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Draft Report

Waitōtara Catchment Flood Study – Calibration Report

Taranaki Regional Council

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1 INTRODUCTION

1.1 Nature-Based Solution for Flooding in Taranaki

The Ministry for the Environment (MfE) has awarded funding to Taranaki Regional Council (TRC) in partnership with Te Kaahui o Rauru to undertake hydrodynamic modelling of nature-based solutions (NbS) to flooding in Taranaki. This project will produce hydraulic models covering the entire Taranaki Region. These hydraulic models will be used to produce the following outputs:

- Flood maps for a range of events and durations considering both existing conditions and climate change
- Impacts of proposed nature-based solutions on flooding

1.2 Waitōtara Catchment

The first stage of the project is to complete a NbS feasibility study for the Waitōtara catchment. The primary objective is to develop and deliver a detailed and calibrated hydrodynamic model for the Waitōtara catchment for a range of rainfall events/climate scenarios. This catchment study considers the latest available topography, land use, and gauged rainfall data, among other key datasets, to identify the most vulnerable areas across the catchment. This model will be used to evaluate the effectiveness of NbS and identify suitable locations for implementing NbS, or a combination of NbS and grey infrastructure to mitigate flood impacts within the Waitōtara catchment.

Water Technology has developed the hydraulic model for the flood study using TUFLOW HPC, which is a high-performance computing model that is based on the 2-dimensional shallow water equations. The TUFLOW HPC model is a reliable tool that can accurately identify flooding and its impact on the built environment, infrastructure, and communities. The modelling outcomes will be used to identify the areas that are most at risk from flooding and to develop appropriate NbS floodplain management strategies to mitigate those risks.

1.3 Purpose of Calibration Report

This summary report has been prepared specifically to describe the hydraulic model calibration and associated outcomes for the Waitōtara catchment. It provides an overview of the hydraulic modelling but does not include a complete or comprehensive description of the input data or overall model development – these will be addressed in the overall flood study report. Its intent is to enable a Peer Review process to be undertaken by the appointed peer reviewer for the study and to culminate in approval for Water Technology to progress with future model development tasks including design modelling, and nature-based solutions testing for both the Waitōtara catchment and region-wide modelling.

2 STUDY AREA AND LOCALITY

The Waitōtara catchment (refer Figure 2-1) is located in the South Taranaki District of New Zealand, occupying a total area of approximately 1,200 km². The lower catchment largely consists of agricultural pastureland and the upper catchment is mostly forested. There are several major tributaries of the Waitōtara River including the Moumahaki (and its tributary the Weraweraonga), Makakaho, and Omaru Streams.

The Waitōtara River discharges into the South Taranaki Bight. The lower river and estuary are influenced by tidal levels. Waitōtara township is situated at the southern end of the western bank of the river on State Highway 3 (SH3). A flood event in June 2015 resulted in the evacuation of 60 homes in Waitōtara township.

Water Technology note that the catchment area/model extent shown in Figure 2-1 does not exactly match the eastern boundary of the Taranaki Region. The extent of the model instead matches the most up-to-date topographical information (2021) providing a more accurate fit to the catchment extent.

Land within the TRC jurisdiction is also excluded from the hydraulic model extent in the south-east including Waiinu Beach. Hydraulic modelling and an analysis of topographical information in this area shows that the excluded area consists of smaller catchments discharging into localised depressions or into the South Taranaki Bight and thus do not contribute overland flow to the Waitōtara catchment.

Figure 2-1 Waitōtara Catchment

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3 METHODOLOGY

3.1 Modelling Approach

The hydraulic model prepared for this study utilised a linked 2D version of the TUFLOW HPC (Heavily Parallelised Compute) model. For this flood study, a Direct Rainfall (also known as Rain on Grid) modelling approach has been utilised; rainfall data inputs with model losses defined based on catchment surface characteristics generate surface runoff, which is then hydraulically routed through the model topography. More detail on the modelling software and approach can be found in Model Schematisation Memorandum prepared by Water Technology date 28 October 2024 including model development, inputs and assumptions.

Additional details will also be provided in the overall flood study report. A copy of the model files and result outputs (including log files) has been provided alongside this report, to enable a comprehensive review of the model.

3.2 Calibration Overview

There are four TRC river/stream gauges recording stage and flow in the Waitōtara catchment. These are summarised in Table 3-1 with locations shown in Figure 3-1.

Table 3-1 River/Stream Gauge Data Summary

Name	Latitude	Longitude	Data Available For
Waitōtara at Rimunui Station	-39.613	174.840	Both calibration events (04/05/1993 – present)
Waitōtara at Township	-39.806	174.735	Second calibration event (17/11/2015 – present)
Weraweraonga at 749 Mangawhio Rd	-39.708	174.720	Second calibration event (07/03/2017 – present)
Moumahaki at Johnston Rd	-39.747	174.701	Second calibration event (04/09/2017 – present)

It is important to acknowledge that the Waitōtara River (and other waterway) channel bed moves, especially in the estuary. The major example of bed shift relevant to hydraulic model calibration is a change in the river alignment at a bend ~750 m downstream of the SH3 Bridge at Waitōtara township in June 2015. This may impact the rating curves of the gauges however, variability in the channel bed was not considered to be a major factor in model calibration as the only noticeable changes have been downstream of all river gauges.

There is limited historical data available for the catchment to inform the model calibration; the only river gauge within the Waitōtara catchment with available data for the June 2015 event is Waitōtara at Rimunui Station. This station is located in the mid-reach of the catchment and records both stage and flow of the Waitōtara River. The three remaining gauges have available data for later events with the latest gauge installed being Moumahaki at Johnston Rd in September 2017. As a result, Water Technology calibrated the model against two events using available TRC gauges recording stage and flow:

1. 19th – 20th June 2015 flood to Waitōtara at Rimunui Station
2. 18th – 19th June 2018 flood to all four gauges described in Table 3-1. There are also three additional rainfall gauges with available records installed within the catchment for this event.

The Model Schematisation Memorandum stated the second calibration event would be February 2022. This event, alongside June 2018 were the two most significant events highlighted by TRC since the installation of additional river gauges. February 2022 was discounted due to abnormal antecedent conditions; the January leading up to the event was the second driest on record[1]. An investigation of gauge records for February 2022 showed far smaller recorded flows than would be expected for the rainfall recorded.

The locations of rainfall and river gauges is illustrated in Figure 3-1. Table 3-2 outlines the respective rain gauge stations available for the calibration events. As noted in the final column of Table 3-2, the final three gauges are only available for the June 2018 calibration event.

Table 3-2 Rainfall Gauge Data Summary

Name	Latitude	Longitude	Regional Council	Data Availability
Waitōtara at Ngutuwera	-39.733	174.742	Taranaki	Both calibration events (02/04/1998 – present)
Waitōtara at Rimunui Station	-39.613	174.840	Taranaki	Both calibration events (21/05/1993 – present)
Omahine at Moana Trig	-39.578	174.702	Taranaki	Both calibration events (08/03/2006 – present)
Omaru at Charlies	-39.338	174.765	Taranaki	Both calibration events (06/04/2005 – present)
Patea at Bore 3	-39.741	174.459	Taranaki	Both calibration events (19/04/2005 – present)
Waitōtara at Hawken Rd	-39.830	174.723	Taranaki	Second calibration event (23/09/2015 – present)
Whanganui at Mataimona Trig	-39.534	174.992	Horizons	Second calibration event (19/02/2018 – present)
Ahuahu at Te Tuhi Junction	-39.640	174.974	Horizons	Second calibration event (20/02/2018 – present)

Recorded rainfall at the gauges was translated into rainfall over the catchment area using inverse distance weighted interpolation. In this approach, nearby rainfall gauge readings are assumed more similar and are given a greater weighting in interpolation to determine a rainfall at any given point within the catchment.

Analysis of rainfall data at gauges in the proximity of the Waitōtara catchment shows a trend of higher rainfall depths for the hill country rain gauges in the northern two thirds of the catchment and lower rainfall in the southern third of the catchment near the coast. This is seen in Figure 3-2 and Figure 3-5. In the catchment, there is only one rainfall gauge in this coastal region for the 2015 event, and two for the 2018 event. Thus, the Patea at Bore 3 gauge, was included in the model. As the model uses inverse distance weighted interpolation, there is a low probability of the inclusion of this gauge disproportionately skewing results.

[1] TRC, (10/02/2022), Monthly Climate Summary

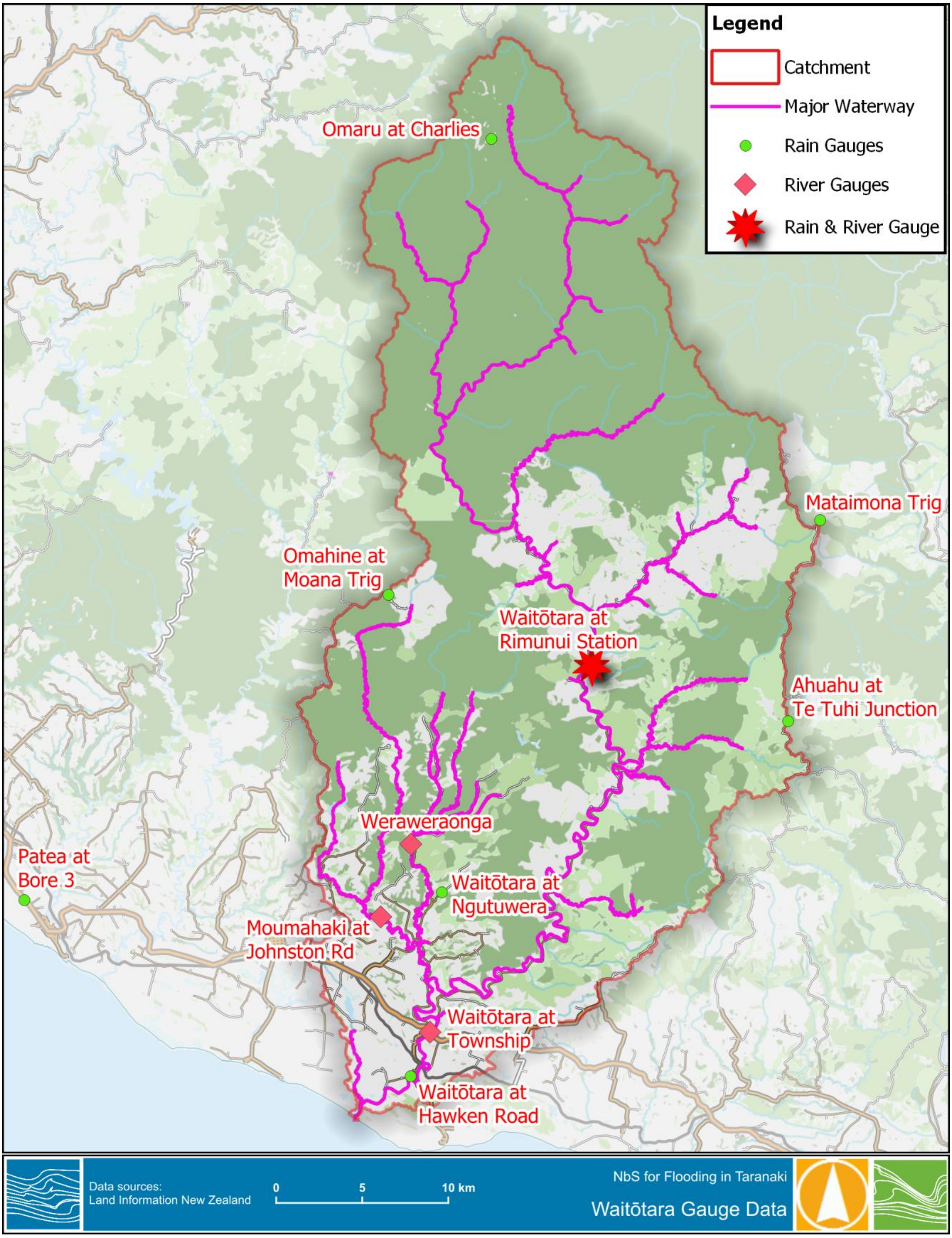

Figure 3-1 Waitōtara Gauge Summary Map

3.3 Calibration Data

3.3.1 June 2015

On the 19th to 20th of June 2015, a high intensity rainfall event occurred over the Waitōtara catchment and surrounding areas. This resulted in significant flooding and required the evacuation of 60 homes in Waitōtara township. The June flood event was the first event used to calibrate the Waitōtara catchment hydraulic model. The June 2015 event occurred over an 80 hour period, from 4 am on 19/06/2015 to 12 am on 22/06/2015. For the June 2015 event, rainfall data from relevant TRC gauges has been sourced from the TRC owned Hilltop Server. Cumulative rainfall depths at these gauges throughout the June 2015 modelled calibration event are shown on Figure 3-2.

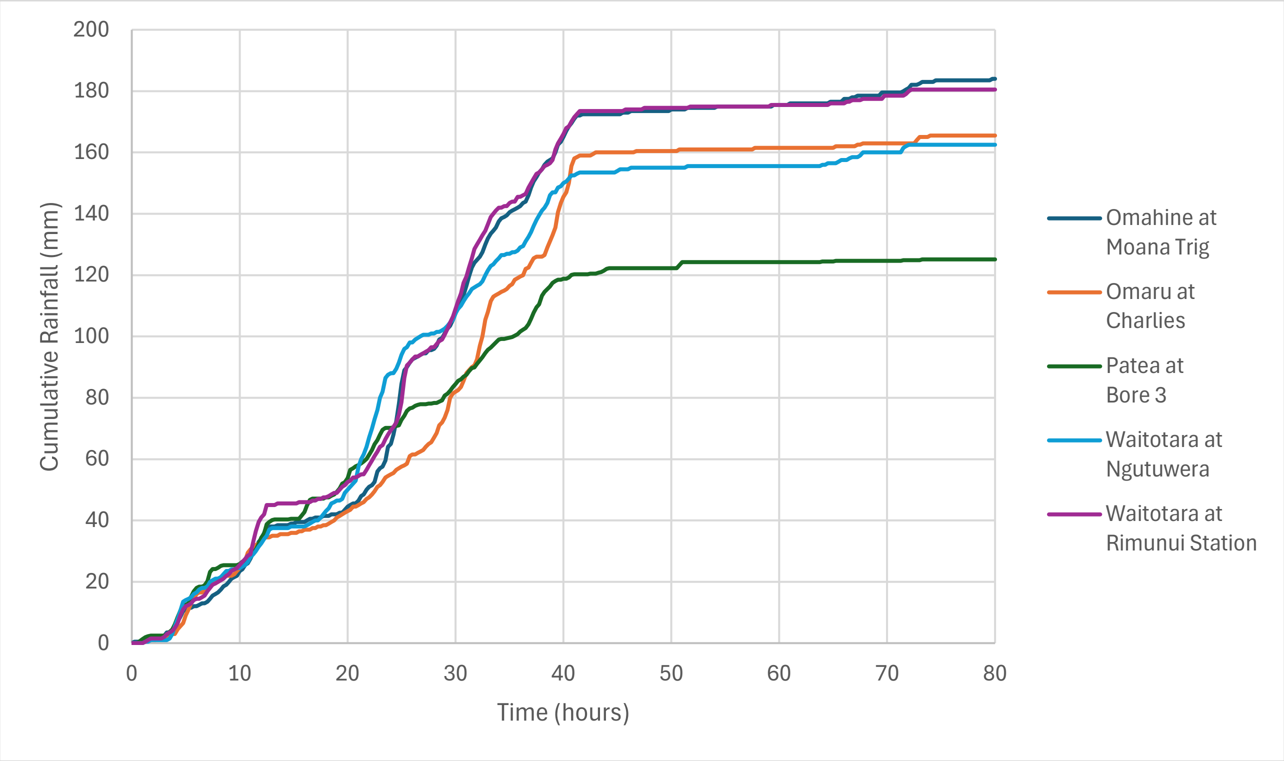

Figure 3-2 Cumulative Hourly Rainfall Depths at Gauges – June 2015

The river stage gauge data and average rainfall (at Waitōtara at Rimunui Station only) for the calibration period are shown on Figure 3-3.

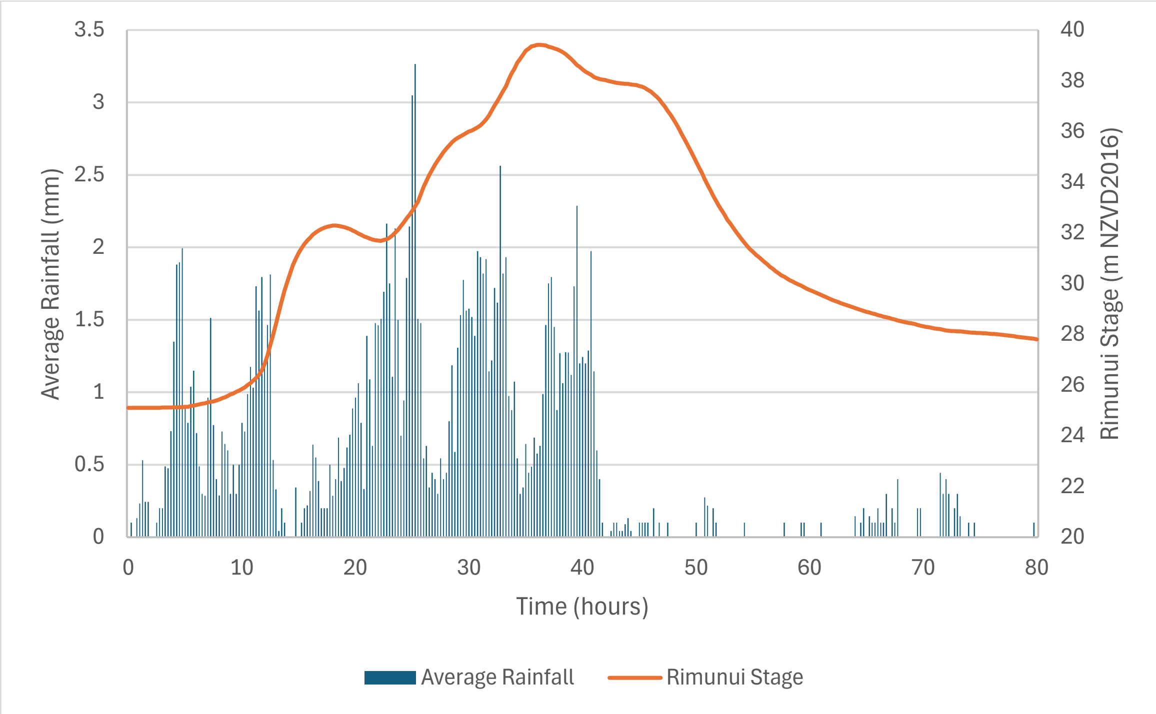

Figure 3-3 Gauge Data for Hydraulic Model Calibration – June 2015

A sinusoidal tidal level was used for the calibration events using sea levels at Port Taranaki for the relevant calibration event dates. Preliminary sea levels and times for specific dates were provided by Land Information New Zealand (LINZ) with approval from Port Taranaki Ltd and are shown in Figure 3-4 for the June 2015 event.

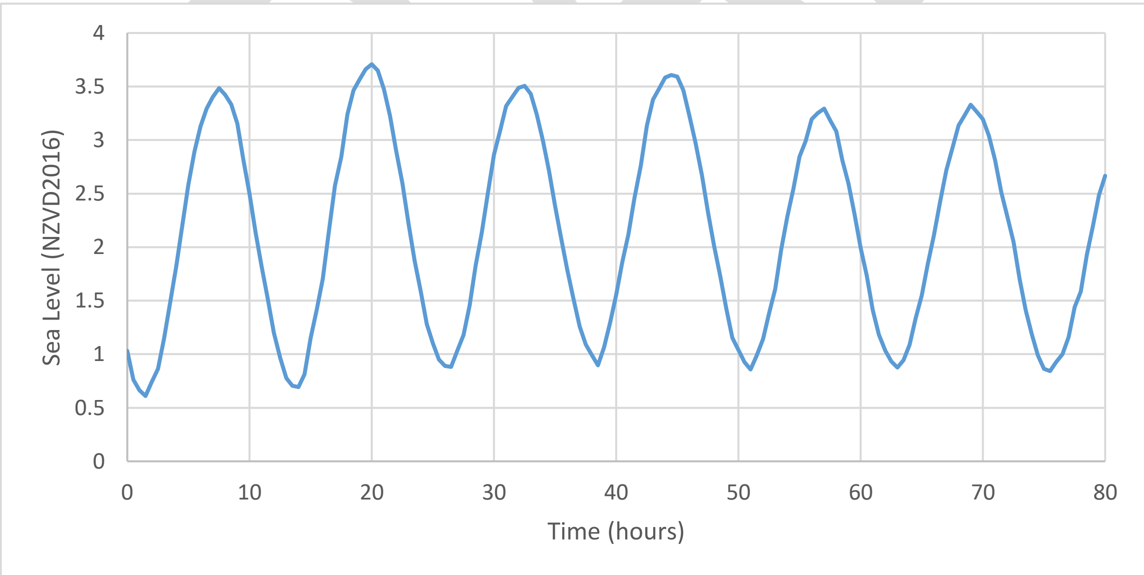

Figure 3-4 Tidal Boundary Conditions – June 2015

3.3.2 June 2018

The second event for calibration of the Waitōtara catchment hydraulic model was selected after consultation with TRC and the Peer Reviewer (Peter Kinley, from MEC). This event occurred in June 2018, allowing Water Technology to utilise the three additional rain gauges installed after the June 2015 event (see Table 3-1) as well as stage data for three additional stream gauges. This permits additional calibration in the lower reaches of the catchment with a more accurate rainfall distribution, albeit for a smaller scale event.

The June 2018 flood event occurred over a 72 hour period, from 12 am on 18/06/2018 to 12 am on 21/06/2018. Rainfall associated with this flood event largely occurred within the first 35 hours. Cumulative rainfall depths at these gauges throughout this modelled calibration event are shown on Figure 3-5.

A linear pattern is observed between 20 and 35-40 hours for the Whanganui at Mataimona Tig and Ahuahu at Te Tuhi Junction gauges. A review of the raw rainfall data from Council showed that there is a 12-hour period where no data was sent from 9:20 pm on 18/06/2018 to 9:06 am on 19/06/2018 before multiples of 0.5 mm are recorded in one instance (the gauge typically reports every 0.5 mm of rainfall). Since it is unknown when exactly this rainfall was recorded it was applied linearly over the data gap period. The depths of rainfall applied linearly over this period is a small portion of the total rainfall depth for these gauges, thus it does not have a significant impact on calibration.

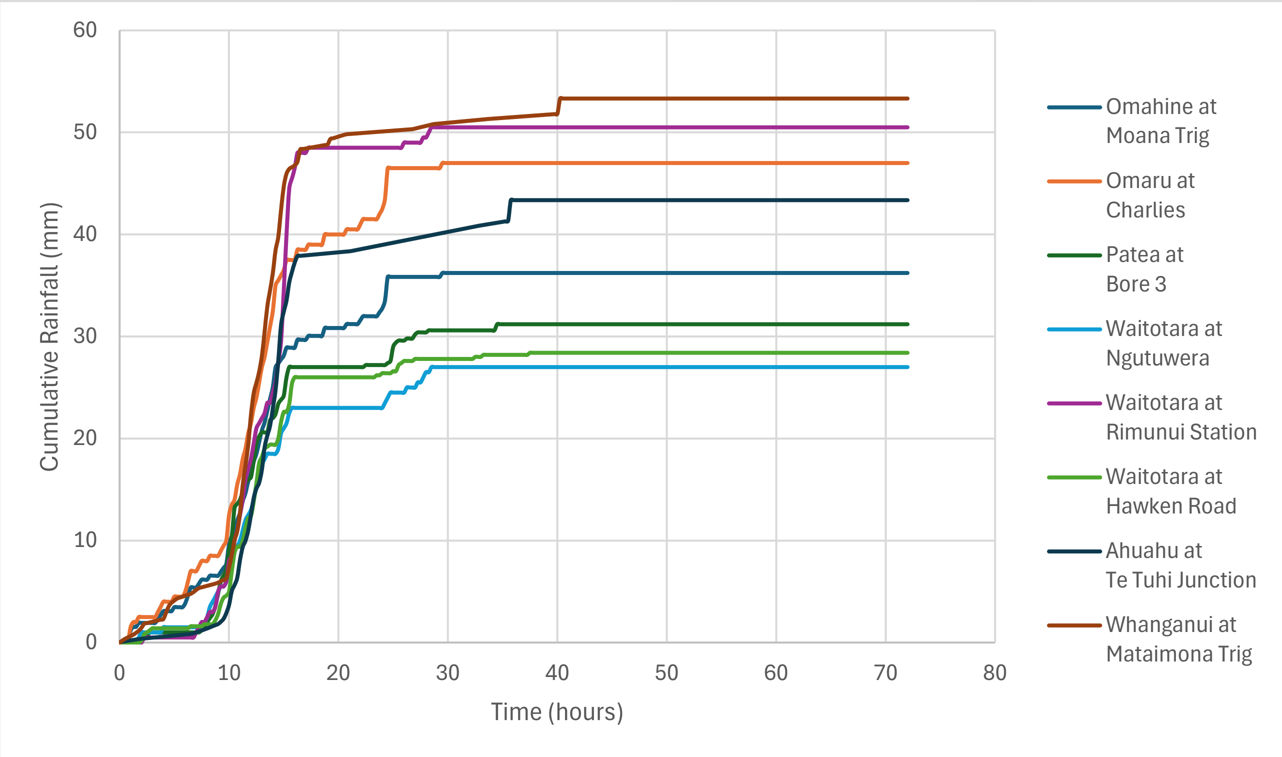

Figure 3-5 Cumulative Hourly Rainfall Depths at Gauges – June 2018

The river stage gauge data and average rainfall (across all gauges) for the calibration period are shown on Figure 3-6.

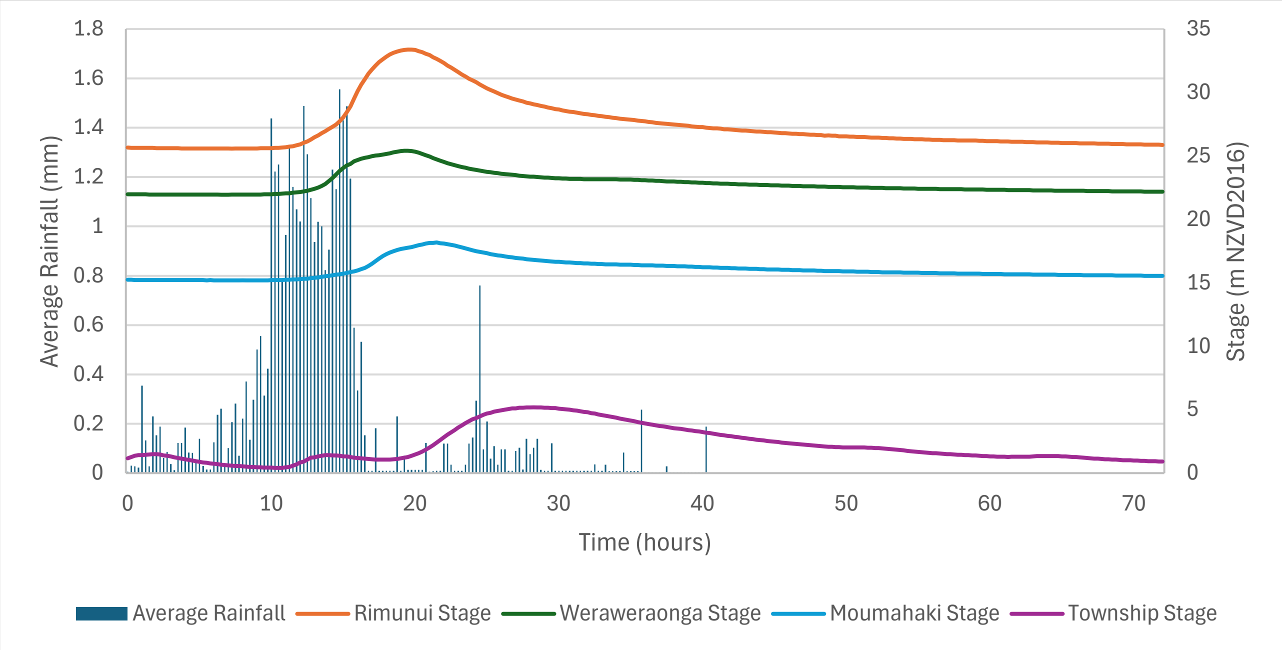

Figure 3-6 Gauge Data for Hydraulic Model Calibration – June 2018

A sinusoidal tidal level was used for the calibration events using sea levels at Port Taranaki for the relevant calibration event dates. Preliminary sea levels and times for specific dates were provided by Land Information New Zealand (LINZ) with approval from Port Taranaki Ltd and are shown in Figure 3-7 for the June 2018 event.

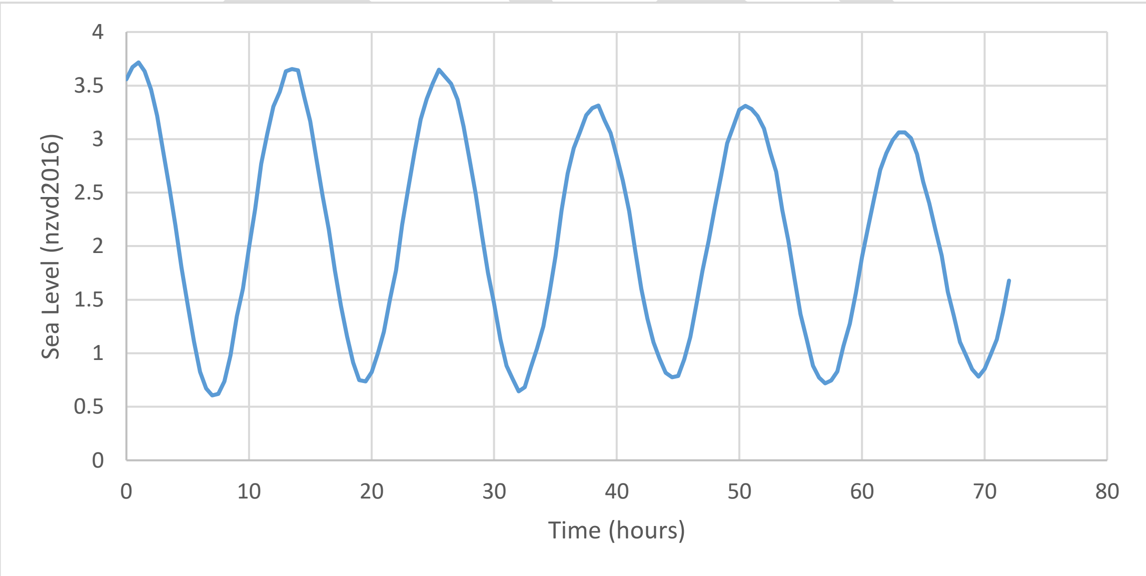

Figure 3-7 Tidal Boundary Conditions – June 2018

3.4 Calibration Method

The modelling aimed to achieve good representation of the overall flood behaviour considering peak levels, peak flows and comparison of recorded hydrographs. The criteria adopted to assess the calibration are detailed in Section 3.4.2.

Peak flow and volume were only considered as secondary reference points for calibration because the rating curves at the gauges on the Waitōtara River catchment have limited accuracy for larger events. Furthermore, the three gauges installed after the June 2015 event have limited data to correlate, especially for major events. The Waitōtara at Township gauge is considered inappropriate for flow or volume calibration as the river is impacted by tides at this location. Thus, peak water levels and timing to peak water level were considered as the primary data to which calibration occurred. Volume and flow recordings were treated as secondary reference points for calibration.

The surface roughness values and initial and continuing rainfall losses were used as the primary calibration parameters for the model, with soil parameters (hydraulic conductivity, porosity, soil thickness) used as secondary calibration parameters. Section 3.4.1 details the result of the iterative adjustment of the surface roughness values and model losses, completed to achieve calibration.

3.4.1 Detailed Calibration of Surface Roughness and Model Losses

After refinement of the river bathymetry (based on cross section surveys of the riverbed relevant to gauging locations from TRC) and inclusion of bridge and culvert structures, surface roughness values and initial and continuing rainfall losses were used as calibration parameters for the model. These parameters are defined concurrently in the model based on surface characteristics for various landuse types.

The mapped landuse categories were adopted from the LUCAS NZ landuse mapping, augmented with mapping of major waterways and roads. The 2016 land use map for the June 2015 calibration event and the 2020 land use map for the 2018 calibration event (and future design modelling). The modelled landuse types are depicted on Figure 3-8 and Figure 3-9, for the 2015 and 2018 calibration event, respectively. Note that changes in the 2018 and 2020 LUCAS landuse maps are minor, only occurring in small plots largely in the south of the catchment.

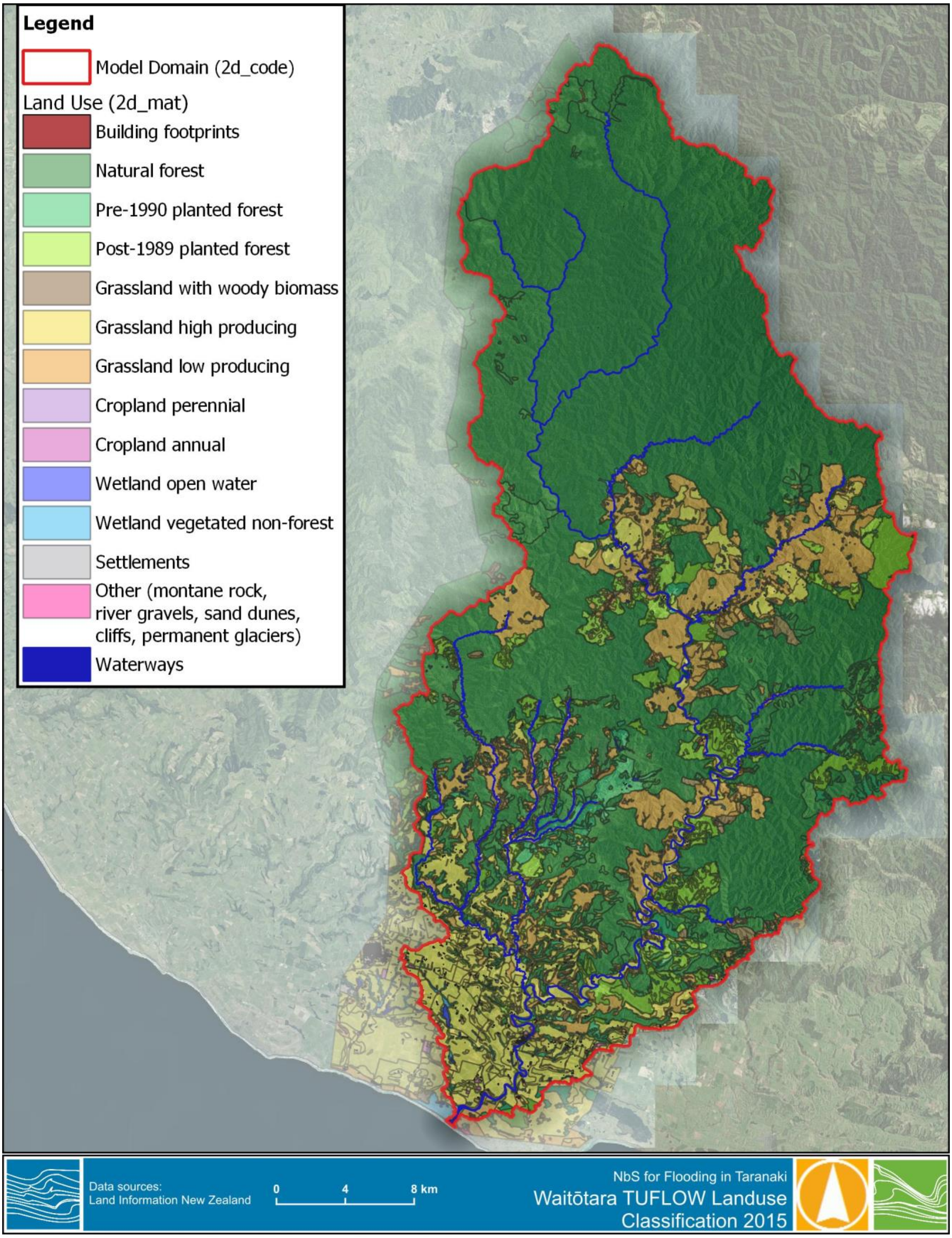

Figure 3-8 TUFLOW Model Landuse Type Classification – June 2015

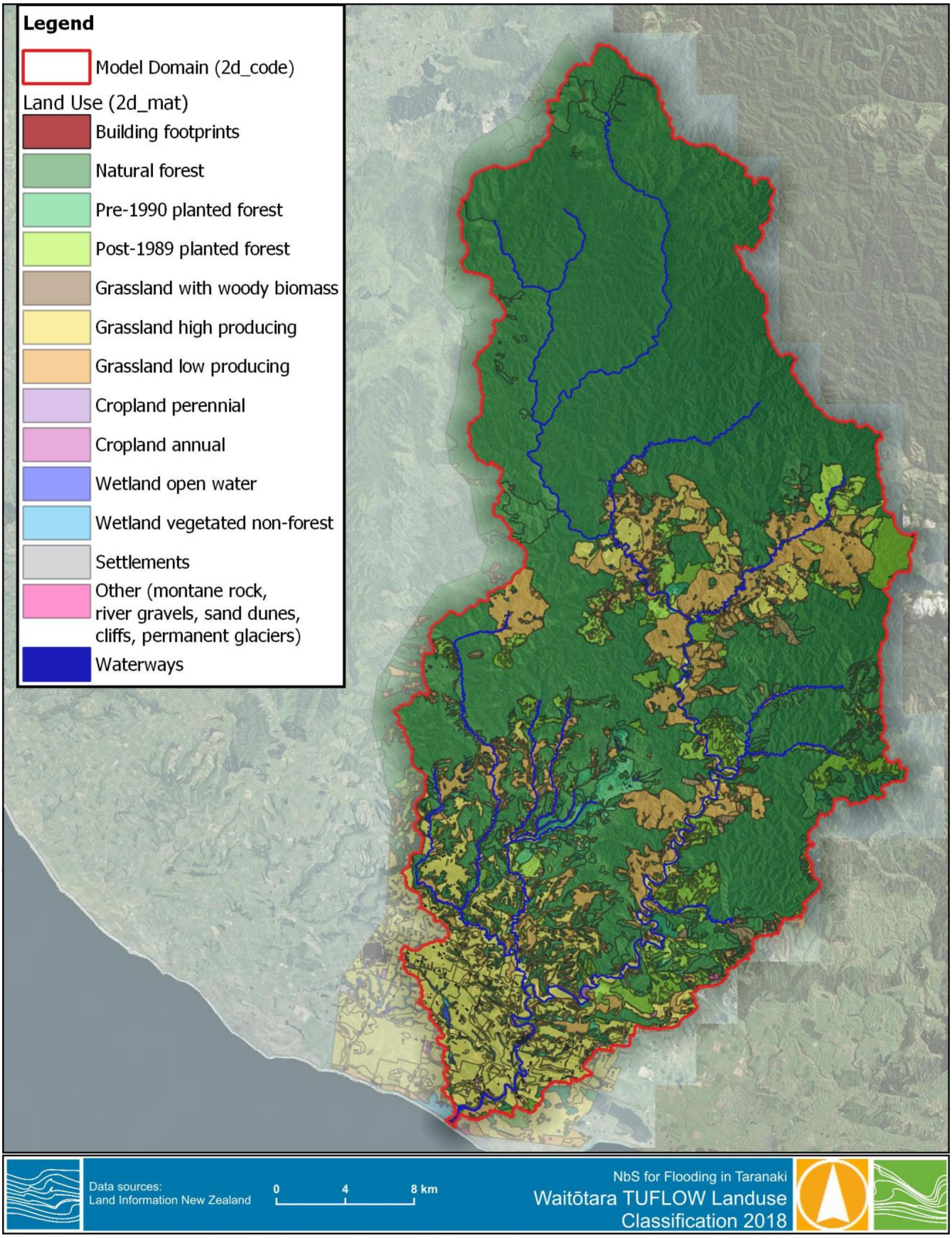

Figure 3-9 TUFLOW Model Landuse Type Classification – June 2018

The final calibrated surface roughness values and losses for each mapped landuse type are provided in Table 3-3.

Table 3-3 Calibrated Hydraulic Roughness and Rainfall Losses

Land Use Type	Material ID	Hydraulic Roughness (Manning's 'n')	Initial Loss (mm)	Continuing Loss (mm/hour)
Buildings	1	0.40	0	0.0
Natural Forest	71	0.10	10	0.8
Pre-1990 Planted Forest	72	0.10	10	0.8
Post 1989 Planted Forest	73	0.10	10	0.8
Grassland With Woody Biomass	74	0.08	8	0.4
Grassland High Producing	75	0.06	8	0.4
Grassland Low Producing	76	0.05	8	0.4
Cropland Perennial	77	0.05	10	0.8
Cropland Annual	78	0.05	10	0.8
Wetland Open Water	79	0.03	0	0.0
Wetland Vegetated Non-Forest	80	0.05	0	0.0
Settlements	81	0.10	5	0.3
Other	82	0.06	15	1.5
Waterways – streams and rivers	83	0.03	0	0.0

In accordance with the Peer Reviewer's recommendation, a soils layer was added to represent rainfall infiltration and transport within the soil. As soil information is highly generalised within the catchment, general assumptions were used for most soil parameters with some sensitivity testing. Soil parameters are shown in Table 3-4.

Table 3-4 Calibrated Soil Parameters

Event	Hydraulic Conductivity (mm/hr)	Porosity (%)	Initial Moisture (%)	Topsoil Thickness (m)
June 2015	5000	50	0	0.3
June 2018	3000	50	0	0.3

The hydraulic model was simulated for the calibration period considering a range of calibration parameter values until a reasonable correlation was achieved between the modelled and recorded data, in terms of both peak stage and timing of the peak. Ranges of calibration parameters tested are summarised in Appendix A.

42 calibration scenarios were modelled for the June 2015 and June 2018 (as well as some for February 2022). Models were initially run at a 20 m grid size with 2 m sub-grid sampling followed by 8 m grid size with 2m sub-grid-sampling once a range of feasible parameters was attained. Over 100 calibration model runs were completed with significant testing of:

- Surface roughness of waterways. This had a significant impact on timing to peak – it was found that a lower Manning's 'n' value of 0.03 achieved good time to peak while higher values delayed the timing to peak and increased peak flood levels.
- Surface roughness and losses in forest land and grassland as these are the predominant land uses in the catchment. Calibration testing included combinations of higher initial and lower continual losses and vice

versa. Initial losses were particularly crucial in matching the shape of the curve prior to the peak; lower initial losses led to poorer representations of early flood levels.

- Soil parameters (hydraulic conductivity, porosity, topsoil thickness) to determine best fit general soil characteristics for the entire catchment and to see the impact of various antecedent conditions (initial moisture).

3.4.2 Criteria

The key calibration requirements for streamflow gauges and surveyed flood levels required by TRC are:

- Peak water levels within 300 mm of those recorded at a gauge (and surveyed levels)
- Timing to peak within 2 hours (~10% of Bransby-Williams time of concentration at Waitōtara at Rimunui Station)
- Nash-Sutcliffe Efficiency (NSE) score above 0.75 (this will be calculated for water levels only)

Secondary calibration requirements for streamflow gauges and surveyed flood levels agreed with TRC are:

- Peak flow and volume within 20% of recorded flow, where Q/H rating curve is considered suitable

3.4.3 Rating Curves

The modelled and provided gauge rating curves have been compared for the largest recorded events available at each gauge. Detailed comparisons of these relationships are described below.

3.4.3.1 Waitōtara at Rimunui Station

Figure 3-10 presents the comparison of the gauge rating curve versus the TUFLOW model outputs for Waitōtara at Rimunui Station. A good correlation in the shape of the curve is achieved for low to moderate flow conditions, with the model showing strong agreement in flow ratings at the gauge between 25 and 32 m. This range aligns with higher confidence in the accuracy of the gauge rating curve.

The highest measured flow at the gauge is 316 m^3/s, corresponding to approximately 34 m NZVD2016, which is near the point where the modelled and gauge curves begin to diverge. Above 32 m, water overtops the river channel and spreads into the surrounding floodplain. The divergence between the modelled and gauge stage-discharge curves is likely due to limitations in the gauge rating curve, which lacks sufficient recorded flow measurements for large flood events. Consequently, the modelled curve is considered more reliable for representing flows within the floodplain, where direct observations are unavailable.

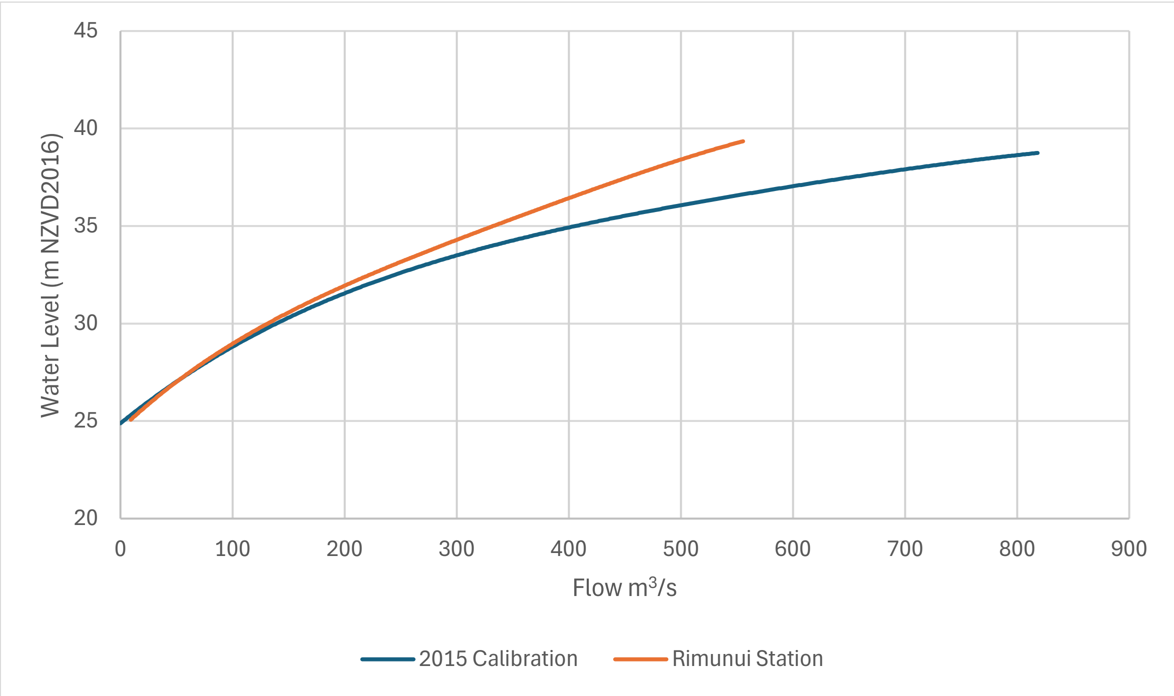

Figure 3-10 Stage-Discharge Rating Comparison – Waitōtara at Rimunui Station – June 2015

3.4.3.2 Moumahaki at Johnston Rd Gauge

A good correlation in the shape of the curve is achieved at Moumahaki at Johnston Rd.

The Moumahaki at Johnson Rd gauge's stage-discharge curve has weak correlation with the calibration model for the 2018 June event; the gauge has higher flows at the same stage when compared to the calibration model. This could be a result of hydraulic model limitations or limitations in the gauge rating curve – as the gauge was installed in 2017, there may be more limited flow readings to validate the gauge curve.

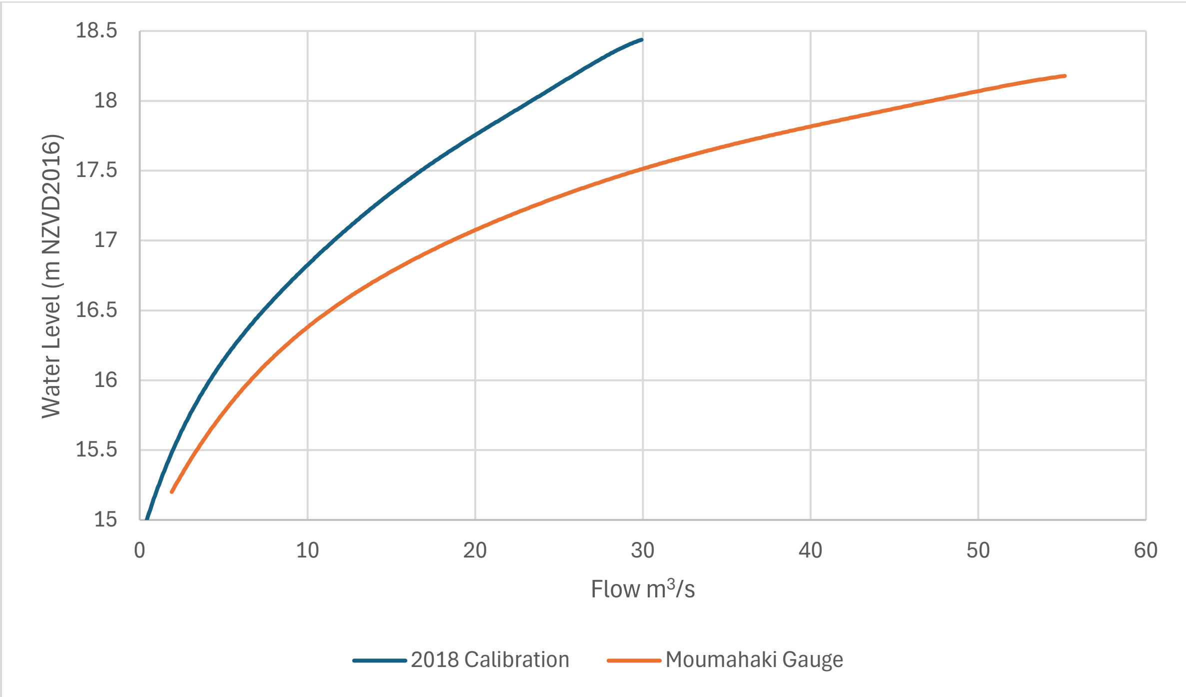

Figure 3-11 Stage-Discharge Rating Comparison – Moumahaki at Johnston Rd – June 2018

3.4.3.3 Weraweraonga at 749 Mangawhio Rd Gauge

Figure 3-12 presents A good correlation in the shape of the curve is achieved Weraweraonga at 749 Mangawhio Rd for both low flow and high flow scenarios.

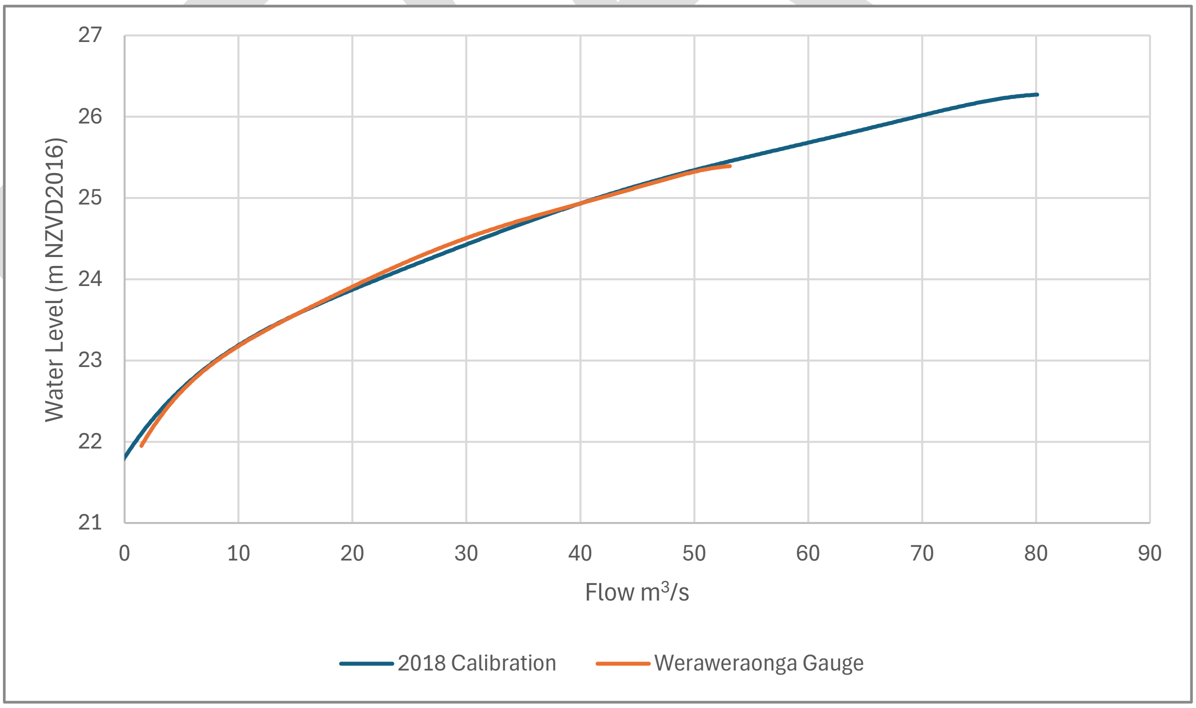

Figure 3-12 Stage-Discharge Rating Comparison – Weraweraonga at 749 Mangawhio Rd – June 2018

3.4.4 Time of Concentration

Time of concentration was calculated to provide an additional point of reference for calibration of time to peak flood levels for the hydraulic model. Following suggestion from the Peer Reviewer, time of concentration was determined using the Ramser-Kirpich and Bransby-Williams formulae. Both these approaches are frequently used in New Zealand. Results from these assessments are shown in Table 3-5.

Table 3-5 Time of Concentration at Gauges in the Waitōtara Catchment

Formula	Gauge	Time of Concentration (hours)
Ramser-Kirpich	Waitōtara at Rimunui Station	10.0
	Moumahaki at Johnston Rd	6.4
	Weraweraonga at 749 Mangawhio Rd	3.4
	Waitōtara at Township	20.7
Bransby-Williams	Waitōtara at Rimunui Station	21.8
	Moumahaki at Johnston Rd	15.5
	Weraweraonga at 749 Mangawhio Rd	7.8
	Waitōtara at Township	43.7

While time of concentration formulae provide an indication of expected time to peak, they are approximations utilising generalisations for the catchment. Table 3-5 shows that the Ramser-Kirpich formula gives a time that is roughly half that of the Bransby-Williams formula. As such, these methods are not considered for calibration and are instead of use as checks that the hydraulic model time to peak flood levels are within an expected region.

4 RESULTS

4.1 June 2015 Results

4.1.1 Water Levels

Figure 4-1 shows the modelled water levels compared to the gauged records for the June 2015 event. The peaks are compared in Table 4-1.

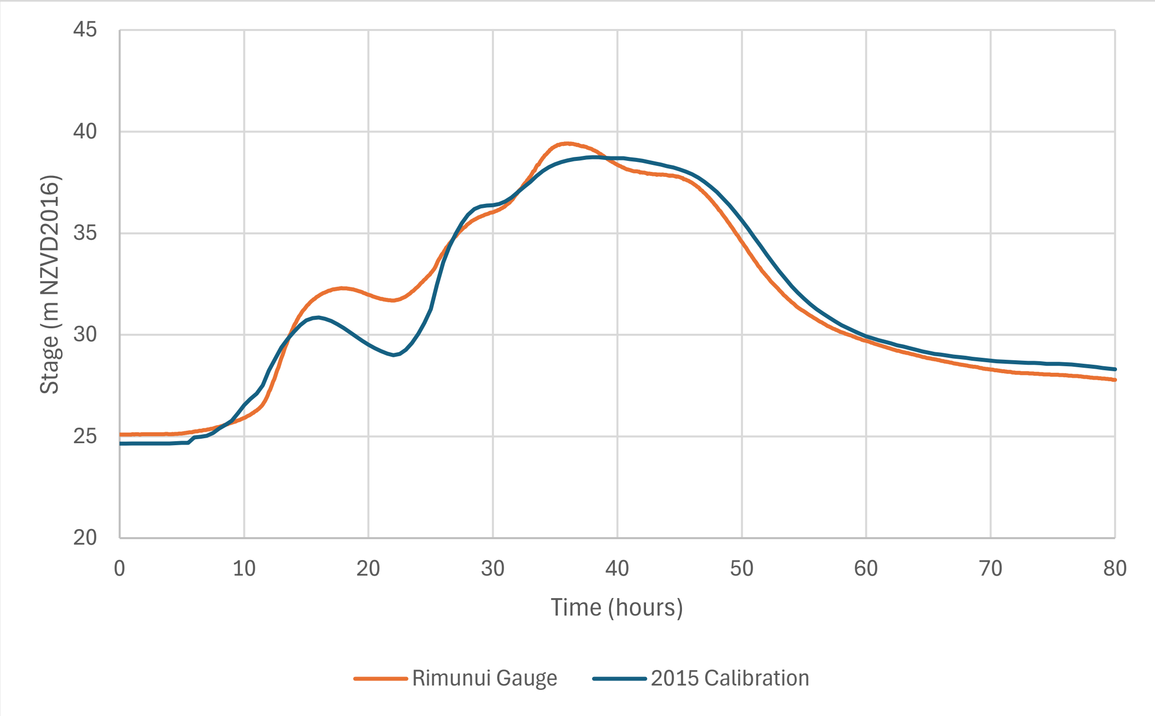

Figure 4-1 Comparison of Recorded and Modelled Water Levels – Waitōtara at Rimunui Station – June 2015

Table 4-1 Comparison of Recorded and Modelled Peak Water Surface Elevation at Gauge

Gauge WSE (mNZVD)	Model WSE (mNZVD)	Difference (m)
39.42	38.74	0.67

The modelled levels of the Waitōtara at Rimunui Station gauge show a good overall correlation with the recorded data throughout most of the calibration period with some discrepancy from 15 to 26 hours and again from 34 to 39 hours. Each discrepancy may be due to misrepresentation of flows in a tributary of the Waitōtara River. We theorise that there may be some inaccuracies in the input rainfall data as there are no available rainfall records in the east of the catchment prior to February 2018.

While the general shape matches closely, the difference in peak water surface elevation (0.67 m) is outside of the calibration target of ±0.30 m. From TRC measurements, we derived a 38.08 m NZVD2016 soffit level for the Rimunui Station Bridge. We believe that, as the water level surpassed the soffit of the suspension bridge, there is lower confidence in the readings during the peak from the gauge located on the bridge itself. While we believe this is the most likely explanation, other possible causes include localised rainfall bursts not picked up on rain gauges or debris build-up on the Rimunui Station bridge.

The Nash-Sutcliffe score for water levels is 0.96 which is above the minimum calibration target of 0.75.

4.1.2 Flows

Figure 4-2 shows a comparison of the modelled and recorded flow at the gauge, and peak flows during the calibration period are compared in Table 4-2.

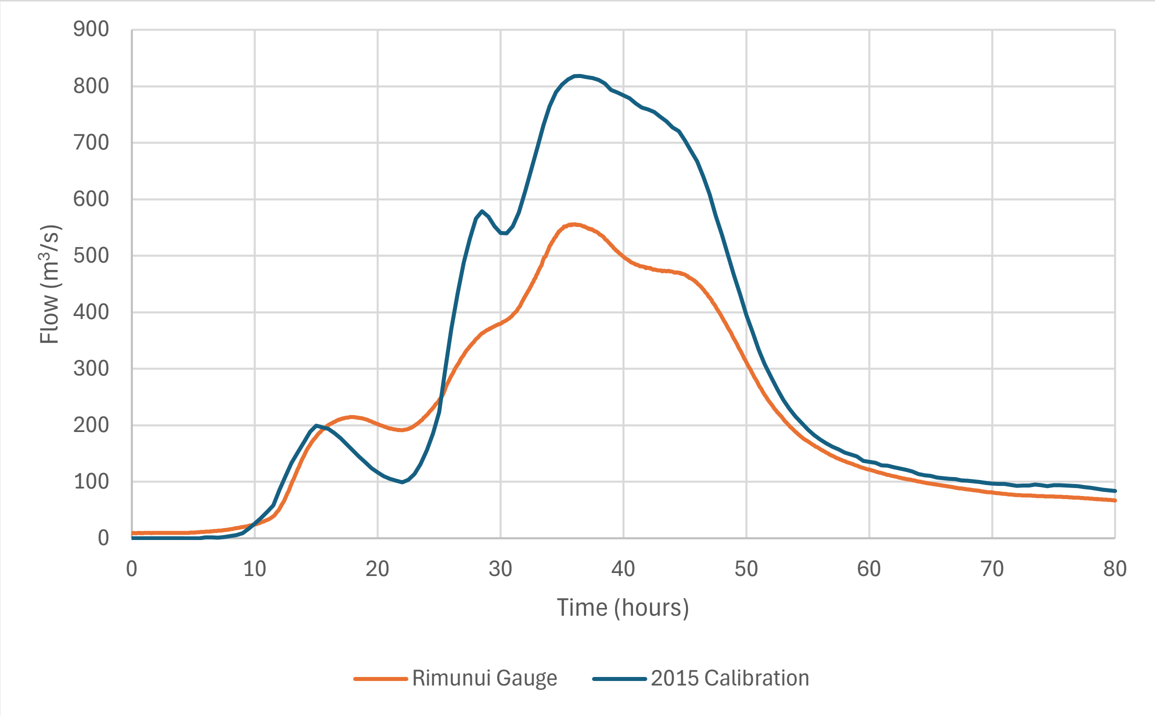

Figure 4-2 Comparison of Recorded and Modelled Flows – Waitōtara at Rimunui Station – June 2015

Table 4-2 Comparison of Recorded and Modelled Peak Flows for June 2015

Recorded Peak Flow (m^3/s)	Modelled Peak Flow (m^3/s)	Difference (m^3/s)	Difference (%)
555.8	818.3	262.5	38.2

The model does not reflect gauge readings when flows begin to exceed ~250 m^3/s. As previously noted, the rating curve at the Waitōtara at Rimunui Station gauge has limited accuracy for larger events and cannot be relied upon for calibration as values at this level are based on extrapolation. The limitations of this extrapolation are evident in larger events such as the June 2015 flood (estimated to be ~2% AEP for flood level, TRC, 2025) where the floodwater rose out of the confined river gully, greatly changing the flow behaviour.

For flows below approximately 250 m^3/s, the model provides a good representation of flow behaviour at the gauge. This corresponds to smaller, more frequent events where the gauge flow readings are more reliable. The timing of the peak is also well captured, with the modelled peak occurring only 25 minutes after the recorded peak.

However, the modelled peak discharge over the calibration period exceeds the target range by 18.2%.

4.1.3 Discharge Volume

The recorded and modelled flow hydrographs have been used to estimate the total volume of discharge passing the gauge throughout the model period. The volumes are detailed in Table 4-3.

Table 4-3 Comparison of Recorded and Modelled Discharge Volumes at Gauge

Gauge Volume (ML)	Model Volume (ML)	Difference (ML)	Difference (%)
61,918	81,199	19,281	26.9

A 26.9% difference in discharge volume is recorded at Waitōtara at Rimunui Station for the June 2015 event. This difference in discharge volume will be largely a result of the discrepancy in flowrate discussed in the previous section.

80.5% of rainfall was converted to runoff or a difference of 19,705 ML. This difference is accounted for in losses and runoff still upstream of Waitōtara at Rimunui Station at 80 hours (the model end time for the June 2015 event). Rainfall and discharge volumes are compared in Table 4-4.

Table 4-4 Hydraulic Model Rainfall to Runoff Conversion June 2015

Model Rainfall (ML)	Model Flow Volume (ML)	Difference (ML)	Difference (%)
100,904	81,199	19.705	80.5

The modelled discharge volume over the calibration period exceeds the target range by 6.9%.

4.1.4 Timing of Peak

The flow (Figure 4-2) and water surface elevation (Figure 4-1) plots both show a reasonable correlation in overall timing and hydrograph shape, supported by a high NSE of 0.96. In general, the modelled catchment response is slightly faster than gauge records indicate, with respect to both rise and fall of each flood wave.

For the gauge data (where flows have presumably been derived using a rating curve) the timing of the peak flows and flood levels is the same.

For the model results, a difference in timing of the peak flows and water levels are noted.

Table 4-5 provides a comparison of the timing to peak of the gauge and model. For the model results, both the flow and flood level peaks are noted and the average of the two has been compared to the gauge records.

Table 4-5 Comparison of Timing of Flood Peaks

Parameter	Gauge peak time (hours, model time)	Modelled peak time (hours, model time)	Difference (hours)
WSE	36.08	38	-1.92
Flow	36.08	36.5	0.42
Average	36.08	37.25	-0.75

Overall, the model returns a slightly earlier flood peak.

The timing to peak for both the gauge and hydraulic model is above the time of concentration estimated although as previously discussed, the time of concentration is a very rough approximation.

The difference in timing of the flood peak is within the calibration target of 2 hours for flood levels, flow, and the average of both.

4.1.5 Summary

Table 4-6 provides a summary of the model calibration outcomes relative to the June 2015 calibration targets.

Table 4-6 Summary of Calibration Results – Waitōtara at Rimunui Station – June 2015

Parameter	Calibration Target	Calibration Result	Target Met
Peak water level	±0.3 m	0.67 m	No
Peak flow	±20%	38.2%	No
Volume	±20%	26.9%	No
Time of peak water level	±2 hours	-1.9 hours	Yes
Nash-Sutcliffe Efficiency	>0.75	0.96	Yes

The model achieves the calibration targets for time of peak and Nash-Sutcliffe Efficiency. The peak water levels, peak flow, and volume do not meet calibration targets. However, we consider the model to be fit for purpose considering:

- Potential error in the Waitōtara at Rimunui Station Gauge reading from floods reaching the bridge deck
- Limitations in rating curves at gauges for larger events; June 2015 was estimated to be a ~2% AEP event for flood levels (TRC, 2025)
- Limitations of the data available to inform the flood study.

4.2 June 2018 Results

4.2.1 Water Levels

Figure 4-3 to Figure 4-6 show the modelled water levels compared to the gauged records at Waitōtara at Rimunui Station, Moumahaki at Johnston Road, Weraweraonga at 749 Mangawhio Road, and Waitōtara at Township gauge, respectively. The peak water levels for each flood event are compared in Table 4-7.

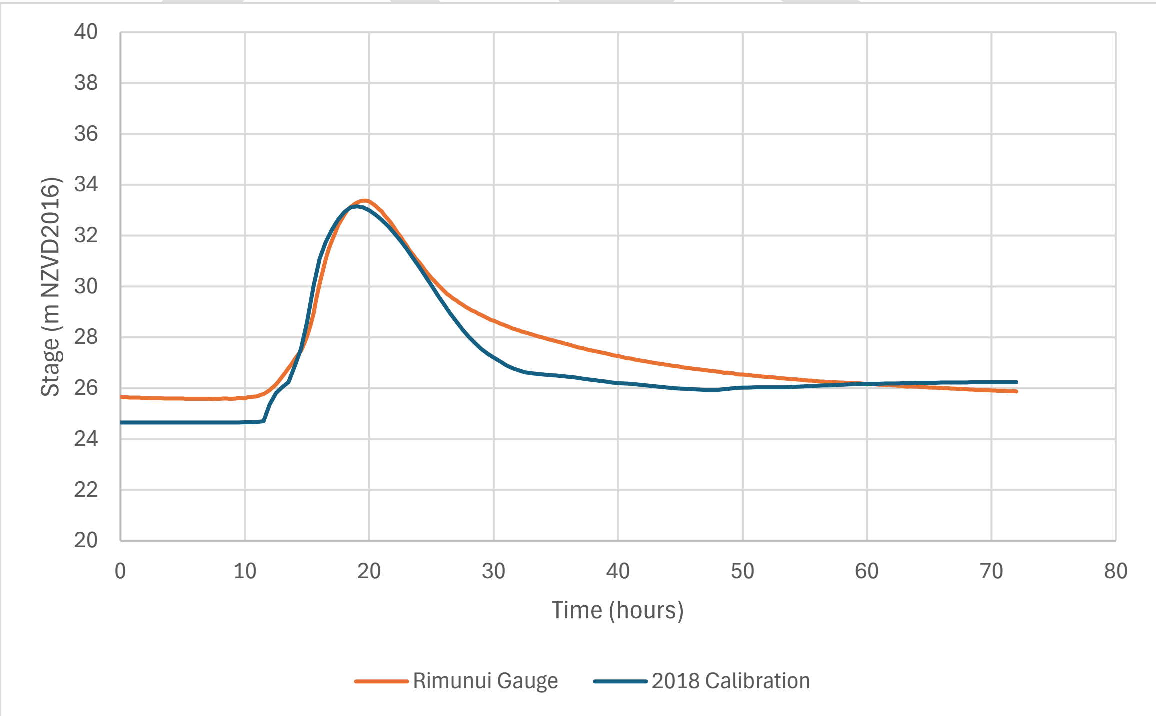

Figure 4-3 Comparison of Recorded and Modelled Water Levels – Waitōtara at Rimunui Station – June 2018

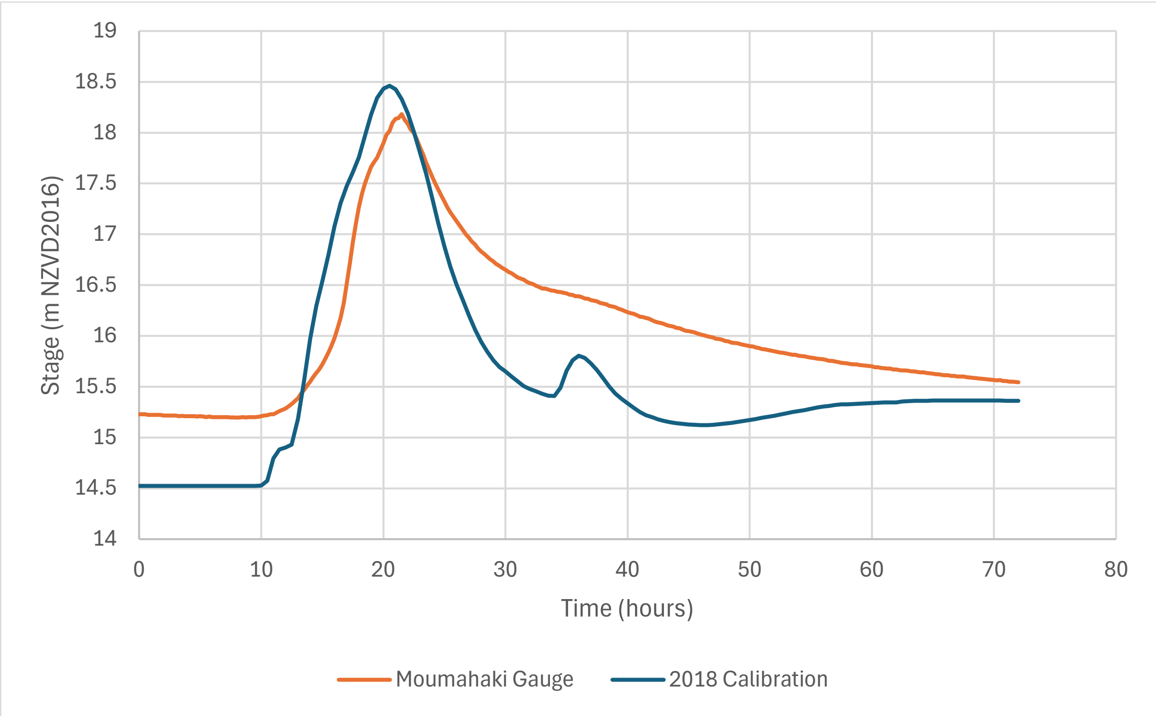

Figure 4-4 Comparison of Recorded and Modelled Water Levels – Moumahaki at Johnston Rd – June 2018

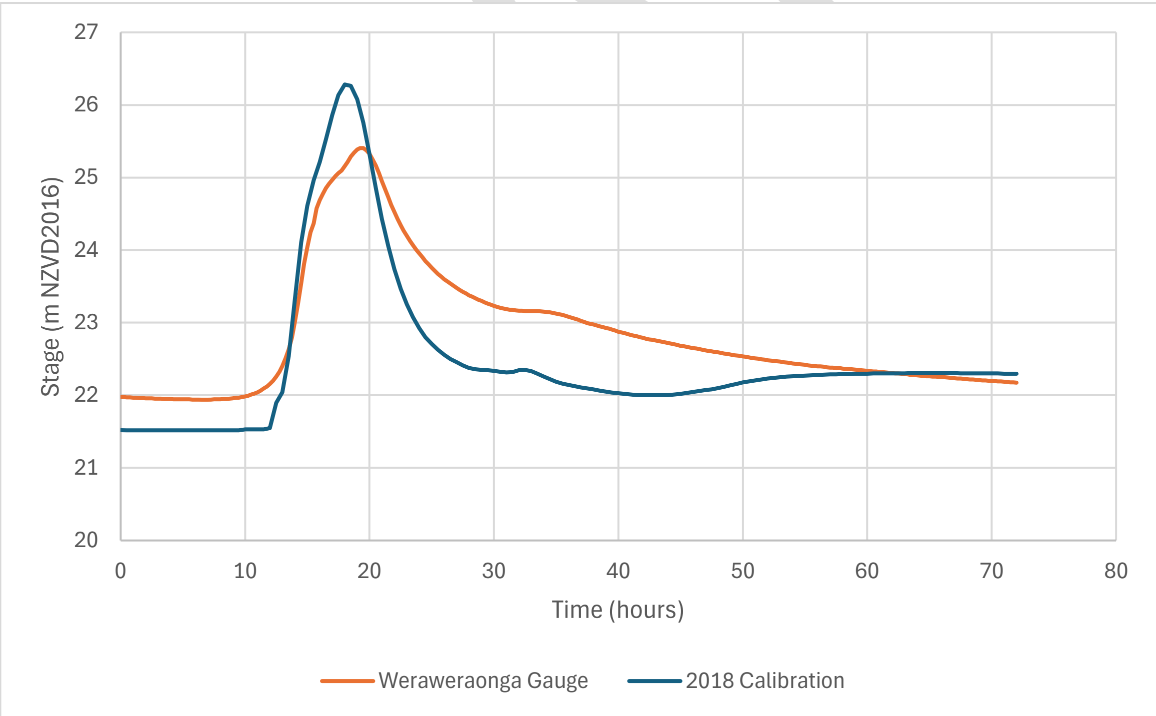

Figure 4-5 Comparison of Recorded and Modelled Water Levels – Weraweraonga at 749 Mangawhio Rd – June 2018

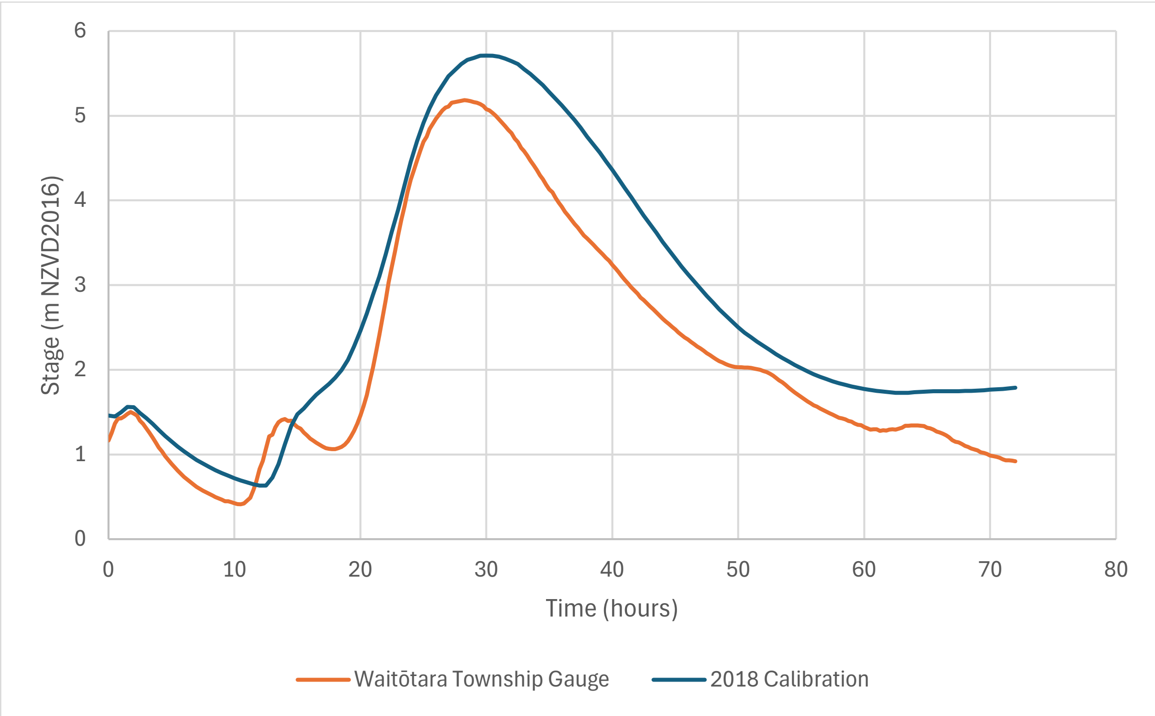

Figure 4-6 Comparison of Recorded and Modelled Water Levels – Waitōtara at Township – June 2018

Table 4-7 Comparison of Recorded and Modelled Peak Water Surface Elevations at Gauges – June 2018

Station	Gauge WSE (mNZVD)	Model WSE (mNZVD)	Difference (m)
Waitōtara at Rimunui Station	33.38	33.15	-0.26
Moumahaki at Johnston Rd	18.18	18.46	0.28
Weraweraonga at 749 Mangawhio Rd	25.41	26.28	0.87
Waitōtara at Township	5.18	5.70	0.52

Table 4-8 Nash-Sutcliffe Efficiency Score at Gauges

Station	Nash-Sutcliffe Efficiency Score for WSE
Waitōtara at Rimunui Station	0.85
Moumahaki at Johnston Rd	0.21
Weraweraonga at 749 Mangawhio Rd	0.53
Waitōtara at Township	0.81

The modelled levels generally show a good overall correlation with the recorded data throughout the calibration period with the most notable discrepancy at the Moumahaki at Johnston Rd gauge. This is supported by the Nash-Sutcliffe efficiency scores for water level shown in Table 4-8. This shows that all gauges except for Moumahaki at Johnston Road are higher than the minimum calibration threshold.

A strong correlation in peak water surface elevation is achieved at Waitōtara at Rimunui Station and Moumahaki at Johnston Rd, with differences well within the calibration target of ±0.30 m. Calibration did not achieve the target range for the Weraweraonga at 749 Mangawhio Rd and Waitōtara at Township gauges.

4.2.2 Flows

Figure 4-7 to Figure 4-9 show a comparison of the modelled and recorded flow at Waitōtara at Rimunui Station, Moumahaki at Johnston Road, and Weraweraonga at 749 Mangawhio Road, respectively. The Waitōtara at Township gauge is not suitable for flow recording as the Waitōtara River is affected by tides at this location. Peak flows for each storm during the calibration period are compared in Table 4-9.

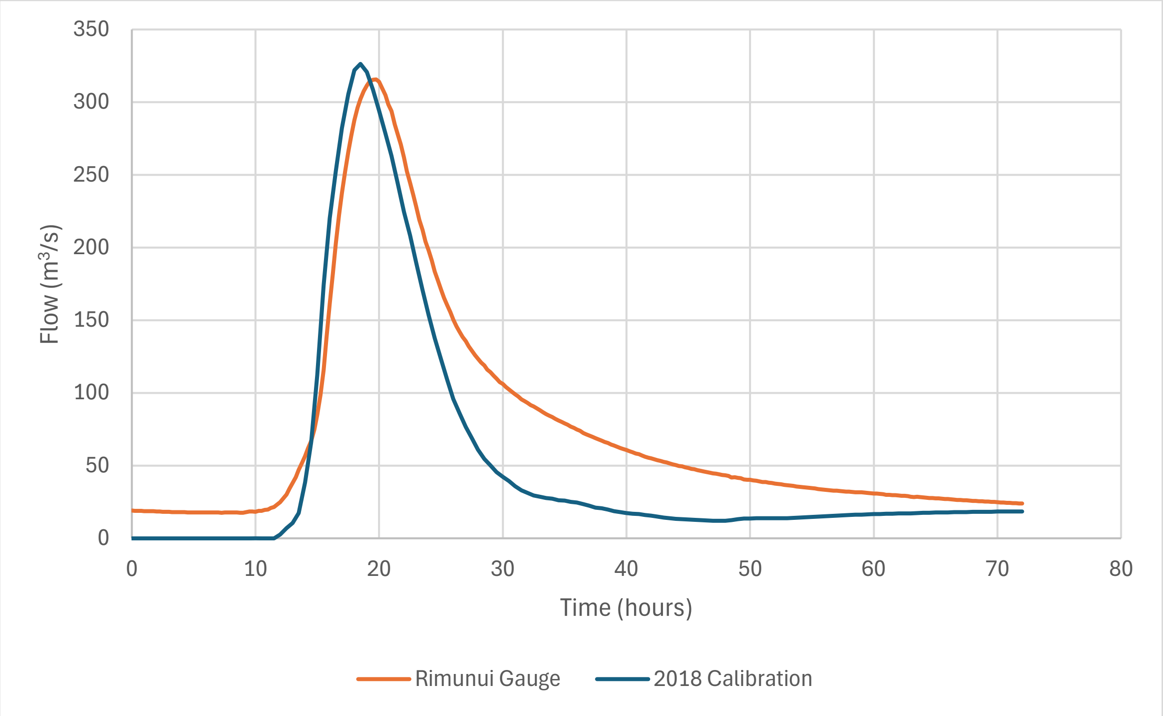

Figure 4-7 Comparison of Recorded and Modelled Flows – Waitōtara at Rimunui Station – June 2018

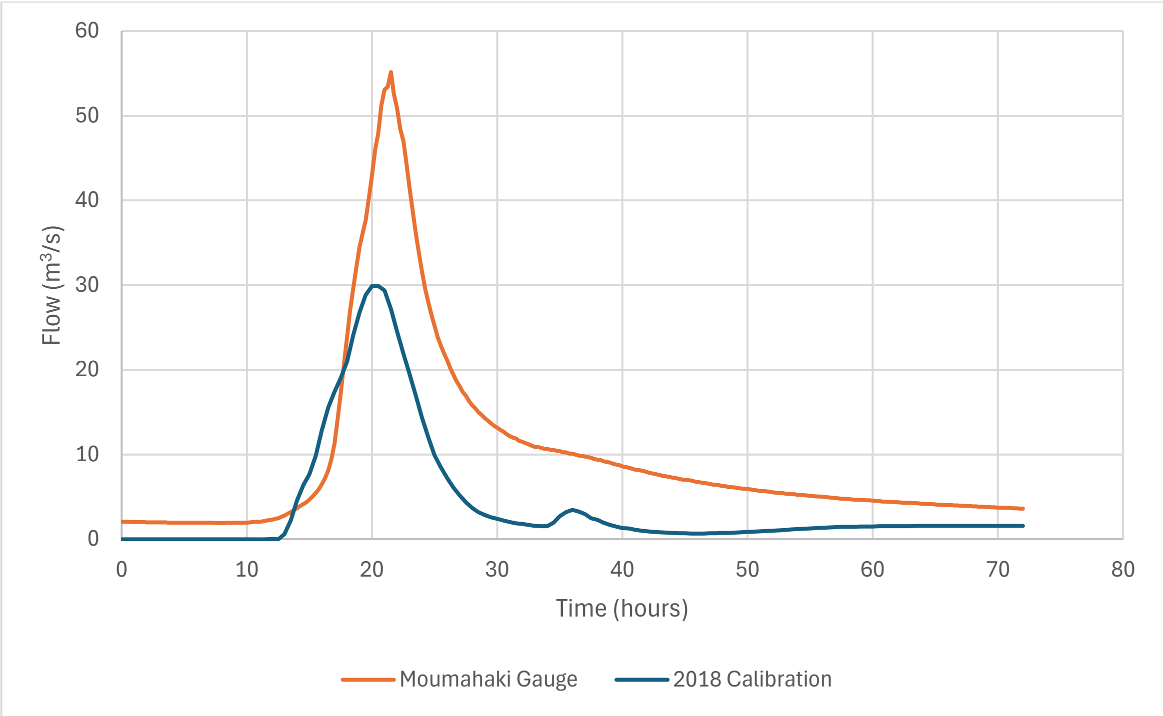

Figure 4-8 Comparison of Recorded and Modelled Flows – Moumahaki at Johnston Rd – June 2018

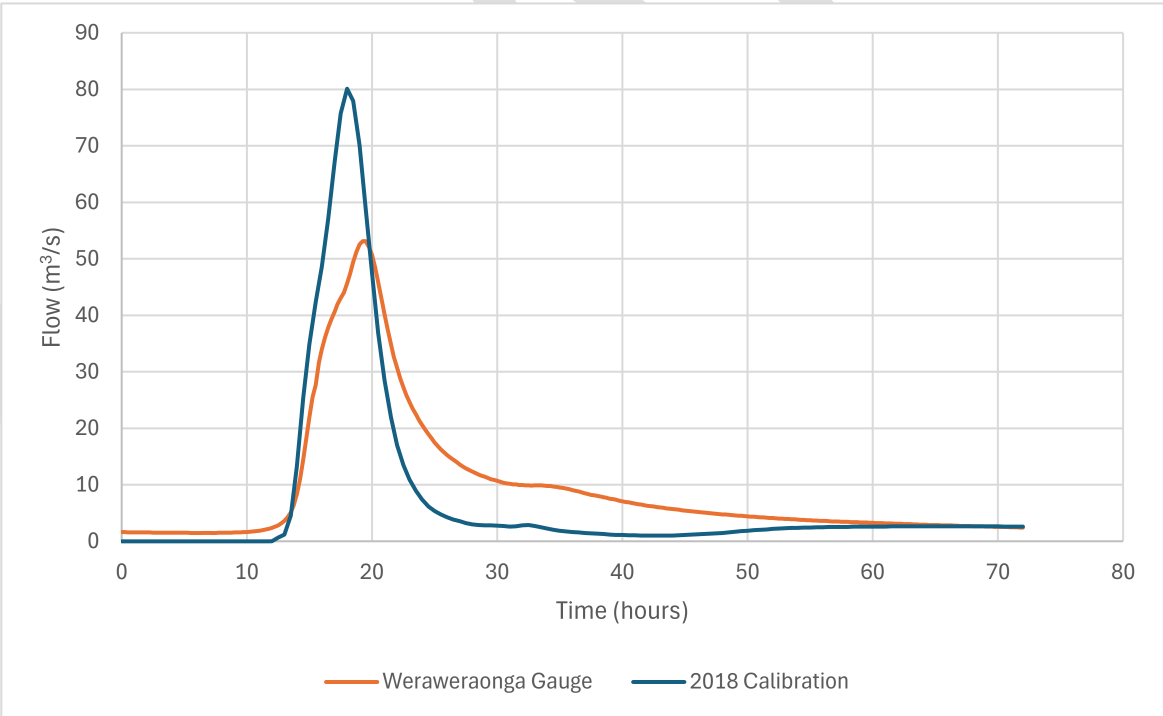

Figure 4-9 Comparison of Recorded and Modelled Flows – Weraweraonga at 749 Mangawhio Rd – June 2018

Table 4-9 Comparison of Recorded and Modelled Peak Flows for June 2018

Station	Recorded Peak Flow (m^3/s)	Modelled Peak Flow (m^3/s)	Difference (m^3/s)	Difference (%)
Waitōtara at Rimunui Station	315.6	326.3	-10.7	-3.3
Moumahaki at Johnston Rd	55.2	29.9	-25.3	-59.4
Weraweraonga at 749 Mangawhio Rd	53.1	80.1	27.0	40.5

Overall, the model provides a good representation of flow behaviour at the Waitōtara at Rimunui Station gauge in terms of meeting calibration requirements for both peak flow rates, timing and shape of the runoff hydrograph.

The model does not meet calibration requirements for flow behaviour at Moumahaki at Johnston Rd and Weraweraonga at 749 Mangawhio Rd. The shape and timing are within requirement; however, peak flows exceed a 20% difference. As discussed in Section 3.4.3, the gauge rating curves are less reliable for larger events. This reliability will be most noticeable for the Moumahaki at Johnston Rd and Weraweraonga at 749 Mangawhio Rd gauges, as these were both installed in 2017 and have few larger events as reference to derive a rating curve.

4.2.3 Discharge Volume

The recorded and modelled flow hydrographs have been used to estimate the total volume of discharge passing the gauge throughout the model period. The volumes are detailed in Table 4-10.

Table 4-10 Comparison of Recorded and Modelled Discharge Volumes at Gauge – June 2018

Station	Gauge Volume (ML)	Model Volume (ML)	Difference (ML)	Difference (%)
Waitōtara at Rimunui Station	19,502	13,068	6,434	-39.5
Moumahaki at Johnston Rd	2,550	1,083	-1,467	-80.8
Weraweraonga at 749 Mangawhio Rd	2,473	1,926	-5.6	-24.8

A significant difference in runoff volume is noted, especially for the Moumahaki at Johnston Rd gauge. This difference can be attributed to the discrepancy between gauge and model flows which are in turn a result of limitations in both methods to determine an accurate flow.

At an estimated base flow rate of 18 m^3/s, 5,216 ML of the recorded volumetric at Waitōtara at Rimunui Station can be attributed to base flows. If this base flow is excluded, the difference between the recorded and modelled volume for the first storm lowers to -8.9%. A base flow of 1.5 m^3/s at Weraweraonga at 749 Mangawhio Rd also reduces the difference between modelled and recorded volume to -5.3%. A -58.4% difference at Moumahaki at Johnston Rd from a 2 m^3/s baseflow still falls below the target range.

Rainfall and discharge volumes are compared in Table 4-11. The difference in volume between rainfall and modelled flows is accounted for in rainfall losses and runoff still upstream of calibration locations at 72 hours (the model end time for the June 2018 event).

More rainfall was converted to runoff at Waitōtara at Rimunui Station in 2015 compared to 2018. The higher volume of rain in 2015 led to a higher ratio of rainfall volume to soil infiltration capacity.

Moumahaki at Johnston Road had the most similar rainfall volume to modelled flow as it is the least forested subcatchment with the lowest average losses.

Table 4-11 Hydraulic Model Rainfall to Runoff Conversion June 2018

Gauge	Model Rainfall (ML)	Model Flow Volume (ML)	Difference (ML)	Difference (%)
Waitōtara at Rimunui Station	26,512	13,068	13,444	49.3
Moumahaki at Johnston Rd	3,274	1,083	2191	33.1
Weraweraonga at 749 Mangawhio Rd	3,826	1,926	1900	50.3

4.2.4 Timing of Peak

The water surface elevation (Figure 4-3 to Figure 4-6) and flow (Figure 4-7 to Figure 4-9) plots show a reasonable correlation in overall timing and hydrograph shape. The modelled catchment response is slightly faster than gauge records indicate, with respect to both rise and fall of each flood wave.

For the gauge data (where flows have presumably been derived using a rating curve) the timing of the peak flows and flood levels is the same. For the model results, some differences in timing of the peak flows and water levels are noted.

Table 4-12 provides a comparison of the timing of the peak for each storm. For the model results, both the flow and flood level peaks are noted and the average of the two has been compared to the gauge records.

Table 4-12 Comparison of Timing of Flood Peaks – June 2018

Station	Parameter	Gauge peak time (hours, model time)	Modelled peak time (hours, model time)	Difference (hours)
Waitōtara at Rimunui Station	WSE	19.75	19	-0.75
	Flow	19.75	18.5	-1.25
	Average	19.75	18.75	-1
Moumahaki at Johnston Rd	WSE	21.5	20.5	-1
	Flow	21.5	20.5	-1
	Average	21.5	20.5	-1
Weraweraonga at 749 Mangawhio Rd	WSE	19.25	18	-1.25
	Flow	19.25	18	-1.25
	Average	19.25	18	-1.25
Waitōtara at Township	WSE	28.5	30	1.5
	Flow	N/A	N/A	N/A
	Average	N/A	N/A	N/A

Overall, the model returns a slightly earlier flood peak in response at all gauging locations except for Waitōtara at Township. The timing of peak water level and flow are generally the same, with the exception of Waitōtara at Rimunui Station. The difference in timing of the flood peak is well within the calibration target of 2 hours. The Waitōtara at Township and Waitōtara at Rimunui Station flood peak is between the two time of concentration formulae considered while the other two calibrated locations are not.

4.2.5 Summary

Table 4-13 to Table 4-16 provide a summary of the model calibration outcomes relative to the calibration targets.

Table 4-13 Summary of Calibration Results – Waitōtara at Rimunui Station – June 2018

Parameter	Calibration Target	Calibration Result	Target Met
Peak water level	±0.3 m	-0.26 m	Yes
Peak flow	±20%	-3.3%	Yes
Volume	±20%	-39.5%	No
Time of peak water level	±2 hours	-0.75 hour	Yes
Nash-Sutcliffe Efficiency	>0.75	0.85	Yes

Table 4-14 Summary of Calibration Results – Moumahaki at Johnston Rd – June 2018

Parameter	Calibration Target	Calibration Result	Target Met
Peak water level	±0.3 m	0.28 m	Yes
Peak flow	±20%	-59.3%	No
Volume	±20%	-80.8%	No
Time of peak (stage)	±2 hours	-1 hour	Yes
Nash-Sutcliffe Efficiency	>0.75	0.21	No

Table 4-15 Summary of Calibration Results Weraweraonga at 749 Mangawhio Rd – June 2018

Parameter	Calibration Target	Calibration Result	Target Met
Peak water level	±0.3 m	0.88 m	No
Peak flow	±20%	40.5%	No
Volume	±20%	24.8%	No
Time of peak (stage)	±2 hours	-1.25 hours	Yes
Nash-Sutcliffe Efficiency	>0.75	0.52	No

Table 4-16 Summary of Calibration Results – Waitōtara at Township – June 2018

Parameter	Calibration Target	Calibration Result	Target Met
Peak water level	±0.3 m	0.52 m	No
Peak flow	±20%	N/A	N/A
Volume	±20%	N/A	N/A
Time of peak (stage)	±2 hours	1.25 hours	Yes
Nash-Sutcliffe Efficiency	>0.75	0.81	Yes

The model achieves the key calibration targets for peak water levels, time of peak, and NSE at the Waitōtara at Rimunui and Moumahaki at Johnston Road gauges. It achieves time of peak and NSE for Waitotara at Township and time of peak for Weraweraonga at 749 Mangawhio Road.

Based on the calibration results, and in the context of the data available to inform the flood study, the model calibration for the catchment is satisfactory and fit for purpose.

5 CONCLUSIONS AND RECOMMENDATIONS

Water Technology has developed a calibrated hydraulic model construction for the Waitōtara catchment on behalf of Taranaki Regional Council. The model will be utilised in nature-based solutions testing and as a basis for region wide flood modelling. The model was constructed in TUFLOW HPC and calibrated against two flood events:

- 19 - 22 June 2015
- 18 - 21 June 2018

The key target criteria for calibration were water level, time to peak, and Nash-Sutcliffe efficiency. Flow and volume were considered as secondary reference parameters as there is a lower confidence in the accuracy of gauge rating curves for larger events in the Waitōtara catchment.

For the June 2015 event, time to peak and NSE targets were met with an especially high NSE of 0.96 reflecting a very close match on the water level curve. The water level target was not met; however, we have a lower confidence in the recorded water levels near the peak as the floodwater began to interact with the Rimunui Station Bridge.

For the June 2018 event, the model met at least two out of three key targets for three of the four calibration locations with the exception being Weraweraonga at 749 Mangawhio Road.

Based on available data and the extensive number of model scenarios assessed, we believe the current model reasonably represents the hydrologic and hydraulic response of the Waitōtara catchment. Any further optimisation of calibration would require a disproportionate amount of time relative to the potential improvement in model accuracy. Therefore, we recommend finalising the calibrated parameters (Manning's 'n', initial and continuing losses, hydraulic conductivity) and progressing with design modelling and NbS testing.

APPENDIX A
RANGE OF VALUES TESTED FOR WAITŌTARA HYDRAULIC MODEL CALIBRATION

Table A-1 Manning's 'n' Roughness Calibration Range

Land Use Type	Material ID	'n' upper limit	'n' lower limit	Final Value
Buildings	1	0.4	0.4	0.4
Natural Forest	71	0.12	0.1	0.1
Pre-1990 Planted Forest	72	0.12	0.1	0.1
Post 1989 Planted Forest	73	0.12	0.1	0.1
Grassland With Woody Biomass	74	0.08	0.05	0.08
Grassland High Producing	75	0.06	0.03	0.06
Grassland Low Producing	76	0.05	0.03	0.05
Cropland Perennial	77	0.05	0.04	0.05
Cropland Annual	78	0.05	0.04	0.05
Wetland Open Water	79	0.045	0.03	0.03
Wetland Vegetated Non-Forest	80	0.05	0.04	0.05
Settlements	81	0.1	0.1	0.1
Other	82	0.06	0.06	0.06
Waterways – streams and rivers	83	0.045	0.03	0.03

Table A-2 Initial Losses Calibration Range

Land Use Type	Material ID	IL upper limit	IL lower limit	Final Value
Buildings	1	0	0	0
Natural Forest	71	15	5	10
Pre-1990 Planted Forest	72	15	5	10
Post 1989 Planted Forest	73	15	5	10
Grassland With Woody Biomass	74	15	4	8
Grassland High Producing	75	15	4	8
Grassland Low Producing	76	15	4	8
Cropland Perennial	77	20	5	10
Cropland Annual	78	20	5	10
Wetland Open Water	79	0	0	0
Wetland Vegetated Non-Forest	80	10	0	0
Settlements	81	5	2.5	5
Other	82	15	7.5	15
Waterways – streams and rivers	83	0	0	0

Table A-3 Continuing Losses Calibration Range

Land Use Type	Material ID	CL upper limit	CL lower limit	Final Value
Buildings	1	0	0	0
Natural Forest	71	2.4	0.5	0.8
Pre-1990 Planted Forest	72	2.4	0.5	0.8
Post 1989 Planted Forest	73	2.4	0.5	0.8
Grassland With Woody Biomass	74	1.2	0	0.4
Grassland High Producing	75	1.2	0	0.4
Grassland Low Producing	76	1.2	0	0.4
Cropland Perennial	77	2.4	0.8	0.8
Cropland Annual	78	2.4	0.8	0.8
Wetland Open Water	79	0	0	0
Wetland Vegetated Non-Forest	80	1	0	0
Settlements	81	1.5	0.3	0.3
Other	82	4.5	1.5	1.5
Waterways – streams and rivers	83	0	0	0

Table A-4 Soil Parameters Calibration Range

Soil Parameter	Upper limit	Lower limit	Final Value
Porosity (fraction)	0.6	0.4	0.5
Initial Moisture (fraction)	0.25	0	0
Horizontal hydraulic conductivity (mm/hr)	100,000	1,500	5000 (2015), 3000 (2018)
Topsoil thickness (m)	0.4	0.2	0.3

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