NRC Regionwide River Flood Model - Peer Review

Review of Calibration Model and Report

Prepared for Water Technology

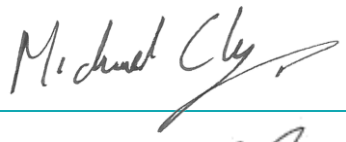
Prepared by Beca Limited

12 February 2021

Revision History

Revision Nº	Prepared By	Description	Date
A	Michael Law	Draft for modeller response	14 January 2021
B	Michael Law	2nd draft for discussion with NRC	26 January 2021
C	Michael Law	Final, including NRC comments	12 February 2021

Document Acceptance

Action	Name	Signed	Date
Prepared by	Michael Law		12 February 2021
Reviewed by	Elliot Tuck		12 February 2021
Approved by	Michael Law		12 February 2021
on behalf of	Beca Limited		

Contents

Executive Summary

Beca has been engaged by Water Technology Limited (WaterTech) to undertake a peer review of their hydrological and hydraulic modelling for the NRC Region-wide River Flood Model. WaterTech's client is Northland Regional Council (NRC). The purpose of the modelling is to map river flood hazard zones across the entire Northland Region.

The focus of this report is the review the Kawakawa and Whangarei catchments TUFLOW flood models for calibration purposes and the accompanying calibration report; ***Calibration Report – NRC Region-wide River Flood Model*** (WT, 2020). The report describes the calibration of five example catchments, including the Kawakawa and Whangarei catchments. Beca's review of the modelling calibration report has confirmed, assessed, or considered:

- Performance against NRC's modelling requirements:
- The type of software and modelling package used for the hydrology and hydraulic model.
- The modelling method used and its appropriateness for both hydrology and the hydraulic model.
- The model extents and model build parameters as defined in the model report.
- Key model inputs (e.g. asset data, survey information) as described in the model report.
- The modelling scenarios and design standards used and their appropriateness.
- Model stability checks.
- Modelling assumptions.
- Whether the model is fit for purpose and if appropriate recommendations for additional investigation have been made.

This is the Final version of the report, and includes comments received from NRC following their meeting with WaterTech's modellers and Beca's reviewer on 28 January 2021 to discuss the 2nd draft of this peer review report, as well as WaterTech's modeller's responses to the 1st draft. The outcomes of the peer review are:

- No fatal flaws were identified in the TUFLOW model files provided for the Kawakawa and Whangarei catchments.
- The calibration report is a good description of the sensitivity and modelling work done, but could be improved with some re-ordering of sections.
- While reasonable calibration to peak water levels has been achieved in most catchments, the calibration results demonstrate the difficulty in developing large catchment scale models to meet all the calibration performance measures specified by NRC. This has been acknowledged by NRC.
- As a result, all parties are aware of the limitations of the modelling, but agree that it is fit for use, and recognise the need to clearly communicate the purpose and limits of the model outputs.
- Improvement in flow rating curves and inclusion of river channel detail and structures will improve model accuracy, and should be included in local area or site-specific flood models.

1 Introduction

1.1 Scope and Purpose

Beca has been engaged by Water Technology Limited (WaterTech) to undertake a peer review of their hydrological and hydraulic modelling for the NRC Region-wide River Flood Model. WaterTech's client is Northland Regional Council (NRC). The purpose of the modelling is to map river flood hazard zones across the entire Northland Region.

The focus of this report is the review the Kawakawa and Whangarei catchments TUFLOW flood models for calibration purposes and the accompanying calibration report; ***Calibration Report – NRC Region-wide River Flood Model*** (WT, 2020). The report describes the calibration of five example catchments; Awanui, Kawakawa, Whangarei, Catchment 13 (Magakahia and tributaries), and Catchment 14 (Wairua and tributaries).

During the peer review process Beca has reviewed the modelling for the Kawakawa and Whangarei catchments (these were considered to be higher priority catchments by NRC and WaterTech) and the calibration report to confirm, assess or consider:

- Performance against NRC's modelling requirements:
  - Peak flow within 15% of recorded flow
  - Flood volume within 15% of recorded flood volume
  - Peak water surface elevation (WSE) within 300 mm of recorded WSE
  - Timing of peak water level within one hour of recorded time
  - Model flow within 10% of recorded flow at the same stage
- The type of software and modelling package used for the hydrology and hydraulic model;
- The modelling method used and its appropriateness for both hydrology and the hydraulic model;
- The model extents and model build parameters as defined in the model report;
- Key model inputs (e.g. asset data, survey information) as described in the model report;
- The modelling scenarios and design standards used and their appropriateness;
- Model stability checks;
- Modelling assumptions;
- Whether the model is fit for purpose and if appropriate recommendations for additional investigation have been made.

1.2 Peer Review Process

A summary of the project timeline to date is as follows:

• August 2020	Beca appointed by WaterTech as peer reviewer
• September-October 2020	Calibration process, priorities and draft report reviewed and discussed between NRC, WaterTech and Beca
• 7 December 2020	Calibration Report (WT,2020) provided to Beca for review
• 17 December 2020	TUFLOW model files provided to Beca for Kawakawa and Whangarei catchments
• 15 January 2021	Calibration Review Report (draft of this report) issued to WaterTech for response.
• 22 January 2021	Response to draft received from WaterTech
• 26 January 2021	2nd draft version of Calibration Review Report issued to WaterTech for discussion with NRC

- 28 January 2021 — Video conference attended by NRC, WaterTech and Beca to discuss the 2nd draft of this review document.
- 5 February 2021 — Email from Jan Van Der Vliet (NRC) to Michael Law (Beca) clarifying NRC's position on items in the 2nd draft peer review that had remained open subject to the outcome of the meeting on the 28 January. NRC's responses have been included in this Final (12 February 2021) version of the peer review report.
  On the same date, WaterTech confirmed (via email) that they had no further comments.

1.3 Model Review Rating Scheme

Elements of the modelling investigation have been reviewed and rated using a 0-3 scoring system outlined in Table 1, to assess the significance of issues identified in this peer review.

Table 1– Model review rating scheme

Description	Audit rating	Fit for use
No issue: The element or parameter being reviewed is modelled acceptably	0	Yes
Minor issue: There is an issue, but it is unlikely to significantly affect model results	1	
Major issue: Failure to resolve the issue compromises the model and should be rectified, but may be resolved by explanation or acceptance of model limitations.	2	Review
Fatal flaw: Failure to resolve this issue severely compromises the model, and should be rectified before the model is accepted.	3	No

For the review of the calibration report, the 'Fit for use' column has been replaced with 'Open/Closed'.

Space has been left in the review table for the modeller to provide comments or responses. NRC's comments of 5 February have also been included. The reviewer has considered the responses and comments in the final audit rating.

1.4 Peer review order

Two models and the calibration report have been reviewed in Section 2

- Section 2.1 Kawakawa model review
- Section 2.2 Whangarei model review
- Section 2.3 Calibration report review

2 Peer Review

2.1 TUFLOW Model Review – Kawakawa catchment

WaterTech provided all the TUFLOW model files with the exception of model results files. As such, the review of the model concentrates on the model file structures and links, and on the catchment input data.

Item	Ref	Beca Review Comment	Water Technology (WT) Response/Action Taken	Initial Audit Rating	Final Audit Rating	Fit for Use
General and model setup						
Version	K1	*14 January 2021:* TUFLOW_2020-01-AB-iSP Not backward compatible	No response required	0		Yes
TUFLOW control files	K2	*14 January 2021:* Standard folder structure used. *Note that results not provided.* *26 January 2021:* Results were provided. Problems with download pre-Christmas resolved.	*22 January 2021:* Results were provided via a One Drive link.	1	0	Yes
Timestep	K3	*14 January 2021:* The timestep of 1.6 seconds (.tcf file) is slightly less than 20% of the default grid cell size (10 m). However, given the variable grid sizing using SGS this is acceptable. *26 January 2021:* Response accepted	*22 January 2021:* Adaptive timestepping was applied for these models as HPC scheme was used. A check of the dt throughout the model was also undertaken to ensure model stability	1	0	Yes
Model configuration and extents						
1D, 2D, 1D/2D	K4	*14 January 2021:* The model is 2D only. While this simplifies the model and allows large areas to be modelled with reasonable run times, the model does not include 1D structures, networks, and channels. This reduces model accuracy but is a pragmatic approach to modelling at the catchment scale. *26 January 2021:* Response accepted	*22 January 2021:* Given the purpose and scale of the project, 1D structures were not included as part of the scope of the project. The use of a 1m LiDAR grid generally provides a good representation of channel capacity in high flow events as there is a significant portion of flow across the floodplain.	1		Yes
1D extents	K5	Not used				
1D setup	K6	Not used				
2D extents	K7	*14 January 2021:* 2d_code layer shapefile (referenced in .tgc file) checked.	No response required	0		Yes

Item	Ref	Beca Review Comment	Water Technology (WT) Response/Action Taken	Initial Audit Rating	Final Audit Rating	Fit for Use
2D grid/mesh	K8	*14 January 2021:* Default grid size of 10 m is appropriate for catchment scale model, when used with SGS and Quadtree *26 January 2021:* Response accepted	*22 January 2021:* Note that Quadtree is not used in the design modelling. Quadtree was initially used to compare model results and run times.	0	0	Yes
	K9	*14 January 2021:* SGS sample distance of 1 m in .tgc file is appropriate.	No response required	0		Yes
	K10	*14 January 2021:* Quadtree areas have been used to provide better definition in some urban areas. This is explained in the calibration report and is appropriate. A nest level of 3 (equivalent to a 2.5 m grid when the default grid is 10 m) has been used for the Kawakawa urban area. Other Quadtree areas could be added. *26 January 2021:* Response accepted. Note confirmation in the Calibration Report that SGS only was used. Quadtree nest level not activated in model files.	*22 January 2021:* It should be noted Quadtree was not used for urban area given the potential significant increase in run time.	1	0	Yes
Terrain data (2D)	K11	*14 January 2021:*.tgc file references .asc DEM four files in *M:\20010434_NRC_Region_River_Flood_Model\Spatial\Data\Grid\LiDAR\...* These are not in the standard TUFLOW file tree and so not able to be checked by the reviewer. *26 January 2021:* File provided.	*22 January 2021:* The only DEM used in the model is "m15.asc" which has been provided via One Drive. This can be changed to ..\model\grid\ prior to hand over of model files if required	2	0	Yes
Cross-sections	K12	*14 January 2021:* No cross-section in model	No response required	n/a	n/a	n/a
2D obstructions	K13	*14 January 2021:* No 2D structures or obstructions included in model, as underlying DEM is the hydro-enforced DEM developed by WaterTech for NRC in a previous project. This loss of definition is an accepted compromise to allow for efficient catchment-scale modelling. *26 January 2021:* Noted. Previous comment was mis-reading of Calibration Report.	*22 January 2021:* Notes that the DEM used in the model has no sinks filled as opposed to the "hydro-enforced" DEM	1	1	Yes

Item	Ref	Beca Review Comment	Water Technology (WT) Response/Action Taken	Initial Audit Rating	Final Audit Rating	Fit for Use
Roughness	K14	*14 January 2021:*.tmf file checked Manning's roughness 'n' values are correctly assigned within the model. The modelled values reflect those reported in Table 5-2 of the calibration report. *See review comment R17 for comment on whether some roughness values are appropriate.* *26 January 2021:* Response accepted	*22 January 2021:* No response required- answered in R17 comment	0	0	Yes
Hydraulic structures and networks						
General	K15	*14 January 2021:* Not included	No response required	n/a	n/a	n/a

Item	Ref	Beca Review Comment	Water Technology (WT) Response/Action Taken	Initial Audit Rating	Final Audit Rating	Fit for Use
Bridges, culverts & blockage	K16	*14 January 2021:* Not included. The effect on water levels and flows of bridges and other obstructions close to flow recorders is not included in the model. These may affect calibration performance and modelled flow ratings. But acceptable for this level of modelling. *26 January 2021:* NRC could confirm this, but the Willowbank recorder is where Stringers Road crosses the river (presumably via a bridge). There is no bridge near the Below Old Mill recorder	*22 January 2021:* No bridge/ hydraulic structure identified close to any of the streamflow gauges used in this model calibration. It is therefore believed only 2D topography below the water level captured in the LiDAR and resultant channel capacity is likely to have major influence on the modelled flow ratings. *NRC comment 5 February 2021:* We recognise that our calibration and validation standards for the modelling has been set high for the purpose and expected outcome of the model, i.e. region wide flood model which forms a flood inundation map guideline and a basis for future in-depth analysis when required. Accurate base data for all our catchments is in cases not available and assumptions have to be made. It would be a preference to include the bridges near the recorders, where present, in the same light as all other structures on our rivers. In light of the expected deliverable from this project we agree with and accept WT statement " LiDAR and resulted channel capacity is likely to have major influence on the modelled flow ratings", as used for the modelling in order to achieve the best outcome in a limited timeframe and for what is a 2D model only, model calibration has focused on replicating the recorded flood behaviour levels, i.e. FIT FOR PURPOSE.	2	1	Yes, as agreed by NRC
Piped Networks	K17	*14 January 2021:* Not included	No response required	n/a	n/a	n/a

Item	Ref	Beca Review Comment	Water Technology (WT) Response/Action Taken	Initial Audit Rating	Final Audit Rating	Fit for Use
Boundary conditions						
Rainfall	K18	*14 January 2021:* Rain on grid Rainfall defined in .trfc file.	No response required	0		Yes
Losses	K19	*14 January 2021:* Defined in .tmf file. Losses as reported in calibration report.	No response required	0		Yes
Catchments	K20	*14 January 2021:* Not applicable as rain-on-grid applied to model	No response required	n/a	n/a	n/a
Inflows	K21	*14 January 2021:* Not used	No response required	n/a	n/a	n/a
Downstream	K22	*14 January 2021:* ***Veronica_tidal*** boundary applied for tidal boundary in 2011 event. Checks made of GIS placement of boundary and links to .csv file	No response required	0		Yes
Errors, checks and warnings						
Model stability	K23	*14 January 2021:* One model stability warning, but not considered significant. *26 January 2021:* Response accepted	*22 January 2021:* Instability at a single cell and timestep was corrected by TUFLOW automatically. No noticeable issue found in the DEM_check. No significant impact considered on the results	1	0	Yes
Scenarios						
Terrain and Development	K24	*14 January 2021:* Single 'hydro-enforced' terrain used that represents current (when the LiDAR was flown in 2019-2020) development. No future development scenario required by NRC *26 January 2021:* No response provided, but note comment for K13 that 'DEM without filling of sinks used, rather than hydro-enforced DEM.		1		Yes

Item	Ref	Beca Review Comment	Water Technology (WT) Response/Action Taken	Initial Audit Rating	Final Audit Rating	Fit for Use
Design Events	K25	14 January 2021: As an independent event, this has been modelled appropriately. However, the event was preceded by heavy rainfall six days earlier. The Okaroro Road raingauge shows 130 mm in 24 hours from midday on 22 Jan and 217 mm in 15 hours from 10am on the 28 Jan. The Willowbank flow gauge didn't record the flows 22-23 Jan event, but the Below Old Mill flow recorder did. (Figure 1) *See comments in review of the calibration report regarding the potential effects on model results.* 26 January 2021: Of the model results presented in the Calibration Report, those for the Kawakawa catchment offer the best calibration. But the difference in response of the Below Old Mill recorder to the two January 2011 events highlights the difficulty of choosing appropriate antecedent conditions for modelling. Recommend that this is discussed with NRC, and whether it would be valuable to run a long duration calibration event (for this or on of the other catchments) to include both of the January 2011 events. That would demonstrate whether any water is left on the surface after the first event, thereby changing the response to the second event rainfall	22 January 2021: The impact of the rainfall event in the preceding week is likely to have impacted on antecedent conditions. When undertaking the calibration for this event, suitable loss values were used to account for this and provided closely match modelled water levels at the streamflow gauges. This helps identify a range of catchment antecedent conditions that can be used for design modelling. A sensitivity test for the catchment which modelled preburst rainfall shows only minor impacts are likely on the modelling results.	1	1	Yes

Item	Ref	Beca Review Comment	Water Technology (WT) Response/Action Taken	Initial Audit Rating	Final Audit Rating	Fit for Use
Sensitivity Checks	K26	*14 January 2021:* Model files not provided for model sensitivity checks. But note from calibration report and previous stages of the project that that sensitivity checks were completed for the region-wide modelling using the Awanui catchment for TUFLOW grid sizing (using Quadtree and SGS), and for each calibration catchment for rainfall losses and roughness. So, no issue.	No response required	0		Yes
Results and outputs						
Results	K27	*14 January 2021:* Not provided, so no check against reported results possible. *26 January 2021:* Results downloaded. Not fully reviewed but no issues noted	*22 January 2021:* Model check and results files were provided in One Drive, they are still available for download from the link provided	2	1	Yes

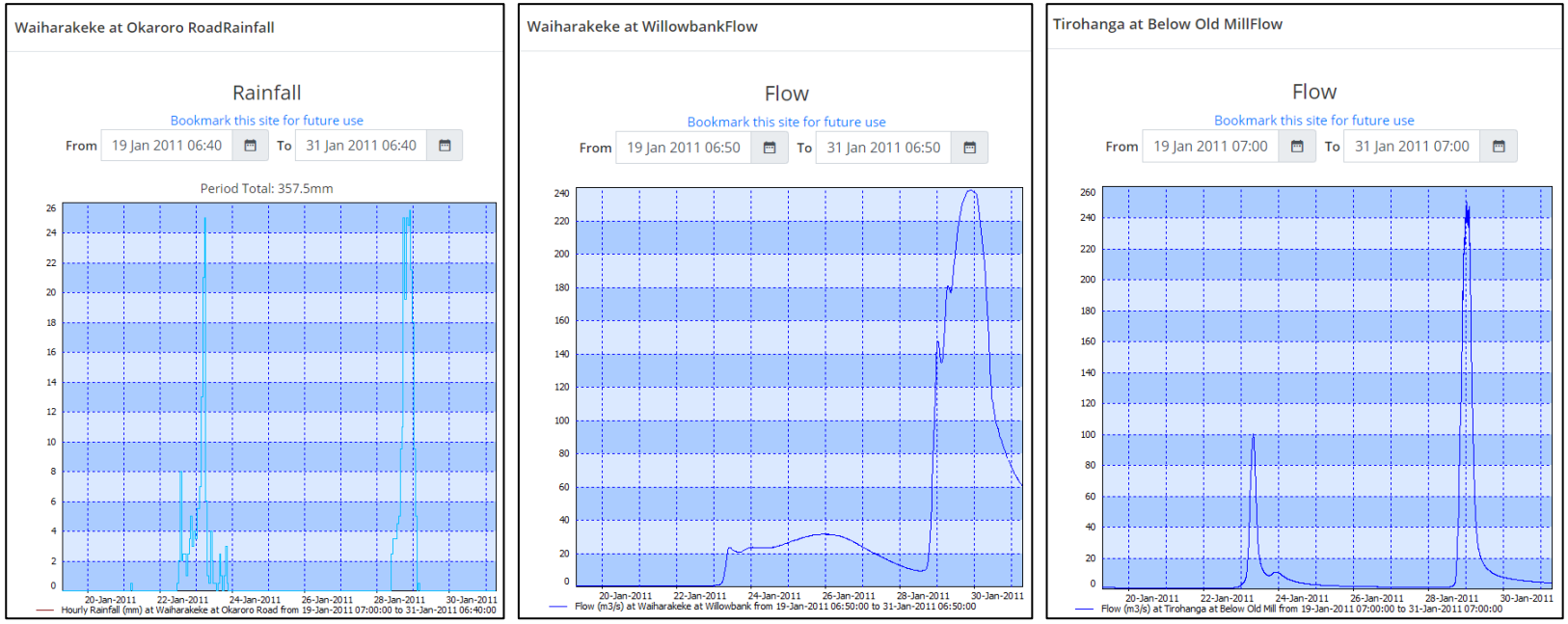


Figure 1 - Kawakawa catchment rainfall hyetograph and flow hydrographs for 19-31 January 2011

2.1.1 Summary

- The model is a relatively simple 2D model, albeit one that covers a large area. This is an appropriate method for catchment-scale modelling for indicative flood risk and planning maps. The limitations of the modelling mean that they can be refined at the local scale through the addition of more model detail.
- The model files provided are set correctly.

2.2 TUFLOW Model Review – Whangarei catchment

WaterTech provided all TUFLOW model files with the exception of model results files. As such, the review of the model concentrates on the model file structures and links, and on the catchment input data.

The model setup is the same as for the Kawakawa catchment, and so the review comments are virtually identical. Differences are from the Kawakawa review are highlighted.

Item	Ref	Beca Review Comment	Water Technology (WT) Response/Action Taken	Initial Audit Rating	Final Audit Rating	Fit for Use
General and model setup						
Version	W1	*14 January 2021:* TUFLOW_2020-01-AB-iSP Not backward compatible	No response required	0		Yes
TUFLOW control files	W2	*14 January 2021:* Standard folder structure used. *Note that results not provided.* *26 January 2021:* Results were provided. Problems with download pre-Christmas resolved.	*22 January 2021:* Results were provided and still available for download.	1	0	Yes
Timestep	W3	*14 January 2021:* The timestep of 1.6 seconds (.tcf file) is slightly less than 20% of the default grid cell size (10 m). However, given the variable grid sizing using SGS this is acceptable. *26 January 2021:* Response accepted	*22 January 2021:* Adaptive timestepping was applied for these models as HPC scheme was used. A check of the dt throughout the model was also undertaken to ensure model stability	1	0	Yes
Model configuration and extents						

Item	Ref	Beca Review Comment	Water Technology (WT) Response/Action Taken	Initial Audit Rating	Final Audit Rating	Fit for Use
1D, 2D, 1D/2D	W4	*14 January 2021:* The model is 2D only. While this simplifies the model and allows large areas to be modelled with reasonable run times, the model does not include 1D structures, networks, and channels. This reduces model accuracy but is a pragmatic approach to modelling at the catchment scale. *26 January 2021:* Response accepted	*22 January 2021:* Given the purpose and scale of the project, 1D structures were not included as part of the scope of the project. The use of a 1m LiDAR grid generally provides a good representation of channel capacity in high flow events as there is a significant portion of flow across the floodplain.	1		Yes
1D extents	W5	Not used				
1D setup	W6	Not used				
2D extents	W7	*14 January 2021:* 2d_code layer shapefile (referenced in .tgc file) checked.	No response required	0		Yes
2D grid/mesh	W8	*14 January 2021:* Default grid size of 10 m is appropriate for catchment scale model, when used with SGS and Quadtree *26 January 2021:* Response accepted	*22 January 2021:* Quadtree was not applied	0	0	Yes
	W9	*14 January 2021:* SGS sample distance of 1 m in .tgc file is appropriate.	No response required	0		Yes
	W10	*14 January 2021:* Quadtree areas have been used to provide better definition in some urban areas. This is explained in the calibration report and is appropriate. A nest level of 3 (equivalent to a 2.5 m grid when the default grid is 10 m) has been used for the Whangarei urban area. Other Quadtree areas could be added if better definition is required elsewhere. *26 January 2021:* Response accepted. Note confirmation in the Calibration Report that SGS only was used. Quadtree nest level not activated in model files.	*22 January 2021:* Notes that Quadtree was only tested in Awanui, and current calibration modelling did not use Quadtree	1	0	Yes

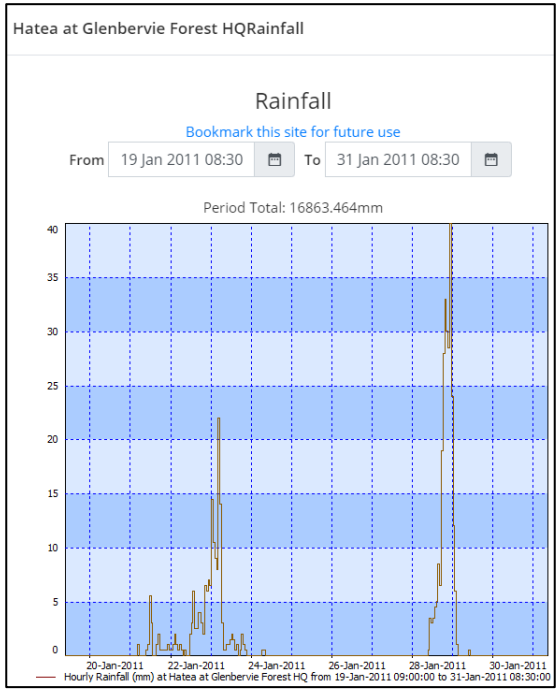
Item	Ref	Beca Review Comment	Water Technology (WT) Response/Action Taken	Initial Audit Rating	Final Audit Rating	Fit for Use
Terrain data (2D)	W11	*14 January 2021:*.tgc file references .asc DEM five files in *M:\20010434_NRC_Region_River_Flood_Model\Spatial\Data\Grid\LiDAR\HydroDEM\...* These are not in the standard TUFLOW file tree and so not able to be checked by the reviewer. *26 January 2021:* File provided. Useful to have the files under TUFLOW file directory tree for reference and review	*22 January 2021:* Only one DEM file is active in the tgc file, namely "m01.asc" which is available for download in the One Drive link provided This can be changed to ..\model\grid\ prior to hand over of model files if required	2	1	Check
Cross-sections	W12	*14 January 2021:* No cross-section in model	No response required	n/a	n/a	n/a
2D obstructions	W13	*14 January 2021:* No 2D structures or obstructions included in model, as underlying DEM is the hydro-enforced DEM developed by WaterTech for NRC in a previous project. This loss of definition is and accepted compromise to allow for efficient catchment-scale modelling. *26 January 2021:* Noted. Previous comment was mis-reading of Calibration Report.	*22 January 2021:* Notes that the DEM used in the model has no sinks filled as opposed to the "hydro-enforced" DEM.	1	1	Yes
Roughness	W14	*14 January 2021:*.tmf file checked Manning's roughness 'n' values are in expected range and correctly assigned within the model. The modelled values reflect those reported in Table 6-2 of the calibration report. OK *26 January 2021:* Response accepted.	No response required	0	0	Yes
Hydraulic structures and networks						
General	W15	*14 January 2021:* Not included	No response required	n/a	n/a	n/a

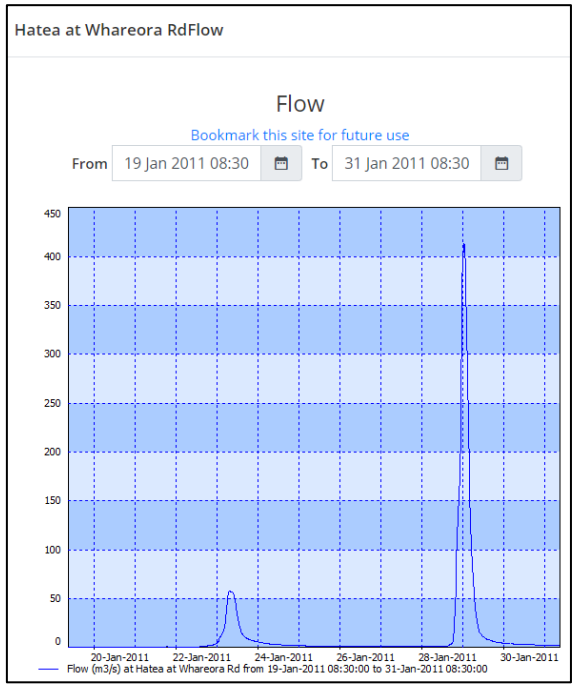
Item	Ref	Beca Review Comment	Water Technology (WT) Response/Action Taken	Initial Audit Rating	Final Audit Rating	Fit for Use
Bridges, culverts & blockage	W16	*14 January 2021:* Not included. The effect on water levels and flows of bridges and other obstructions close to flow recorders is not included in the model. These may affect calibration performance and modelled flow ratings. But acceptable for this level of modelling. *26 January 2021:* NRC could confirm this, but the recorders at Whareora Road, Lovers Lane and Bernard Street all appear to be in close proximity to bridges.	*22 January 2021:* No bridge/ hydraulic structure identified close to any of the streamflow gauges used in this model calibration. It is therefore believed only 2D topography below the water level captured in the LiDAR and resultant channel capacity is likely to have major influence on the modelled flow ratings. *NRC comment 5 February 2021:* We recognise that our calibration and validation standards for the modelling has been set high for the purpose and expected outcome of the model, i.e. region wide flood model which forms a flood inundation map guideline and a basis for future in-depth analysis when required. Accurate base data for all our catchments is in cases not available and assumptions have to be made. It would be a preference to include the bridges near the recorders, where present, in the same light as all other structures on our rivers. In light of the expected deliverable from this project we agree with and accept WT statement "….. LiDAR and resulted channel capacity is likely to have major influence on the modelled flow ratings", as used for the modelling in order to achieve the best outcome in a limited timeframe and for what is a 2D model only, model calibration has focused on replicating the recorded flood behaviour levels i.e. FIT FOR PURPOSE.	2	1	Yes, as agreed by NRC
Piped Networks	W17	*14 January 2021:* Not included	No response required	n/a	n/a	n/a

Item	Ref	Beca Review Comment	Water Technology (WT) Response/Action Taken	Initial Audit Rating	Final Audit Rating	Fit for Use
Boundary conditions						
Rainfall	W18	*14 January 2021:* Rain on grid Rainfall defined in .trfc file.	No response required	0		Yes
Losses	W19	*14 January 2021:* Defined in .tmf file. Losses as reported in calibration report.	No response required	0		Yes
Catchments	W20	*14 January 2021:* Not applicable as rain-on-grid applied to whole 2D area.	No response required	n/a	n/a	n/a
Inflows	W21	*14 January 2021:* Two external flow boundaries (2d_bc_M01_culv_L.shp "dam inlet at Kotuku Dam Intake") referenced in .tbc file. Modeller to confirm how these are used *26 January 2021:* Response accepted	*22 January 2021:* The flow boundaries identified in the shape file are CN/SX (connection) lines. These are used for 1D/2D connection. A 1d pipe was added at Kotuku Dam with dimension information given by NRC. These boundaries are used to connect the 1d pipe with the 2d floodplain. Flood water from the upstream of the Dam will flow through this pipe to the downstream. Given the size and likely impact of the culvert flow through the major retarding basin on flood levels across the catchment, this was one of the only 1d structures included in the model.	2	0	Yes
Downstream	W22	*14 January 2021:* MarsdenPt_TWL tidal boundary applied for tidal boundary in 2011 event. Checks made of GIS placement of boundary and links to .csv file	No response required	0		Yes
Errors, checks and warnings						
Model stability	W23	*14 January 2021:* One model stability warning, but not considered significant. *26 January 2021* Response accepted*:*	*22 January 2021:* Instability at a single cell and timestep was corrected by TUFLOW automatically. No noticeable issue found in the DEM_check. No significant impact considered on the results	1	0	Yes

Item	Ref	Beca Review Comment	Water Technology (WT) Response/Action Taken	Initial Audit Rating	Final Audit Rating	Fit for Use
Scenarios						
Terrain and Development	W24	*14 January 2021:* Single 'hydro-enforced' terrain used that represents current (when the LiDAR was flown in 2019-2020) development. No future development scenario required by NRC *26 January 2021:* No response provided, but note comment for K13 that 'DEM without filling of sinks used, rather than hydro-enforced DEM.		1		Yes
Design Events	W25	*14 January 2021:* Storm event of 28-29January 2011. As an independent event, this has been modelled appropriately. However, the event was preceded by heavy rainfall six days earlier. The Glenberervie Forest HQ raingauge shows 174 mm in 48 hours from midday on 21 Jan and 257 mm in 15 hours from 10am on the 28 Jan. Figure 2 shows the rainfall hyetograph and the flow hydrographs for Whareora road and Lovers Land. Both hydrographs show significantly higher peak flows for the second event *See comments in review of the calibration report regarding the potential effects on model results.* *26 January 2021:* As noted under K25, the proximity of the two January 2011 events highlights the difficulty of choosing appropriate antecedent conditions for modelling, and so recommend that this is discussed with NRC, and whether it would be valuable to run a long duration calibration event (for this or on of the other catchments) to include both of the January 2011 events. That would demonstrate whether any water is left on the surface after the first event, thereby changing the response to the second event rainfall	*22 January 2021:* The impact of the rainfall event in the preceding week is likely to have impacted on antecedent conditions. When undertaking the calibration for this event, suitable loss values were used to account for this and provided closely match modelled water levels at the streamflow gauges. This helps identify a range of catchment antecedent conditions that can be used for design modelling. A sensitivity test for the catchment which modelled preburst rainfall shows only minor impacts are likely on the modelling results.	1		Yes

Item	Ref	Beca Review Comment	Water Technology (WT) Response/Action Taken	Initial Audit Rating	Final Audit Rating	Fit for Use
Sensitivity Checks	W26	*14 January 2021:* Model files not provided for model sensitivity checks. But note from calibration report and previous stages of the project that that sensitivity checks were completed for the region-wide modelling using the Awanui catchment for TUFLOW grid sizing (using Quadtree and SGS), and for each calibration catchment for rainfall losses and roughness. So no issue.	No response required	0		Yes
Results and outputs						
Results	W27	*14 January 2021:* Not provided, so no check against reported results possible. *26 January 2021:* Results downloaded. Not fully reviewed but no issues noted	No response provided	2	1	Yes





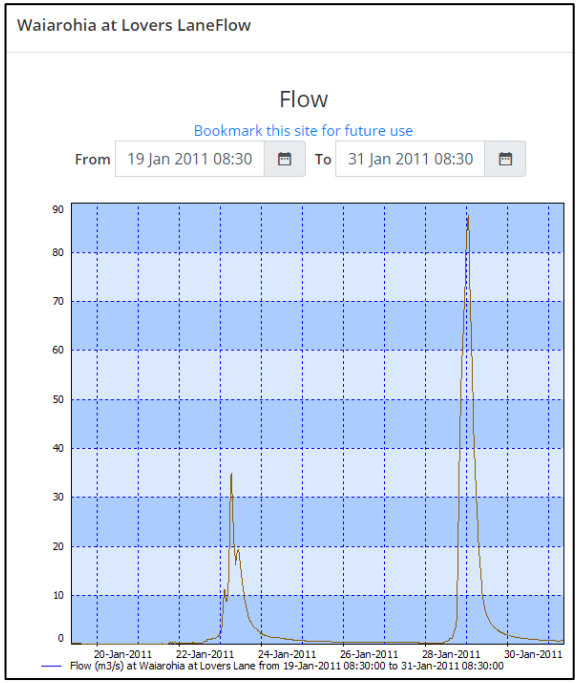


Figure 2 - Whangarei catchment rainfall hyetograph and flow hydrographs for 19-31 January 2011

2.2.1 Summary

The key points are the same as for the Kawakawa model, namely

- The model is a relatively simple 2D model, albeit one that covers a large area. This is an appropriate for catchment-scale modelling for indicative flood risk and planning maps. The limitations of the modelling mean that they can be refined at the local scale through the addition of more model detail.
- The model files provided are set correctly.
- As the model results have not been provided, the reviewer has not been able to check whether the result provided in the calibration report are correct.

2.3 Model Calibration Report

Whereas the reviews of the Kawakawa and Whangarei model files concentrated on the setup of the models and correct links to input files and data, the review of the calibration report raises issues and questions relating to the modelling and calibration approaches. As such, there are more items that require a response from the modeller and so rated as 2s in the initial audit rating. It is expected that the modeller's response will allow these items to be rated as 0 or 1, and the item closed out.

<table>
<tr><th>Report item</th><th>Ref</th><th>Beca Findings & Comments</th><th>Water Technology (WT) Response / Action Taken</th><th>Initial Audit Rating</th><th>Final Audit Rating</th><th>Open/ Closed</th></tr>
<tr>
<td>Section 1
Page 9</td>
<td>R1</td>
<td>14 January 2021: 5th paragraph: This paragraph reports the dates of the storm/flood events used for calibration, including the 28 January 2011 event. That event was preceded by heavy rainfall across the regions 6-7 days earlier (see Figure 1 and Figure 2). Rainfall totals for gauges in three of the calibration gauges were:
<table>
<tr><th>Catchment (rain gauge)</th><th>21/23 Jan</th><th>28/29 Jan</th></tr>
<tr><td>Awanui (Te Rore)</td><td>105 mm</td><td>116 mm</td></tr>
<tr><td>Kawakawa (Okaroro Rd)</td><td>130 mm</td><td>217 mm</td></tr>
<tr><td>Whangarei Glenbervie (Forest HQ)</td><td>175 mm</td><td>257 mm</td></tr>
</table>
Would soils have still been saturated and catchment surface storage not fully drained prior to the onset of rainfall on the 28 Jan? If so, then the recorded flows and flood volumes could be expected to be significantly higher than modelled flows that do not account for these antecedent conditions.
This would affect the perceived performance of the calibration models against NRC’s calibration criteria.
26 January 2021: While flows may have dropped back to normal low flows prior to the 28 January 2011 event, I was concerned that the catchment would still be saturated, resulting in greater than expected runoff from the 28 January event. I’ve had a look at soil moisture data for Kerikeri (downloaded from Cliflo), which indicates that soil moisture had almost dropped back to normal to levels.
So, how can the difference in hydrographs (catchment response) shown in Figures 1 and 2 be explained.
NRC need to agree WaterTech’s response</td>
<td>22 January 2021: The impact of the rainfall event in the preceding week is likely to have impacted on antecedent conditions. When undertaking the calibration for this event, suitable loss values were used to account for this and provided closely match modelled water levels at the streamflow gauges. This helps identify a range of catchment antecedent conditions that can be used for design modelling.

A sensitivity test which included preburst rainfall (10mm depth rainfall 5hr prior the event) has shown that minor impacts were found on the modelling results. In addition, according the flow records in the calibration gauges, the flows from the first event had been attenuated to a low flow prior the calibration events.
NRC comment 5 February 2021:
As mentioned under point 1) above the model calibration has focused on replicating the recorded flood behaviour levels, i.e. FIT FOR PURPOSE in light of the purpose and ‘audience’ of the flood maps.</td>
<td>2</td>
<td>1</td>
<td>Close as agreed by NRC</td>
</tr>
</table>

Report item	Ref	Beca Findings & Comments	Water Technology (WT) Response / Action Taken	Initial Audit Rating	Final Audit Rating	Open/ Closed
Page 10	R2	*14 January 2021: 2nd paragraph:* There are too many examples where the modelled results do not meet NRC's model performance criteria to be able to categorically state that the *"modelling approach will provide suitable and fit for purpose model results"*. That conclusion can only be made once agreed with NRC, and accounting for the antecedent conditions and flow rating accuracy concerns. Focusing the calibration on fitting recorded levels rather than hydrological processes, could result in a risk translating model parameters to ungauged catchments. *26 January 2021:*	*22 January 2021:* There appears to be a level of uncertainty in the streamflow rating curves across the study area. The approach taken has provided a higher level of certainty upon the recorded streamflow levels (whilst maintaining appropriate hydraulic modelling parameters). Where available, additional validation to recorded flood levels has also been carried out. Antecedent conditions and appropriate hydrological processes have been taken into account by adjusting loss and infiltration values across the catchment. *NRC comment 5 February 2021:* We acknowledge that the performance criteria set by NRC are high for a modelling exercise and expected deliverables for a project of this nature. We would also like to 'remind ourselves', with reference to the Calibration and Validation project brief, that; • The model flow tolerances of +/- 10% (site recorded flow) to be for the same stage and • +/- 15% of recorded peak flow (telemetered sites) for the model peak flow and flow volume • Model peak to occur within +/- 1 hour of recorded peak at telemetered locations • Modelled flood levels to be within 300mm of aby surveyed historic levels. In light of the above and with reference to the WT statement we are SATISFIED TO CLOSE THIS ACTION.	**2**	**1**	**Close as agreed by NRC**
Section 2.2 Page 12	R3	*14 January 2021:* See comment under Ref R29 regarding unexplained spatial anomalies in HIRDSv4 rainfall depths.	No response required	**1**		**Closed**

Report item	Ref	Beca Findings & Comments	Water Technology (WT) Response / Action Taken	Initial Audit Rating	Final Audit Rating	Open/ Closed
Section 3.2 Pages 17-19	R4	*14 January 2021:* The use of Quadtree and Sub-Grid Sampling (SGS) is appropriate for the modelling, and the model reviews confirmed that they had been applied correctly *26 January 2021:* Response accepted	*22 January 2021:* Notes Quadtree was not considered for all the model runs given the additional run time tested in the Awanui model	**0**		**Closed**
Section 3.2 Page 22	R5	*14 January 2021:* *Hydro-enforced LiDAR DEM testing* *1st paragraph: What is meant by a "conservative assessment". 'Conservative' is an ambiguous word, that can mean low (i.e. not much risk of flooding), or as a precautionary approach (i.e. high risk of flooding). Please clarify.* *26 January 2021:* Explanation accepted	*22 January 2021:* Can reword the sentence. But what we are trying to emphasize here is the filling of sinks could result in reduction in catchment storage and therefore, an increase in flooding elsewhere. Also if shallow waterways and small depression areas were filled, it would result in a loss of connectivity along the waterway and these areas could be modelled as dry.	**1**	**1**	**Closed**
	R6	*14 January 2021:* *Hydro-enforced LiDAR DEM testing* *2nd paragraph and Figure 3-6:* Has any validation been done of the area shown in Figure 3-6 to confirm whether the hydro-enforced DEM provides a better representation of what occurs at the site? *26 January 2021:* Explanation accepted. The use, or not, of hydro-enforced DEMs remains a point for discussion, and could benefit for more detailed modelling over a smaller area with detailed calibration data. This level of detail would not be for this project.	*22 January 2021:* No feature survey information or validation was undertaken for this area. The report highlights that the "hydro-enforced DEM" may not provide better representation of the topography across all areas due to sinks being filled. The DEM without filling of sinks was selected to provide flood mapping outputs that identify areas of high risk and maintain connectivity along waterways.	**1**	**1**	**Closed**

Report item	Ref	Beca Findings & Comments	Water Technology (WT) Response / Action Taken	Initial Audit Rating	Final Audit Rating	Open/ Closed
Section 3.3 Pages 23-24	R7	*14 January 2021:* This section might sit better earlier in the report (even as part of Section 1) as it provides a succinct summary of the calibration process. It could also be broken down into three sub-sections: 3.3.1 – Catchments 3.3.2 – Calibration process 3.3.3 – Calibration criteria *26 January 2021:* Not a critical issue. To be agreed between WaterTech and NRC.	*22 January 2021:* Noted: Will discuss with NRC. Currently, we would prefer to have this section stay in Section 3, because Section 1 focuses a brief summary of the overall project. Can discuss about this if updates needed.	**1**	**1**	**Closed**
Comments are provided below on each of the calibration catchments. The modeller should consider whether general comments made for one catchment are applicable to other catchments, as the reviewer has attempted not to duplicate the same comment.						
Section 4 – Awanui catchment						
Figure 4-1	R8	*14 January 2021:* Rotating catchment maps so that there are larger is a good idea and could be applied to other figures in the report. *26 January 2021:* Not a critical issue. To be agreed between WaterTech and NRC.	*22 January 2021:* Noted, will discuss with NRC	**1**	**1**	**Closed**
Figure 4-5	R9	*14 January 2021:* How does the spatial variability of rainfall compare to weather radar estimates (if available and robust)? *26 January 2021:* Not a critical issue, but flagged for NRC as an area for refinement.	*22 January 2021:* No comparison has been undertaken	**1**	**1**	**Closed**
Section 4.2 Pages 32 to 36	R10	*14 January 2021:* This section might fit better after (or as part of) Section 4.3, or as an appendix to the report. *26 January 2021:* Not a critical issue. To be agreed between WaterTech and NRC	*22 January 2021:* Will discuss with NRC if needed to make this change	**1**	**1**	**Closed**

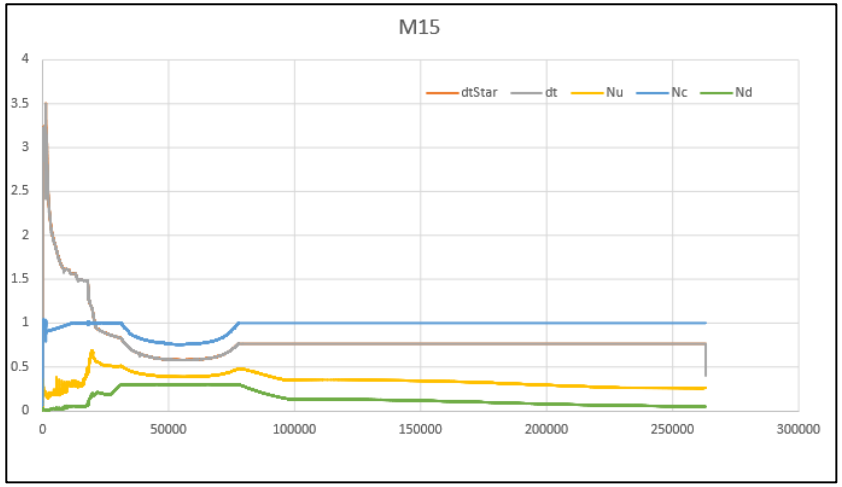
Report item	Ref	Beca Findings & Comments	Water Technology (WT) Response / Action Taken	Initial Audit Rating	Final Audit Rating	Open/ Closed
Section 4.3	R11	*14 January 2021:* *Table 4-5 (Volume columns):* The units are incorrect. They are not m^3. They could be ,000 m^3, but the values in the columns do not look correct. From the hydrograph in Figure 4-15, the reviewer estimated the modelled flood volume to about 10,600,000 m^3 and the gauged flood volume to be about 15,300,000 m^3. Modeller to correct table and confirm flood volumes. **This issue applies to the equivalent table for other calibration catchments.** *26 January 2021:* Item will be closed when report re-issued.	*22 January 2021:* Noted: The hour time wasn't converted to seconds when calculating the volumes. Will correct them in the next version of the report.	**2**	**1**	**Open**
	R12	*14 January 2021:* *Figure 4-19 and Figure 4-20:* The difference between modelled and gauged flow ratings is significant, indicating that modelled water levels are generally 1 m above the recorded levels for a given flow. *26 January 2021:* Agree with modeller's comments. Should be discussed with NRC	*22 January 2021:* Agree, there is a large discrepancy between the modelled and gauged rating curves. Information on the current gauging's shows the maximum flow gauged is 44.3 m^3/s. The development of a model based rating curve with further feature survey of the site may provide more information on the rating curve at high flows when compared with extrapolation of small in-channel gaugings	**2**	**1**	**Closed**
Section 4	R13	*14 January 2021:* *General comment:* The Awanui catchment is complicated by spills that make it difficult to model flows in the vicinity of the flow recorders using a simple 2D model. This is a contributing factor to the poor results shown in the 'Quantitative Assessment' shown in Table 4-6.	No response required	**1**		**Closed**

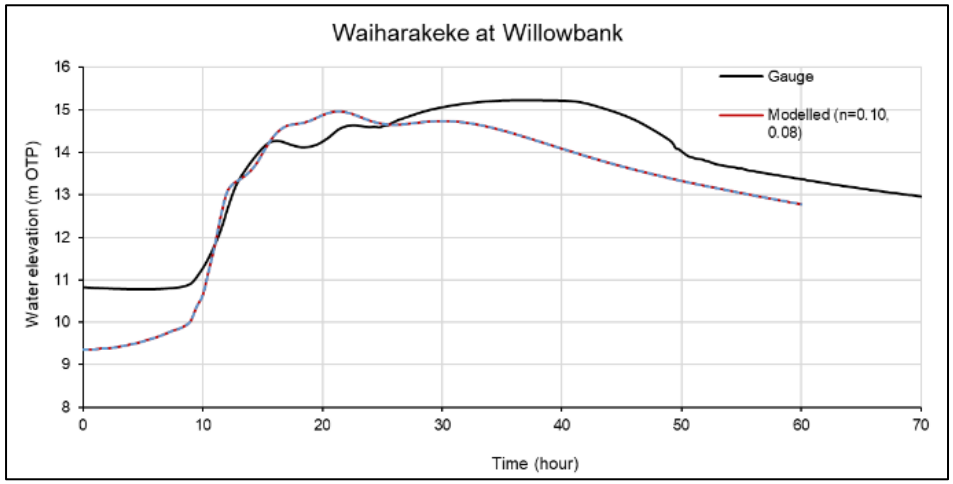
Report item	Ref	Beca Findings & Comments	Water Technology (WT) Response / Action Taken	Initial Audit Rating	Final Audit Rating	Open/ Closed
Section 5 – Kawakawa catchment						
General	R14	*14 January 2021:* This is one of the catchments for which TUFLOW model files were provided. At the beginning of the section, the key TUFLOW files should be listed, so that the results reported in the report can be checked against the model results; ensuring that the correct model setup is referred to. This applies to all calibration catchments. *26 January 2021:* Agree, to proposal to discuss with NRC. At a minimum the model files should be referenced in an appendix. Can be closed once next version of report addresses the issue.	*22 January 2021:* Noted, can discuss with NRC if needed to list TUFLOW files in the report? Where possible, the report aims to reduce technical detail.	**2**	**1**	**Open**
Table 5-1 Page 46	R15	*14 January 2021:* ***Rainfall*** is fairly consistent across the catchment, which should aid calibration, though note other comments about antecedent conditions. *26 January 2021:* With regard to antecedent conditions, see previous comments	*22 January 2021:* Antecedent conditions taken into account.	**0**	**0**	**Closed**
Figure 5-6 Page 50	R16	*14 January 2021:* The hydraulic model ***material layer*** shown in the figure has been checked against Google Earth aerial photos and is appropriate.	No response required	**0**		**Closed**

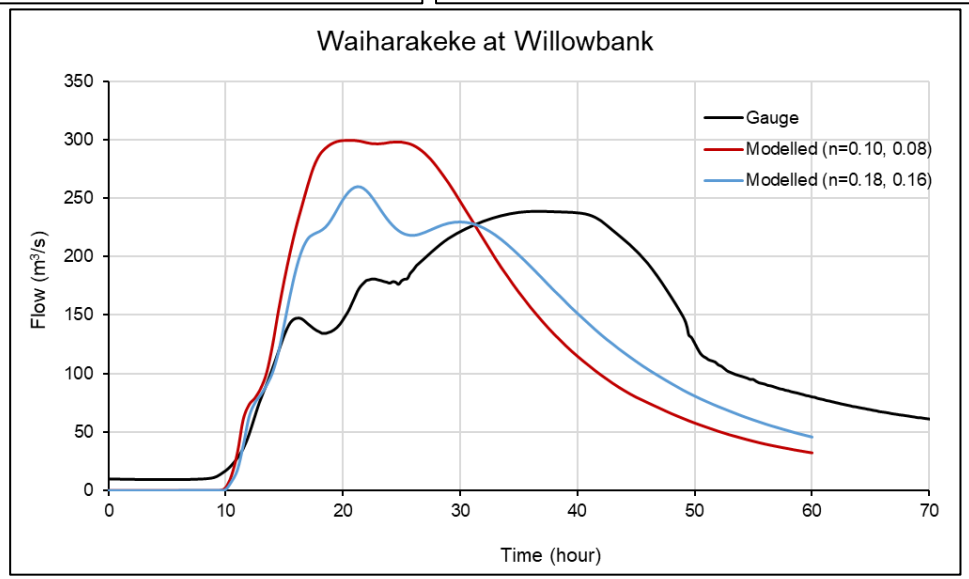
Report item	Ref	Beca Findings & Comments	Water Technology (WT) Response / Action Taken	Initial Audit Rating	Final Audit Rating	Open/ Closed
Table 5-2 Page 51	R17	*14 January 2021:* The ***catchment roughness and rainfall loss*** parameters shown in the table are as modelled. The Mannings roughness values of 0.16 and 0.18 for the Upper Kawakawa are high for floodplains, but could be appropriate for overland/sheet flow. Are there known difficulties in TUFLOW modelling rain-on-grid over steep catchments, and if so, are the high 'n' values adopted to overcome these issues, or are they a true reflection of the hydraulic characteristics? *26 January 2021:* Explanation of roughness accepted, as is the acknowledgement of issues around steep catchments, and how HPC deals with it.	*22 January 2021:* The roughness values were calibrated through matching the modelled water levels with the records at Willowbank gauge. The material roughness and loss/infiltration layers have been developed at a catchment wide scale. The level of detail provided in the model has been based on catchment wide modelling and where possible, catchment conditions have been lumped together with the aim of producing fit for purpose modelling results. The roughness values adopted for the upper Kawakawa are on the higher side and are high to take into account the relatively dense forested area and higher vegetation across the floodplain. The figures below show the gauged flow/water level hydrographs using lower roughness values (n = 0.10 and 0.08) compared to current calibrated values. Steep catchments have previously presented instability issues when using rain-on-grid within TUFLOW Classic. TUFLOW HPC is inherently more stable due to being an explicit finite solver. The three key control numbers which adjust the timestep that the explicit solution can use are: • Courant Number, Nu • Wave Celerity Number, Nc • Diffusion Number, Nd A review of the model health shows the model timestep remains relatively stable through the model run. Generally, the Nc appears to be the controlling factor within the model.	**2**	**1**	**Closed**

Report item	Ref	Beca Findings & Comments	Water Technology (WT) Response / Action Taken	Initial Audit Rating	Final Audit Rating	Open/ Closed

Plots provided by WaterTech (22 January 2021) in response to R17







Report item	Ref	Beca Findings & Comments	Water Technology (WT) Response / Action Taken	Initial Audit Rating	Final Audit Rating	Open/ Closed
Table 5-4 Page 52	R18	*14 January 2021: Model calibration:* The calibration results indicate that the model generally meets the performance criteria and can be considered fit for use, but note review comment R17 about roughness.	No response required	0	0	Closed
Section 6 – Whangarei catchment						
General comment	R19	*14 January 2021:* This is one of the catchments for which TUFLOW model files were provided, and so checks have been made against the reported model inputs and parameters, and those in the model files provided. As with the Kawakawa catchment these were correct.	No response required	0	0	Closed
Table 6-4 and result plots	R20	*14 January 2021:* The modelling indicates good performance regarding peak water levels and the timing of the peaks, significant under-estimates in flood volume and peak flow. This may be due to antecedent condition for the January 2011 calibration event and/or issues with the flow ratings at high flows. Further investigation could refine the model *26 January 2021:* My understanding of the pre-burst was that it was 10 mm or rain five hours before the start of the event, and not 100 mm+ a few days before. Are NRC and the modeller confident that the antecedent conditions are appropriate for the required project outcomes?	*22 January 2021:* The sensitivity test with preburst has shown minor impacts on the modelling results. It is unlikely the antecedent condition causes the underestimation of the flood volume and peak. This difference may be associated with the uncertainty of the rating curves at high flows. *NRC comment 5 February 2021:* Reference is made to R1 above. Two different preburst 'conditions' were mentioned in the findings column of the report. With WT's response, and subsequent discussions at the above referred project meeting, NRC are SATISFIED TO CLOSE THIS ACTION, i.e. fit for purpose and required project outcomes.	2	1	Closed as agreed by NRC

Report item	Ref	Beca Findings & Comments	Water Technology (WT) Response / Action Taken	Initial Audit Rating	Final Audit Rating	Open/ Closed
Figure 6-20	R21	*14 January 2021:* Figure 6-20 shows that while modelled and recorded peak water levels are close along the river upstream of the town centre, the modelled peak water levels are significantly higher (red dots) than recorded downstream of the town centre and away from the river. This may be due to water being trapped by the 2D model surface, whereas it could drain via the stormwater network in reality. This is a potential limitation of a 2D-only approach in urban areas, even where a hydro-enforced DEM has been adopted to minimise the risk of excessive surface water. *26 January 2021:* Response accepted	*22 January 2021:* Yes, the addition of the stormwater network in the township might help reduce the water levels within the township. This is out of the scope and purpose of this project. It is likely that urban modelling would be undertaken in a detailed flood study of the township.	**1**	**1**	**Closed**
General	R22	*14 January 2021:* The calibration results indicate that the Whangārei model could be refined and model performance improved. However, it performs well at the flow recorder sites for peak water levels. The over-estimation of peak water levels shown in some areas in Figure 6-20 mean that flood maps created from the current model will be precautionary in such areas. *26 January 2021:* Response accepted	*22 January 2021:* Agreed, detailed mapping in the town centre would likely provide more accurate results.	**1**	**1**	**Closed**

Report item	Ref	Beca Findings & Comments	Water Technology (WT) Response / Action Taken	Initial Audit Rating	Final Audit Rating	Open/ Closed
Section 7 – Mangakahia catchment and tributaries						
General comment	R23	*14 January 2021:* Generally, the model results do not meet the calibration performance criteria. The exception is the Kaikou at Moengawahine location, for which the performance is acceptable based on volume, peak water level and timing of peak. The reviewer agrees with WaterTech that a review of rating curves is required to confirm the performance of the model. At the moment it is not possible to judge the model performance *26 January 2021:* Response accepted. Discussion needed with NRC as to whether the calibration criteria are appropriate, still valid, or should be relaxed for acceptance of the models.	*22 January 2021:* For the purpose of the study, an emphasis on ensuring the timing and peak water levels of the model at gauge locations match well with recorded levels. This highlights model behaviour is well replicated with hydrological processes and hydraulic behaviour matching well, the model results can be used for the catchment wide flood risk mapping project. The results should be used with caution given not only the uncertainty around rating curves, but also the scale of the results. Where applicable, detailed flood modelling results should be used in preference to the model results produced for the catchment wide project. *NRC comment 5 February 2021:* Reference is made to R2 above and Section 3.5 Calibration and Validation of the Project Brief (Tender Document). We acknowledge that we have set the "bar high" for the purpose of the study. The results to date show that the model behaviour is well replicated with hydrological and hydraulic perspectives. There are of course a number of uncertainties, e.g. rating curves. The scale and purpose of this study is of a 'high level / flood (modelling) mapping nature' and the results should be used with caution. Bearing the above in mind we are SATISFIED TO CLOSE THIS ACTION with the acceptance to relax the stated calibration criteria to accept the models, i.e. fit for purpose and required project outcomes.	**2**	**1**	**Close as agreed by NRC**

Report item	Ref	Beca Findings & Comments	Water Technology (WT) Response / Action Taken	Initial Audit Rating	Final Audit Rating	Open/ Closed
Kaikou	R24	*14 January 2021:* Kaikou at Moengawahine: Though the modelled results at this gauge meet the volume, water level and timing performance criteria, the receding limbs of the modelled water level and flow hydrographs are different from the recorded hydrographs. The modelled water levels and flows drop a lot quicker than recorded. The rising limb of the flow hydrograph is a good match to about 300 m^3/s, and note WaterTech's comments regarding the rating, but the modeller should explain why the recorded water levels stay high on the receding limb of the hydrograph. *26 January 2021:* issue brought to the attention of the modeller.	*22 January 2021:* Noted, there may be a slightly higher amount of volume on the receding limb. This may be a result of the spatial variation in rainfall not accounting for gaps in between the rainfall stations available for use,	**2**	**1**	**Closed**
Section 8 – Wairua catchment and tributaries						
General comment	R25	*14 January 2021:* The reviewer agrees that: • The model performs well in matching the peak water surface elevations, and that the water level hydrographs are a good fit generally • Some of the modelled rating curves show significant hysteresis and differences from NRC's ratings, which help explain the differences in modelled and recorded flow hydrographs WaterTech need to agree with NRC whether it is acceptable to test models against water level only in these circumstances. *26 January 2021:* Response accepted	*22 January 2021:* Discussions with NRC to be undertaken. *NRC comment 5 February 2021:* Reference is made to K16 and W16 above, last paragraphs, and NRC data made available to Water Tech, e.g. rating curves and hydrographs. Our modeller Sher Khan was unfortunately not available for the above referred project meeting. However, at this moment in time we find it acceptable to test models against water levels only, i.e. fit for purpose and required project outcomes. SATISFIED TO CLOSE THIS ACTION for the moment.	**2**	**1**	**Close as agreed by NRC**
Sections 9, 10, and 11						
Section 9 Page 108	R26	*14 January 2021:* *2nd line:* Missing text after "… of which" *26 January 2021:* Response accepted	*22 January 2021:* Updated in report	**2**	**1**	**Closed**

Report item	Ref	Beca Findings & Comments	Water Technology (WT) Response / Action Taken	Initial Audit Rating	Final Audit Rating	Open/ Closed
	R27	*14 January 2021: Last sentence of first paragraph, and comments for each calibration catchment:* The reviewer agrees that flow ratings uncertainty could be a key factor in failure to meet some of the calibration performance criteria. However, further investigation is required to understand whether the apparent underestimation of modelled flows for the 28-29 January calibration event is due to the event following heavy rain less than a week earlier. Was soil and surface storage still full after that event, leading to higher recorded peak flows than would normally have been expected. *26 January 2021:* Response accepted	*22 January 2021:* Agree that further investigation will be required to validate rating curves. However, this is out of the scope and will require discussion with NRC but given the timeline and budget, it is unlikely achievable.	**2**	**1**	**Closed but discuss with NRC**
Section 10 Pages 109 & 110	R28	*14 January 2021: Sections 10.2 and 10.2.3, and Table 10-1:* The table shows a range of roughness and rainfall losses for each soil and land use type. Could the modeller confirm whether these will be refined down to single figures following calibration of the next five catchments (see Section 12.2) in readiness for use on non-gauged catchments? *26 January 2021:* Thanks for the explanation	*22 January 2021:* Currently, the average values of calibrated parameters were used for non-calibrated catchments within Whangarei district. Selected catchments will be calibrated in other regions (Far North and Southern region) and the average parameter values will be applied for non-calibrated/non-gauged catchments in that region.	**1**	**1**	**Closed**
	R29	*14 January 2021: Section 10.2.1:* A colleague of the reviewer has reviewed spatial variability of HIRDSV4 data at 1 km spacing for another region in NZ, and noted unexpected anomalies in rainfall depths. It is recommended that the modellers undertake a similar check for Northland catchments prior to modelling design events. *26 January 2021:* Response acknowledged	*22 January 2021:* Noted, to discuss with BECA review team and NRC	**1**	**1**	**Closed**

Report item	Ref	Beca Findings & Comments	Water Technology (WT) Response / Action Taken	Initial Audit Rating	Final Audit Rating	Open/ Closed
	R30	*14 January 2021: Section 10.2.2:* The reviewer cannot comment on the temporal hyetograph patterns as they have not been supplied. Modeller to provide comment *26 January 2021:* Assumed the "version 4 of HIRDS hyetograph shape" means a nested storm profile developed from the HIRDSv4 rainfall depth/intensity-duration-frequency tables.	*22 January 2021:* The version 4 of HIRDS hyetograph shape was adopted for design modelling as it was recommended to replace the Priority Rivers Hyetograph in a previous project undertaken by Macky & Shamseldin (2020)	**2**	**1**	**Closed**
	R31	*14 January 2021: Section 10.2.4:* The approach to modelling downstream boundaries is appropriate.	No response required	**0**		**Closed**
Section 11 Page 112	R32	*14 January 2021:* Section 11.2: Should the third word of the paragraph be "without", rather than "where"? *26 January 2021:*	*22 January 2021:* Will correct this in the next version of report	**2**	**1**	**Closed**

2.3.1 Summary of the Calibration Report

The calibration report provides a good description of the calibration modelling. The report model inputs and parameters for the Kawakawa and Whangarei catchments match the information in the model files for those two catchments. The report indicates that calibration has been difficult, due in part to the following factors:

- Flow rating uncertainty
- The effect of antecedent conditions for the 28-29 January 2011 calibration event
- Modelling hydraulically complex catchments using a relatively simple 2D-only approach. *The reviewer notes that this approach is appropriate for the scale of modelling.*

Some of the Manning's roughness values are high. These may be due to difficulties that most flood modelling software has in modelling rain-on-grid in steep terrain. WaterTech should confirm whether this is an issue for TUFLOW.

3 Conclusions

This is the Final version of the report, and includes comments received from NRC following their meeting with WaterTech on 28 January 2021 to discuss the 2nd draft of this report, as well as WaterTech's modeller's responses to the 1st draft. The reviewer has provided replies to the modeller responses and updated the audit rating, noting where any outstanding issues have been either accepted as a limitation of the modelling or addressed by updates and as such can be closed out.

The outcomes of the peer review are:

- No fatal flaws were identified in the TUFLOW model files provided for the Kawakawa and Whangarei catchments.
- The calibration report is a good description of the sensitivity and modelling work done, but could be improved with some re-ordering of sections.
- The calibration results indicate the following modelling performance for each of the calibration catchments:
  - **Awanui catchment:** Modelled water levels at the calibration points are acceptable, but the calibration does not meet the other calibration criteria.
  - **Kawakawa catchment:** The best performing of the calibration models when compared to recorded data, generally meeting the performance criteria.
  - **Whangarei catchment:** Good calibration peak water levels and the timing of the peaks, but not so good for flow and flood volume. This may be a combination of rating uncertainty and antecedent conditions for the calibration event. Flood maps developed from the model are likely to be precautionary.
  - **Mangakahia catchment and tributaries:** Generally poor calibration against the performance criteria
  - **Wairua catchment and tributaries:** Good calibration against peak water levels, but poor for flood volumes and peak flows. WaterTech have identified uncertainty regarding flow ratings as a concern.
- Following the meeting on 28 January 2021:
  - The simplifications required for a region-wide model that make it unrealistic to meet all the calibration performance measures in NRC project specification have been acknowledged.
  - All parties are aware of the limitations of the modelling, but agree that it is fit for use. However, NRC will need to clearly communicate the purpose and limits of the model outputs.
- Improvement in flow rating curves and inclusion of river channel detail and structures will improve model accuracy, and should be included in local area or site-specific flood models.

4 References

Calibration Report – NRC Region-wide River Flood Model. Water Technology PTY Ltd. 7 December 2020 (WT, 2020)

RE: Peer review discussion and agreement. Email from Jan Van Der Vliet (NRC) to Michael Law (Beca), dated 5 February 2021.