamaru	Whareroa
Acacia Bay	Mangakino	Waihi
Turangi	Hatepe	Tauranga Taupo
Tukaanu	Waitahanui	Motuapa
Kuratau	Kinloch	

The preliminary models were limited by LIDAR availability and generally excluded rural catchments which have now been included where necessary with point source inflows based on hydrological analysis by Te Miro Consultants Ltd.

With the availability of new LiDAR data and the rural inflows being applied to many catchment models, a higher degree of model accuracy can now be expected in areas of most interest.

3.2 TOPOGRAPHY

The latest LIDAR data has been sourced from TDC in the form of ASCII files so that the models include the latest available topographical information. The LIDAR used for modelling to-date was converted specifically for the modelling into a 1m grid for the 2D ground model. It has been recommended that LIDAR inputs are updated to be sure the latest data (with audit trail) is utilised.

The latest LiDAR data is now slowly being made available from the Waikato Regional Council (as of the 4th quarter of 2023). Currently, the latest LiDAR extents cover the stormwater models for Taupo, Nukuhau, Acacia Bay and Kinloch. The models will be updated as the latest LiDAR data is released for the remaining models.

3.3 RURAL INFLOWS

Previously, rural inflows were inconsistently applied to the models due to the lack of LiDAR data extending beyond the urban catchment. Te Miro Consultants Ltd were commissioned by the Taupo District Council to provide hydrographs from rural catchments into the urban catchments.

The rural inflows were calculated and applied in accordance with the TP108: Guidelines for stormwater runoff modelling in the Auckland region. These guidelines have been developed for steep catchments with little to no natural hydraulic storage within Auckland and identified as being similar to the catchment conditions in Taupō. In order to check the validity of this input data, all inflow hydrographs were checked against the rainfall hyetographs to identify whether the time of peak was within appropriate ranges.

The time to peak flow from the rural catchment depends on the size of the catchment and its respective time of concentration (t_c).

3.4 GEOLOGY AND SOILS

Taupo region generally has volcanic pumice sandy soils with good drainage characteristics. The soil type and geology are not explicitly modelled. The original urban stormwater models assumed that the ground is saturated with no infiltration, which is the worst-case scenario considered appropriate for high level planning purposes. Given the importance of the outputs, a qualified Hydrologist at Te Miro Consultants provided appropriate rainfall-runoff, hydrological inputs, and infiltration rates for rural areas to better refine the modelling.

3.5 INFILTRATION MODEL

Initial "Rain on Grid" models assumed 100% runoff, so the model runs resulted in conservative flooding estimates. This assumption was made based on the worst-case scenario, assuming flash flooding with limited ability for ground infiltration. This provided the maximum flood extent to be identified during stormwater modelling.

Highly infiltrative pumice-rich soils are dominant in Taupō. These soils are known to be hydrophobic in antecedent dry conditions, as a result of the soil's unique macro-porosity. Hence, the worst-case scenario was considered to be reasonable in simulating a 100% runoff scenario with no infiltration for a design event.

Table 1: Infiltration measurement sites

Soil	Classification	Texture Class	General Location
Tirau	Typic Orthic Allophanic Soil	Silt Loam	South of Tirau
Tihoi	Humose Orthic Podzol	Sand	East of Benneydale
Taupo	Immature Orthic Pumice Soil	Sandy Loam	East of Tokoroa
Ngakuru	Typic Orthic Allophanic Soil	Sandy Loam	North of Mokai
Waipahihi	Immature Orthic Pumice Soil	Sand	Tahora

Due to model conservatism, a certain level of infiltration was assumed in the non-urban areas (with 100% runoff being sustained in the urban areas). Scarce amount of research have been conducted on the infiltration characteristics of pumice soils. The above table from the *"Infiltration Characteristics of Soils Under Forestry and Agriculture in the Upper Waikato Catchment"* by NIWA identifies that Taupō soils are identified as an Immature Orthic Pumice Soil type. Based on this perception, Taupō soils can be said to assume similar infiltration characteristics to Sandy Loam (Reference Paragraph 9 - Simcock R 2006. *Stormwater and erosion in the urbanising Acacia Heights Catchment, Taupo*. Landcare Research Contract Report: LC0607/034).

Texture class	Effective water capacity (Cw) (mm)	Infiltration rate (f) (mm/hour)	Hydrologic soil grouping
Sand	8.89	210.1	A
Loamy sand	7.874	61.2	A
Sandy loam	6.35	25.9	A
Loam	4.826	13.2	B
Silt loam	4.318	6.9	B
Sandy clay loam	3.556	4.3	C
Clay loam	3.556	2.3	D
Silty clay loam	2.794	1.5	D
Sandy clay	2.286	1.3	D
Silty clay	2.286	1.0	D
Clay	2.032	0.5	D

The above table has identified that Sandy Loam has an infiltration rate of 25.9 mm/hr. Pumice soils may have a greater infiltration rate than this. This, however, was when water was allowed to come into steady infiltration to avoid any hydrophobic effects. The relatively lower infiltration rates for the pumice soils (that have been adapted in the model) that have also been justified in multiple studies (Vogeler 2008, Simcock 2006) may be due the low macro-porosity of pumice soils, and also due to soil compaction.

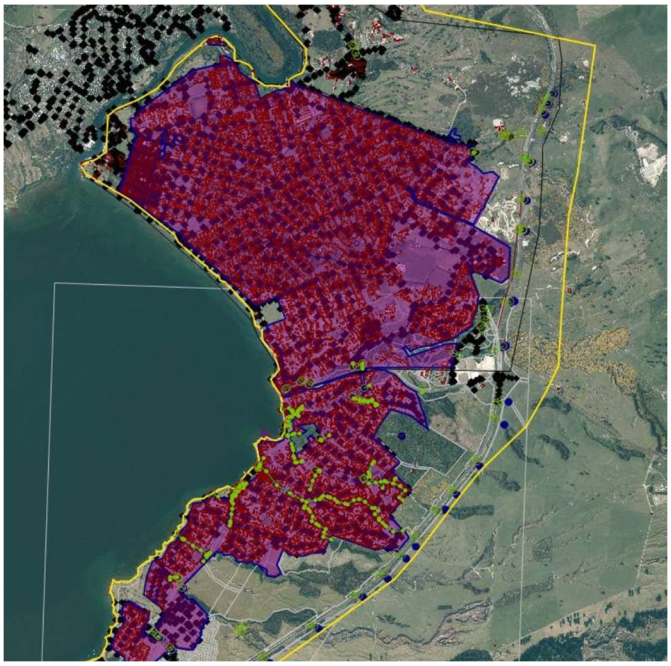
Initial abstraction losses in the catchment through surface storage are inherently applied as the "rain on grid" model surface has depressions that will create storage for stormwater as it passes over the catchment.

The rural inflows that have been applied to the model have infiltration included (in accordance with the TP108 guidelines; SCS-CN). This is justified as the flow that is received at the model has had time to travel through the pervious surface before reaching the model extents.

3.6 SURFACE ROUGHNESS

Initially, the surface roughness of the model was set to 0.035 (Manning's) for the entire model. However, as advised by Tonkin & Taylor and with further research, varying roughness has since been applied throughout the model.

Land Use	**Manning's Roughness**
Grass Land	0.035
Urban/Built up Area	0.015

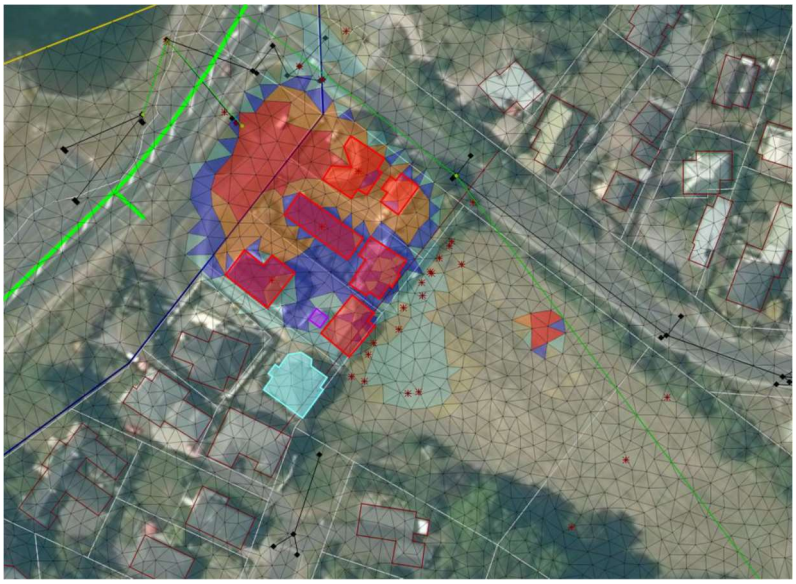


The roughness around the urbanized areas was changed to 0.015 according to the recommendations by Tonkin & Taylor, whilst the roughness in the rural grass land was increased to 0.035. The image below shows the urban area (highlighted in purple) and the non-urban/grass land area (contained within the yellow boundary).

Varying roughness for every land use category has not been applied as it would arguably over define the model without justification through calibration.

3.7 TERRAIN & RESOLUTION

For faster preliminary runs, the model used a triangular mesh resolution ranging between 25m^2 to 100m^2 to define the 2D topography of the model.



A coarse resolution may potentially incorrectly identify a property as being a flood risk. It is simple to re-mesh the grid and make it finer as required. It will not change the direction of major flow paths, but it will make the flooding around residential areas more detailed.

A coarser mesh has been used in non-residential areas to reduce the simulation timescales. As an example, the Kinloch model has a coarser mesh upstream and a finer mesh towards the dwellings. This is so that the "at risk" properties are more accurately identified. The minimum resolution suggested in the report by Tonkin & Taylor was 4m^2. The resolution for the triangular mesh will vary from location to location. The resolution used outside of the dwellings (non-urbanized) is 5 to 25m^2 whilst the mesh within the areas of properties (urbanized) is 4 to 16m^2. We believe that this resolution is appropriate for the identified scope of this project.

It was considered that the finest resolution necessary is in the order of 4m^2 although this can be better determined on a location-by-location basis and is dependent on land use, steepness, and the presence of hydraulic features (e.g. streams, culverts, storage basins/dams, etc).

3.8 STORMWATER NETWORK OVERVIEW

As agreed, models were developed with limited pipe network included due to lack of invert data. Pipe data was interpolated where pipes could affect property flooding. This is described within section 4.

In many cases, pipe inverts have been estimated due to the lack of available asset information. This is not considered critical for 100-year or 50-year ARI storm events, but invert levels may be important when assuming the effects of backwater in pipes. Further, locations where stormwater pipes do not affect flooding, then stormwater pipes were not always modelled. This decision was made based on engineering judgement.

3.9 LAND USE

The catchments of interest are mainly urban residential, commercial and industrial areas where human occupation and livelihood is at risk.

4.0 MODEL BUILD

4.1 HYDRAULIC MODEL

InfoWorks ICM software was used to combine one-dimensional (1D) pipe models with two-dimensional (2D) ground models.

Inflows to the stormwater network were modelled with "2D" manholes. There are no known higher inlet capacity 'Hushpits' or 'Megapits' within the Taupo Region allowing inlet flows up to 800-litres per second.

A 1-metre grid based on latest LiDAR data was provided to update the previously developed ICM ground models. LIDAR data was imported directly into InfoWorks ICM, which uses this grid to form the ground model as a flexible mesh.

4.2 ASSET DATA

Asset data was supplied by TDC and stormwater network was modelled where it was considered to have an effect on property flooding as determined using engineering judgement. Pipe invert levels were estimated where necessary.

There are no pump stations modelled as TDC has just three pump stations catchment-wide which only empty retention ponds. Where considered necessary, pumps could be modelled with their corresponding head-discharge curves if provided by TDC.

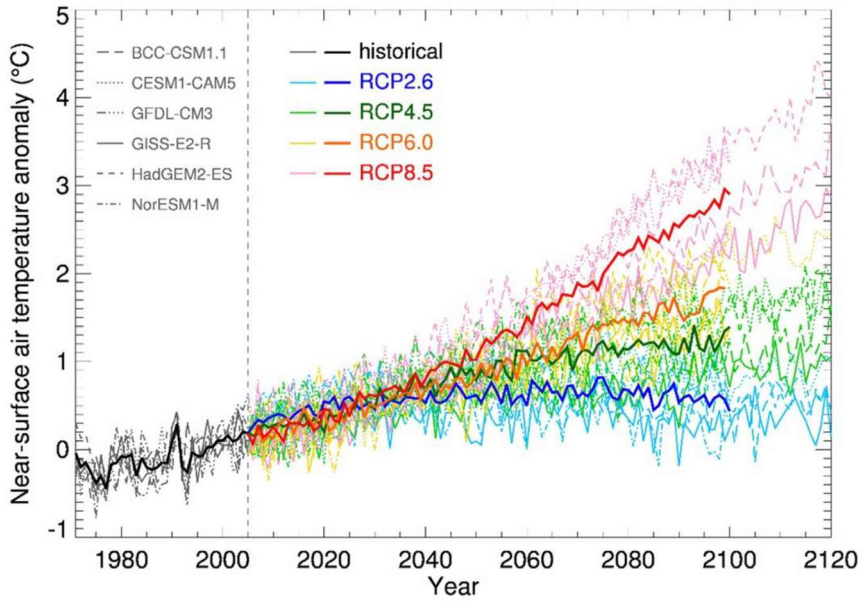
4.3 HYDROLOGICAL MODEL / APPROACH

The hydraulic models were run with 'Rain-on-Grid' where the simulation represents 100% rainfall falling directly onto the 2D ground model. The ground model elevations dictate the direction of overland flow path towards the pipe network and/or Lake Taupo.

4.4 RAINFALL / CLIMATE CHANGE

NIWA's HIRDS (High Intensity Rainfall Design System) design rainfall was previously used for the preliminary scenario modelling. This was initially represented with HIRDS Version 3 total rainfall depths for associated return periods of interest, accounting for climate change at 3% which increased rainfall intensities by approx. 19%. The latest HIRDS version 4 is now

available and has been applied accordingly HIRDS v4 (RCP 6.0 2081-2100) 24-hour design rainfall patterns were adapted for the 10-, 50- and 100-year events.



The usage of future rainfall event data allows for more accurate and latest predictions on the flooding arising from rainfall. The current scenario for the 100-year rainfall has also been included in the modelling.

4.5 BOUNDARY CONDITIONS

Due to the generally steep nature of Taupo's catchments and elevation above lake level, no lake level or river boundary conditions have been applied for the purposes of modelling to-date. This could be considered where necessary for TDC's proposed District Plan Review flood hazard mapping.

Bay of Plenty Regional Council (BoPRC) Hydrological & Hydraulic (H&H) Guidelines suggest that the 100-year design rainfall event should be modelled in combination with a 20-year outlet tidal level boundary condition, and vice versa.

4.6 DATA ISSUES

The supplied stormwater network asset data had limited invert information and there was limited specific budget available for survey. It was agreed that assuming/interpolating missing invert levels would likely have limited adverse effects on the overall hydraulics given that the stormwater flows are mainly head driven and limited by pipe capacity. Where necessary, data may be improved later if it is agreed to adversely impacts on modelling outcomes.

Additionally, latest LIDAR data is required in ASCII format, together with an audit trail to its source.

4.7 ASSUMPTIONS / SIMPLIFICATIONS / LEVEL OF CERTAINTY

The existing models assume 100% runoff in the urban areas whilst a constant 25.9 mm/hr infiltration rate applied to the non-urban areas (as detailed on section 3.5). A constant infiltration rate was used due to the lack of data to calibrate/validate an infiltration model.

The 2D model has not been calibrated/validated as it requires records of actual flooding to do so. Further, the outlet conditions for the culverts reaching the lake have not been modelled explicitly as there are multiple possible scenarios available.

5.0 MODEL SENSIBILITY CHECKS

5.1 SENSIBILITY CHECKS / GROUND TRUTHING

Model sensibility checks were completed by means of site checks on flood affected properties. This has not identified any concerns with the modelled flood affected areas. Council has provided some limited flood records which have been validated well against the modelled flood areas, which TDC has also been doing through the use of latest flood maps.

5.2 STORM EVENT VALIDATION / CALIBRATION

Model calibration / validation would ideally improve confidence in the models by checking the modelled flood levels/depths and ideally flow-rates against measured values for a measured intensity of storm event.

Unfortunately due to lack of available measured validation data, the models have not been calibrated / validated. TDC has advised that there are limited historical flows or flood levels available for this purpose.

5.3 MASS BALANCE CHECKS

InfoWorks ICM undertakes mass balance checks automatically and they were within expected tolerances for the completed model runs.

6.0 MODEL CONFIDENCE AND RECOMMENDATIONS

6.1 MODEL CONFIDENCE

A high level of confidence can be considered on the location of overland flow-paths, and therefore on flood hazard areas. Until further recommended model development can be completed, there is lower level of confidence in the exact flood width, depths and velocities. It must be understood that a hydraulic model is often the best available information at the time.

Model validation has only been achieved in some areas by means of reviewing previous overland flow-path flood mapping. This has provided reasonable confidence in model outputs.

There is low confidence in a significant amount of stormwater pipe network asset data, however this is not generally believed to have a significant impact for 100-year return period rainfall events.

6.2 RECOMMENDATIONS

It would be in the best interests of TDC to continue investing in improvements and updates for this important project to better understand overland flow path flood risks in order that residents can be advised on flood risk potentially affecting them where necessary.

The models (although populated with the most recent data) are not absolutely finalized. Latest LIDAR is still being released to continue updating the models, and subsequently, the extent of flood affected properties.

Outstanding data includes:

- The most recent LiDAR data (in some remaining areas).
- Culvert/pipe data (to be updated as more recent data is made available).
- Ongoing research to identify more optimized infiltration/roughness data for all models.
- Model optimization through further auditing changes where considered necessary.

In addition to this, the critical outlet conditions for the culverts reaching the lake could be modelled to improve model accuracy where considered necessary.

7.0 AUDIT RESPONSE

This section details the response to the individual comments by Tonkin & Taylor in their audit report titled "Review of Taupo District Council Flood Modelling" as dated 11 May 2020. The revisions suggested by Tonkin & Taylor have been considered and included in the model where considered appropriate. Where the proposed suggestions were not implemented, the reasoning is clearly outlined within this section.

Model Extent (Overall)

T&T Comment:

Ensure all communities and areas of importance have a flood assessment carried out. Use TDC requirement for improved flood hazard representation as part of business case for more LiDAR data.

CDM Response:

Updated LIDAR data at a higher resolution and greater extent should be made available for use in the models. This will allow for better flood extent visualizations and more accurate surface storage estimations. CDM has requested WRC provide the latest LIDAR data at their earliest convenience.

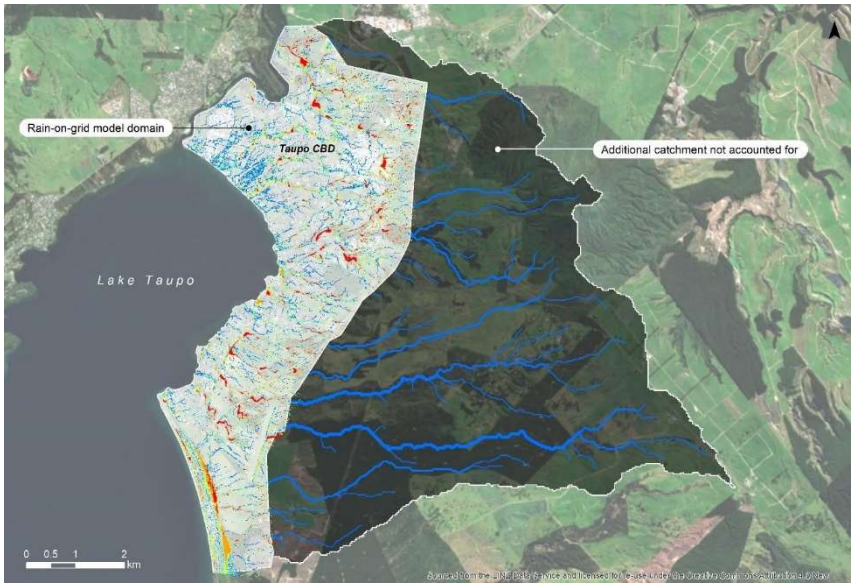
It was confirmed that the new LiDAR data will be available for public use in the 1st quarter of 2024 (but this keeps extending out) so is yet to be included within all of the models. *(Currently, the first set of LiDAR data has been released for the main Taupo region, the models can be updated as new LiDAR data is provided).*

All 17 models now have had their urban areas modelled. Models that were previously split into two (Nukuhau and Taupō) have been combined to more accurately represent the hydrology of entire catchment without any breaks.

T&T Comment:

It has been identified that large amounts of non-urban area are not accounted for. No other inflows from beyond the 2D surfaces are accounted for. Each 2D model domain was limited by the extent of available LiDAR data and therefore, many models significantly under-represent runoff from the catchment beyond the LiDAR extents.

The remaining 13 models represent less than 40% of the catchment (i.e. there are no catchments representing between 40% and 80% of the catchment).



CDM Response:

Preliminary Rain-on-Grid Models were initially limited by the extent of LIDAR available. Hydrology was not previously available, however rural inflow sources have now been included within the models to represent the large amounts of non-urban area that were not accounted for within the 2D extent for all the model sites. These inflows were calculated based on the Auckland Council's TP108: Guidelines for modelling stormwater runoff in the Auckland region. TDC commissioned Te Miro Consultants to carry out the hydrology to identify the rural inflows into the urban catchment based on the above guidelines. More information on the rural inflows can be provided as the audit progresses.

Adding the rural inflows into the model also represents the inflows from the additional area of the catchment not accounted for. The inflow sources have been calculated and included for all of the models unless specifically stated.

Design Rainfall

T&T Comment:

Adopt HIRDSv4 depths specific to each catchment. Account for climate change in accordance with latest MfE advice. Develop hyetographs for multiple durations for 1% AEP floodplain derivation (with and without climate change). Develop a programme of works with support from WRC to improve confidence in design rainfall in Taupō District.

CDM Response:

For all sites, the HIRDSv4 (RCP 6.0 2081-2100) has been adapted as rainfall data (100, 50 and 10-year design rainfall) for each urban area as recommended. The use of future rainfall event data allows for more accurate and up to-date predictions on the flooding arising from rainfall. The current scenario for the 100-year rainfall has been included for all models as well. Design rainfall data has been obtained from NIWA'S (National Institute of Water and Atmospheric Research) HIRDS. TDC to lead further development of rainfall data.

T&T Comment:

Longer duration storms such as the 72-hour period simulated have lower rainfall intensities which in turn generate relatively low peak flow rates. This is important because the performance of culverts and other conveyance structures is limited by peak flow rates rather than total runoff volumes.

Run the models with multiple storm durations to identify the critical storm event, i.e., that which generates the greatest floodplain extent.

CDM Response:

The auditor appears to have misunderstood the fact that the nested design rainfall profile utilized (24-hour) combines all HIRDs rainfall duration intensities into a nested storm event, so naturally includes all the most critical shorter duration rainfall within this 'nested' storm. Further to this, TP108 configures its rural runoff to a 24-hour rainfall duration. Hence it is considered appropriate to use the 24-hour design rainfall event with all smaller durations and intensities 'nested' within this hyetograph.

Hydrological Losses & Infiltration

T&T Comment:

The modelling assumed complete ground saturation such that 100% of rainfall was converted to runoff. This will produce conservative (i.e. high) estimates of runoff for a given rainfall event. The highly permeable pumice-based soils that dominate the Lake Taupō catchment are likely to allow significant infiltration although we acknowledge that their hydrological and hydrogeological behaviour can be very difficult to predict, and a precautionary approach may well be justified.

CDM Response:

Presenting the worst-case scenario without any hydrological losses will allow for the maximum flood extent to be identified; highly infiltrative pumice-based soils are dominant in Taupō. However, these soils are known to be hydrophobic in antecedent dry conditions, as a result of the soil's unique macro-porosity.

The worst-case scenario would therefore be a 100-year ARI storm event occurring after an extended dry period. High intensity and "flash" rainfall events may also lead to hydrophobic conditions.

The initial models therefore adapted a 100% runoff on the rain-on-grid model, as the above stated is a possibility. Notwithstanding this, it infiltration has been included based on studies in the proximity of Taupō.

Table 1: Infiltration measurement sites

Soil	Classification	Texture Class	General Location
Tirau	Typic Orthic Allophanic Soil	Silt Loam	South of Tirau
Tihoi	Humose Orthic Podzol	Sand	East of Benneydale
Taupo	Immature Orthic Pumice Soil	Sandy Loam	East of Tokoroa
Ngakuru	Typic Orthic Allophanic Soil	Sandy Loam	North of Mokai
Waipahihi	Immature Orthic Pumice Soil	Sand	Tahora

The above table from the *"Infiltration Characteristics of Soils Under Forestry and Agriculture in the Upper Waikato Catchment"* by NIWA identifies that Taupō soils are identified as an Immature Orthic Pumice Soil type. Reference Section 8, the texture class for the above soil can best be represented as Sandy Loam. Based on this perception, Taupō soils can be said to assume similar infiltration characteristics to Sandy Loam.

Texture class	Effective water capacity (Cw) (mm)	Infiltration rate (f) (mm/hour)	Hydrologic soil grouping
Sand	8.89	210.1	A
Loamy sand	7.874	61.2	A
Sandy loam	6.35	25.9	A
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Initial abstraction losses in the catchment through surface storage are inherently applied as the "rain on grid" model surface has depressions that will create storage for stormwater as it passes over the catchment.

The rural inflows that have been applied to the model have infiltration included (in accordance with the TP108 guidelines; SCS-CN). This is justified as the flow that is received at the model has had time to travel through the pervious surface before reaching the model extents.

T&T Comment:

In subsequent flood studies, we recommend that hydrological losses are applied to the model based on land use and soil type, and that where there is uncertainty a precautionary approach is adopted that will result in more runoff.

CDM Response:

Varying infiltration rates were not considered for the models, and a fixed 25.9 mm/hr of infiltration was used throughout the catchment for relevant areas. The reasoning behind this is that an unvalidated infiltration model could introduce another unnecessary variable to the model.

Terrain & Resolution

T&T Comment:

Refine resolution as appropriate in models. Ensure long-term needs of TDC are accounted for (e.g., future land uses and stormwater interest areas).

CDM Response:

Acknowledged, the model represents all areas of interest for stormwater for current and future scenarios. Model resolution was increased in all models for latest runs with ranging from $4m^2$ to $16m^2$ mesh triangulation size.

Surface Roughness

T&T Comment:

Apply spatially varying roughness to model on the basis of landcover maps (e.g. LCDB5) or aerial photographs.

We consider that a variable roughness value is more appropriate for floodplain modelling for District Plan purposes in which areas of reduced roughness (e.g. impervious surfaces) and increased roughness (e.g. vegetated areas) are more appropriately represented. The effect of adjusting the roughness is unclear since some areas will experience more conveyance, passing more flow downstream, and other areas may experience more attenuation and increased flood depths.

CDM Response:

A scenario was modelled to change the surface roughness of the entire model (South Taupō) from the existing 0.035 to 0.015 (Manning's). The results outcome showed that the flooding levels did not change significantly. When comparing the time to peak and the time for the flood to dissipate; time to peak was unaltered, however, the time for flood dissipation was slightly quicker for the scenario with the lower roughness. This was identified by looking at the inflow hydrograph from one of the outlets.

Therefore, the roughness around the urbanized areas was changed to 0.015 as according to the recommendations by Tonkin & Taylor, whilst the roughness in the rural, grass land was 0.035.

Land Use	Manning's Roughness
Grass Land	0.035
Urban/Built up Area	0.015

Stormwater Pipes

T&T Comment:

Add all stormwater pipes to models. Prioritise work in most important areas, e.g. Taupō town centre.

Ensure appropriate pipe inlet capacity is allowed for the models.

CDM Response:

All stormwater pipes have been included where appropriate. Certain stormwater pipes (smaller pipes & pipes not located in flooding areas) were not included in the model. This decision was made based on budget and using engineering judgement for the agreed scope.

In many cases, pipe inverts have been estimated due to the lack of asset information. This is not likely important for 100-year or 50-year ARI storm events, but invert levels may be important for when assuming the effects of backwater on the pipes. Further, locations where stormwater pipes cannot alleviate flooding also had no stormwater pipes modelled. All major stormwater networks were included in the model (where data was available).

Culverts & Bridges

T&T Comment:

Ensure high-level representation of culverts and bridges in all modelled areas. Where as-built design information exists, this should be used. Otherwise, assume structure specifications and record assumptions.

A total of 85 culverts are recorded in the TDC stormwater asset dataset within the 17 modelled areas. Due to lack of culvert information, only six were included in the preliminary models – five in the Taupō model and one in the Turangi model.

Implement the programme of works to capture asset information for bridges and culverts by survey.

Identify areas of cross-drainage not represented by TDC asset data. Plan a programme of works to capture unrecorded information (i.e. survey).

CDM Response:

Culverts of significance have now been included in all the models with site visits undertaken to ensure that the correct information is being used in the model. This includes site surveys to measure pipe diameter, and the tributary gulley depth and width.

The images of these culverts were included in the model (where available) as hyperlinks for some models. The models are continuously being updated as more recent information is made available (both through site survey and through the council databases).

Attenuation Structures

T&T Comment:

Represent all flood attenuation structures using as-built information where available.

CDM Response:

Flood attenuation structures (e.g., Detention ponds, dams) were not explicitly modelled, but they are locations of depression within the model. Since the Digital Elevation Model represents these depressions on the ground, by extension, the 2D modelling will treat these depressions as locations of storage. Hence, flow attenuation structures are included in the model.

Pipes that connect to these flood attenuation structures were also included if not previously.

Boundary conditions – Water levels

T&T Comment:

Apply 1% AEP downstream water levels to all models based on river flood levels (e.g., Opus reports) and Lake Taupō operating levels.

The operating levels of Lake Taupō vary by 1.40 m between 355.85 and 357.25 m RL (Mercury website) to meet electricity generation requirements and therefore the interaction between water level assumptions and outlet levels (refer Section 4.6.4) can be important.

CDM Response:

The steepness of the catchment means that backwater conditions generally have no effect on the Taupō urban area models. However, final runs can be run with an agreed typical lake level if considered necessary.

T&T Comment:

Undertake sensitivity tests across the range of Lake Taupō operating levels for pipes and channel discharging directly to the lake.

CDM Response:

All modelled conduits were reviewed to ascertain if all the outfalls discharge properly towards the boundary of the model. From sensitivity testing, most outfall boundary conditions are not considered to significantly affect the flooding of concern upstream, but depending on the use of the model, runs can be undertaken for any lake condition (noting there could be infinite scenarios) so should be analysed on a case-by-case basis depending on the area of interest and objective for the particular study.

Boundary Conditions – Inflows

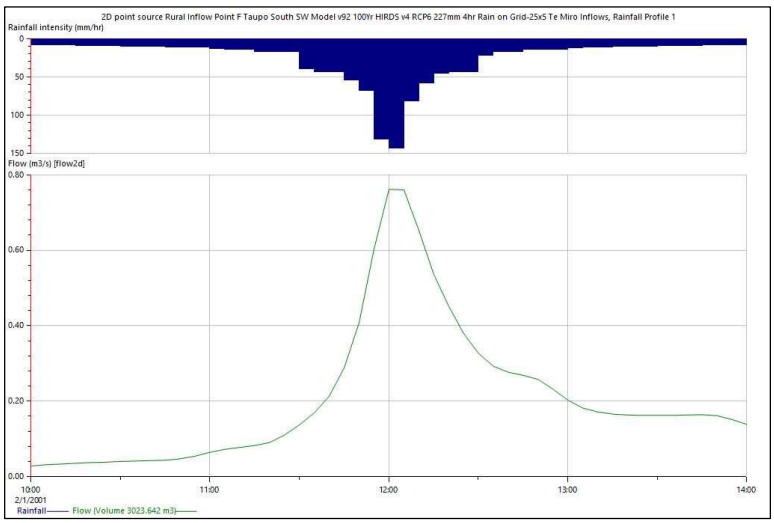
T&T Comment:

Apply inflow boundaries as point source inputs to the edge of the model domains where upstream catchments are not accounted for by the rain-on-grid models.

CDM Response:

The rural runoff was calculated and applied in accordance with the TP108: Guidelines for stormwater runoff modelling in the Auckland region. These guidelines have been developed for steep catchments with little to no natural hydraulic storage within Auckland. This was identified as being similar to the rural catchments in Taupō. In order to check the validity of this input data, all inflow hydrographs were checked against the rainfall hyetographs to identify whether the time of peak was within appropriate ranges.

The time to peak flow from the rural catchment depends on the size of the catchment and its respective time of concentration (t_c).



Assessment of Modelled Flows

Peak flow rates from the model were compared with high-level flow estimates at selected locations across the model domains as a sense check.

Due to the missing catchments noted in the model report due to limited LIDAR availability, the flow comparisons indicated large disparities for most locations tested, including both overestimates and under-estimates.

T&T Comment:

Due to the missing catchments noted in the model report due to limited LIDAR availability, the flow comparisons indicated large disparities for most locations tested, including both overestimates and under-estimates.

- **Where the full flow contribution is contained within the model domain and the upstream catchment is significantly rural, modelled peak flows were significantly greater than the independent estimates (e.g. Acacia Bay). This is to be expected due to hydrological losses associated with pumice soils not having been accounted for in the model.**
- **Where the upstream flow contribution has not been fully accounted for, but significant rural catchment is included in the model domain, the modelled flows were moderately to significantly lower than the independent estimates, e.g., Kinloch.**
- **Modelled and estimated peak flows generally concurred where the full catchment is accounted for and the catchment is predominantly urban, e.g., Taupō 1 and 2. This is to be expected as hydrological losses are minimised in urban areas due to the higher proportion of impervious surfaces.**
- **The Taupō 3 comparison does not fit this pattern as a bifurcation upstream of the sampling location deflects a portion of the surface flows away from the main flow path, resulting in a reduced modelled peak flow rate.**
- **A close match between the modelled and estimated flows for the Taupō 7 location is misleading and results from a coincidental balancing out of factors contributing to overestimates and under-estimates. Modelled flows are under-estimated due to one-third of the catchment being omitted, and they are over-estimated due to no hydrological losses being accounted for.**

CDM Response:

As new LiDAR data is being made available, all catchment models have been continuously updated. Previously missing catchments extents due to LiDAR availability have generally now been included wherever available.

Further to this, larger rural catchments well beyond the model have rural inflows based on TP108 guidelines applied, which provides a holistic approach to the modelling efforts.

Currently, the full extents of the new LiDAR data is not available (the new LiDAR data is only available for the extents of Taupo, Nukuhau, Acacia Bay and Kinloch). The models will be updated as the remaining LiDAR data is released.

Model Calibration & Validation

T&T Comment:

Develop a programme of works to calibrate/validate hydraulic model.

CDM Response:

It is very difficult to calibrate a 2D model as it requires actual flooding and surcharging to be measured/photographed in order to do so. In order to calibrate the models, flood levels and photographic evidence of flooding during a known event must be available. This allows the models to be calibrated/validated based on the flood depth and extent.

CDM has not been provided with flow or validation data that can be used as calibration/validation data for the models. TDC must allocate budget within their Long Term Plan if they wish to gather improved model validation data.

8.0 REFERENCES

HYDROLOGICAL & HYDRAULIC GUIDELINES, BOPRC, 2012/02
This guideline provides recommendations for modelling outlet conditions and design parameters.

Vogeler I 2008. *Effect of long-term wastewater application on physical soil properties*. Water, Air & Soil Pollution 196: 385-392

Simcock R 2006. *Stormwater and erosion in the urbanising Acacia Heights Catchment, Taupo*. Landcare Research Contract Report: LC0607/034. Taupo District Council, Taupo

9.0 LIMITATIONS

9.1 GENERAL

This report is for the use by Taupo District Council only and should not be used or relied upon by any other person or entity or for any other project.

This report has been prepared for the particular project described to us and its extent is limited to the scope of work agreed between Taupo District Council and CDM Consultants Limited. No responsibility is accepted by CDM Consultants Limited or its directors, servants, agents, staff or employees for the accuracy of information provided by third parties and/or the use of any part of this report in any other context or for any other purposes.