





Kāpiti Flood Hazard Management

Wharemauku Model Build Report

2/12/2024



Kāpiti Flood Hazard Management

Wharemauku Model Build Report

Project number	J000775 Flood Hazard Management Model Build
Version number	Flood Hazard Management, Wharemauku Model Build Report 6.0
Project Manager	Tony Trueman
Author	Tony Trueman
Additional technical contributors	Carl Johnson, Craig Martell

VERSION	DATE	DESCRIPTION	AUTHOR	REVIEWED
1.0	15/11/2023	Draft	Tony Trueman	CMM
2.0	20/12/2023	Draft	Tony Trueman	CMM
3.0	15/01/2024	Updates	Tony Trueman	CMM
4.0	25/07/2024	Final Draft	Tony Trueman	CMM
5.0	2/09/2024	Final Draft for Review	Tony Trueman	RO
6.0	2/12/2024	Final Draft	Tony Trueman	SS



Executive Summary

Awa Environmental (AWA) were engaged by Kāpiti Coast District Council (KCDC) to build a hydrological and hydraulic model of the Wharemauku catchment.

The model build has been undertaken utilising TUFLOW modelling software (Release 2023-03-AB) and includes all Council-owned manholes, pump-stations, sumps, and pipes identified from KCDC's asset database; privately-owned pipes are excluded along with publicly owned pipes that discharge to the kerb and channel.

The model is a substantial update on the historic models developed over 20 years in the DHI MIKE software suite. Key changes from the historic model include:

1. The new TUFLOW models include the modelling of static groundwater layers from Greater Wellingtons' Regional Groundwater Model. This limits the available storage in the soil over the course of modelled storms and highlights areas that are impacted by groundwater flooding. This is currently an issue of concern in the district and is expected to worsen with climate change, especially in coastal areas affected by Sea Level Rise (SLR).
2. The Wharemauku model uses a hybrid hydrological modelling approach:
    - the rain-on-grid hydrological approach is applied to low-lying, flat land, particularly where there is the potential for ponding and where interaction with groundwater is likely; and
    - the sub-catchment-based hydrological approach is applied to steeper catchments where flow is channelised.
3. Open channels throughout the district have been modelled using sub-grid sampled 2D grids rather than traditional 1D cross sections. This generally provides more stable models and faster runtimes.
4. The models include a great deal of additional data including updated ground surface levels, additional stormwater network detail, and the inclusion of the new State Highway.

The Wharemauku model has been validated using available historic data, including the discharge gauge at the coastland's weir, and achieved a good validation.

The report is structured as follows:

Section 1 – Report Overview
Section 2 - An overview of the study location.
Section 3 - A summary of model features, approaches applied, and model build process.
Section 4 – A summary of the calibration results
Section 5 – Comparison with historic calibration model
Section 6 – Wider Model Validation
Section 7 - Conclusions and Recommendations

The model has been validated to the May 2015 and December 2021 storm events. Several iterations were carried out as part of model validation, with parameters defined in the 2nd validation simulation applied to design simulations. The model has been used to simulate the existing development (2017), 20%, 10%, 2%, 1% AEP joint probability events.

Contents

1. Introduction 1
   1.1. Background 1
   1.2. Objectives 1
   1.3. Previous Modelling 2
   1.4. Modelling Approach 3
   1.5. Report Structure 3
   1.6. Important Model Updates 3
2. Catchment Description 5
   2.1. Location and topography 5
   2.2. Geology 5
   2.3. Existing Land Use 6
   2.4. Stormwater system 6
3. Model Build 7
   3.1. Model Overview 7
   3.2. Data Sources 7
      3.2.1. Spatial Data 8
      3.2.2. Non-spatial Data 8
   3.3. Model Domain 9
   3.4. Pipe Network 14
   3.5. Key Structures and Assets 16
   3.6. Computational Approaches 20
   3.7. Boundaries 25
   3.8. Model Limitations 26
   3.9. Assumptions 27
4. Flow Gauge Model Calibration 28
   4.1. Introduction 28
   4.2. Modelled Catchment Characteristics 28
   4.3. Flow Gauging Station 31
   4.4. Rainfall 32
   4.5. Event Selection 33
      4.5.1. May 2015 Event 33
      4.5.2. December 2021 Event 34

4.6. Validation 35
4.6.1. October 1998 Event 35
4.6.2. June 2002 Event 36
4.6.3. April 2008 Event 37
5. Model Summary 39
5.1. Results Comparison 39
6. Wider Model Validation 44
6.1. Introduction 44
6.2. Flood Events 44
6.2.1. May 2015 44
6.2.2. December 2021 47
6.3. Validation 57
7. Recommendations 58
7.1.1. Recommendations 58
8. References 59
Appendix A – Wharemauku Hill Subcatchment Characteristics 62
Appendix B – 100YR-ARI 2130 peak depth results 63

1. Introduction

1.1. Background

Awa Environmental (AWA) were engaged by Kāpiti Coast District Council (KCDC) to build a hydrological and hydraulic model of the Wharemauku catchment.

KCDC have a legacy MIKE FLOOD stormwater model of the Wharemauku Catchment which has been modified over time in response to evolving modelling requirements.

- The Wharemauku Stream catchment was originally modelled in MIKE11 by Connell Wagner in 2001.
- Jacobs (formerly SKM) extended an existing MIKE FLOOD two-way coupled model in 2009 and incorporated the pipe network using the surcharging manhole hydrographs from MOUSE as inputs into MIKE21. This version of the model was used to define the current District Plan flood hazard layer.
- In 2013 Jacobs (formerly SKM) updated the Wharemauku MIKE FLOOD model to a three-way coupled model using MIKE URBAN and MIKE FLOOD.
- In 2014 Jacobs updated the model hydrology and the MIKE FLOOD three-way coupled model of the Wharemauku model to include the M2PP expressway for the Q100 event with climate change to 2115.

The legacy model is currently configured to simulate the 2115-climate-horizon 100 year-ARI storm event and no provision has been made to easily simulate other events. The hydrologic model is complex and difficult to easily update cost effectively. In addition, the model does not incorporate asset data, land use, or network changes since 2014.

Use of the legacy model in current assessments of effects analysis has highlighted the difficulty of using the legacy model and the narrowing of its usefulness as modelling standards have evolved over time.

The details of the standards used and the methodology for the model build are covered in the Kāpiti Flood Hazard Methodology report.

1.2. Objectives

The overarching objectives of the Wharemauku model build are covered in the initial contract terms.

> *To provide KCDC with a TUFLOW stormwater model of the Wharemauku catchment that allows the model to be more agile and transparent within the wider statutory framework for managing hazards, particularly for the assessment [and communication] of risk implications for a range of future sea-level rise and climate change scenarios and that the models need to be a sufficient quality and detail to ensure outputs are robust, transparent, and defendable.*

The objectives were further developed into a purpose statement through client workshops and represented in the Kāpiti Flood Hazard Methodology report.

The specific objective of the Wharemauku model build is to develop a TUFLOW stormwater model of the Wharemauku catchment which can simulate a range of rainfall and tidal scenarios.

The model will support scenario and mapping capability to assist KCDC with the management of stormwater and flood risks within the catchment. The model must be suitable for:

- Determining flood levels - depths, extents, and hazard information for a range of design flood events to inform flood information products including flood mapping, property search for flood levels and overlays in the District Plan.
- Support council planning policy and flood risk management.
- Inform strategic network planning - establishing performance of existing public stormwater network and identify deficiencies in the level of service to support network renewals and upgrades.

1.3. Previous Modelling

KCDC have a legacy MIKE FLOOD stormwater model of the Wharemauku Catchment updated by Jacobs in 2014.

Key features of the 2014 legacy model include:

PIPE NETWORK

- Simplified pipe network representation in MIKE URBAN.
    - Pipes > 300mm modelled,
- Sumps not modelled,
    - Sump types not considered,
    - Sump inlet capacity not considered,
- Manholes coupled to surface,
    - Hydrographs loaded into manholes.

OPEN CHANNEL NETWORK

- Open channel representation in MIKE11.
    - Cross-sections from survey data,
    - Channel roughness from imagery,
    - Connection to Tidal boundary.

2D DOMAIN

- Domain grid resolution of 4 m.

HYDROLOGY

- Sub-catchment-based hydrology.
    - 2115-climate-horizon 100 year-ARI storm event,
        - No consideration of more frequent events,
    - SCS Curve Number,
        - Curve numbers used to approximate losses,
        - HEC-HMS used to calculate input hydrographs,
    - Groundwater not considered.

MODEL COUPLING

- 3-way coupled M21, M11, MU model.

1.4. Modelling Approach

This report describes the process of building, calibrating, and validating the Wharemauku catchment model. The process follows the steps outlined in Figure 1.

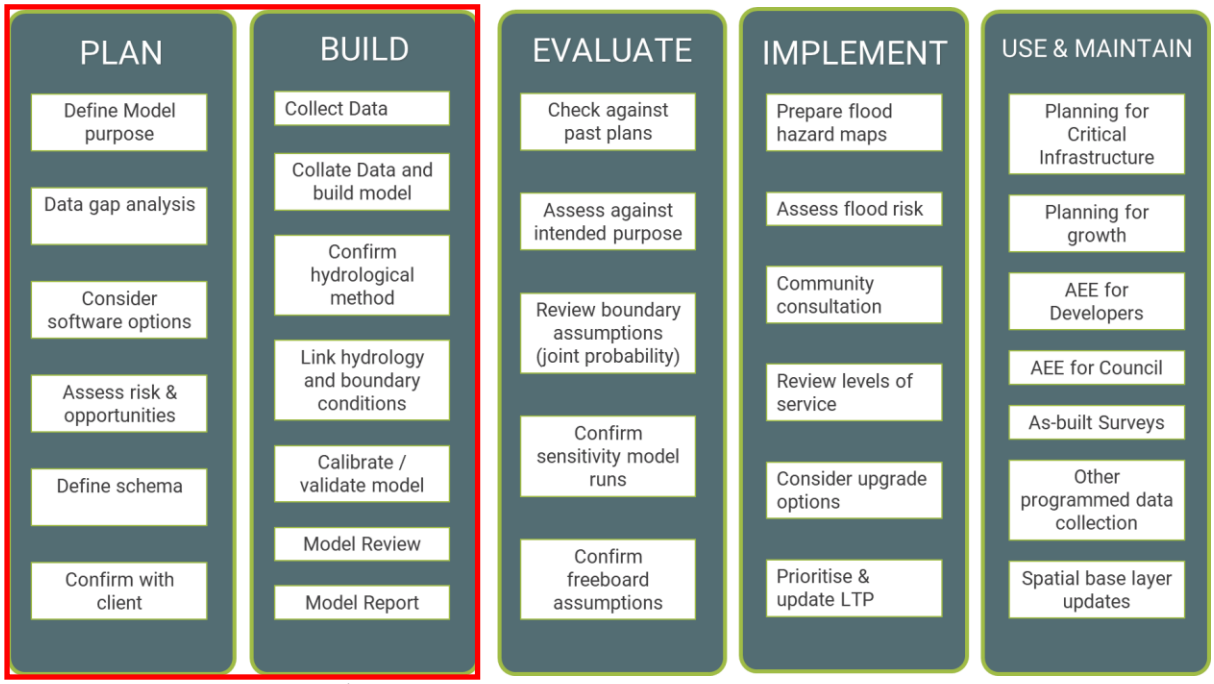


Figure 1. Modelling approach.[1]

1.5. Report Structure

The report is structured as follows:

Section 2 - An overview of the study location.
Section 3 - A summary of model features, approaches applied, and model build process.
Section 4 – A summary of the calibration results
Section 5 – Comparison with historic calibration model
Section 6 – Wider Model Validation
Section 7 - Conclusions and Recommendations

1.6. Important Model Updates

The model is a substantial update on the historic models developed over 20 years in the DHI MIKE software suite. Key changes from the historic model include:

1. The new TUFLOW models include the modelling of static groundwater layers from Greater Wellingtons' Regional Groundwater Model. This limits the available storage in the soil over the course of modelled storms and highlights areas that are impacted by groundwater flooding. This is currently an issue of concern in the district and is

[1] Adapted from the National Modelling Guidelines

expected to worsen with climate change, especially in coastal areas affected by sea level rise (SLR).

2. The Wharemauku model uses a hybrid hydrological modelling approach:
    a. the rain-on-grid hydrological approach is applied to low-lying, flat land, particularly where there is the potential for ponding and where interaction with groundwater is likely; and
    b. the sub-catchment-based hydrological approach is applied to steeper catchments where flow is channelised.
3. Open channels throughout the district have been modelled using sub-grid sampled 2D grids rather than traditional 1D cross sections. This generally provides more stable models and faster runtimes.
4. The models include a great deal of additional data including updated ground surface levels, additional stormwater network detail, and the inclusion of the new State Highway.

2. Catchment Description

2.1. Location and topography

The Wharemauku catchment covers an area of approximately 15 km^2 and is located within the Kāpiti District. The catchment is bounded by the steep topography of the Tararua Foothills along its south-eastern extent, the Mazengarb catchment to the north and the Raumati Beach catchment to the south, as shown in Figure 2.

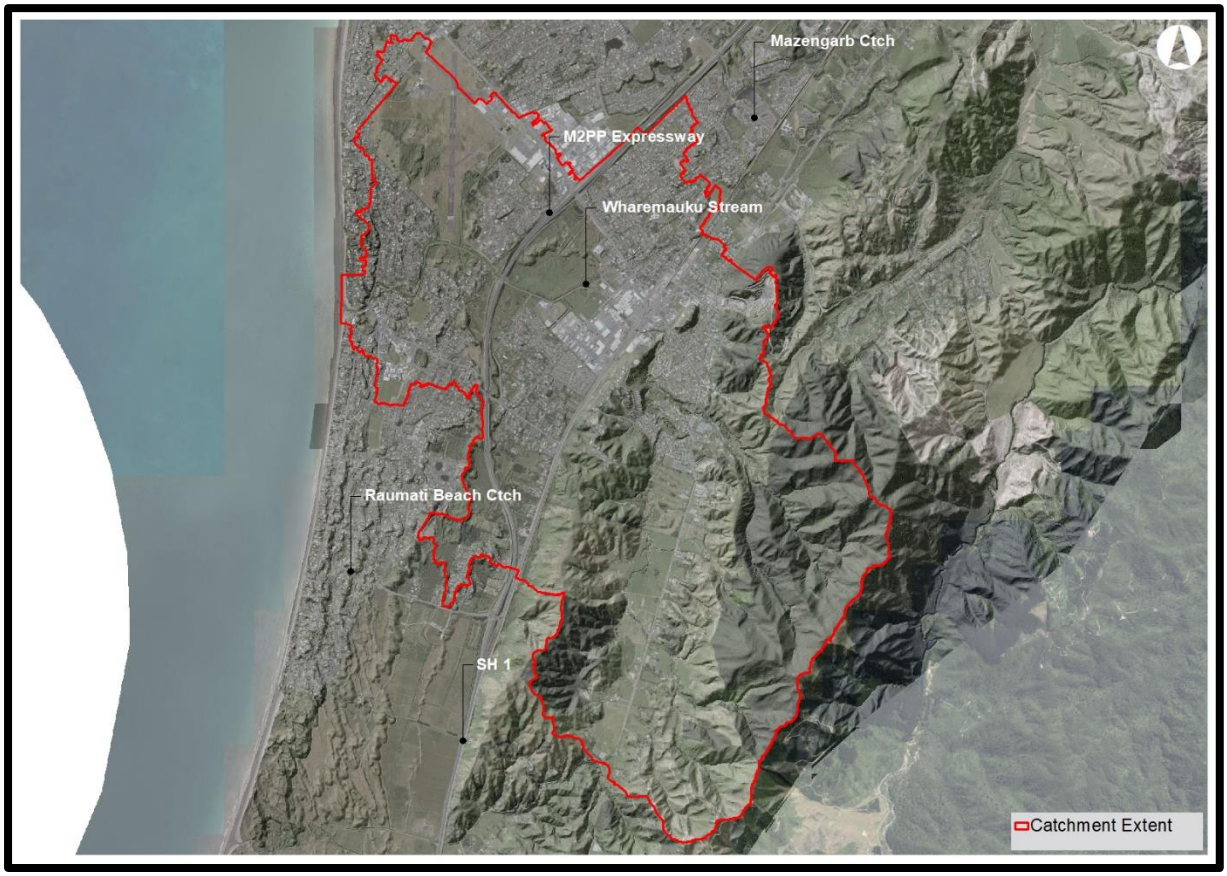


Figure 2. Wharemauku catchment extent.

2.2. Geology

The geology of the catchment has been shaped by the interaction of aeolian and fluvial processes resulting in several dune phases, with interdune areas of peat and floodplain gravels. It is within this context that the urban coastal margin has developed, with hydraulic conditions ranging from high soakage sands and gravels to areas of low-lying peat impacted by seasonal groundwater conditions.[2]

[2] Kāpiti Flood Hazard Management Methodology Report, 2024.

2.3. Existing Land Use

In the lower reaches of the Wharemauku catchment, west of the M2PP expressway, the land-use is largely residential with some isolated commercial activities along Kāpiti Road. The airport represents the largest area of undeveloped land. Between State Highway 1 and the M2PP Expressway, land-use is a mixture of residential at the southern and northern extents and commercial in centre of the catchment. Open space in this area, (including the Town Centre Zone) is under further commercial and residential development pressure. Within the lower valley, east of State Highway 1, commercial land-use gives way to residential land-use. The upper valley is characterised by rural land-use, dominated by lifestyle blocks and farmland, with limited commercial activities in the valley floor giving way to predominantly native, exotic, and grasslands in the steeper ranges.

2.4. Stormwater system

The Wharemauku stormwater network consists of pipes, catchpits, manholes, pump-stations, detention ponds and interconnected streams and drains with culverts under road and rail crossings. The Wharemauku Stream is the main open channel in the catchment. It has been modified along its length to increase floodway capacity, as it is the primary form of conveyance of runoff out of the catchment.

3. Model Build

3.1. Model Overview

The final model schema and purpose is discussed in the Kāpiti Flood Hazard Methodology report.

The following section defines the conceptual schema utilised to represent the real-world characteristics of the Wharemauku catchment within the model. Table 1 summarises key details of the model build.

Table 1. Key details of the model build.

AREA	HEADING
Software	TUFLOW version 2023-03-AB
Coordinate system	New Zealand Transverse Mercator 2000 (NZTM 2000)
Vertical datum	Wellington 1953 Vertical Datum (WVD53)
Validation scenarios	The May 2015 and December 2021 storm events.
Design events	• Rain-on-grid rainfall inputs derived from HIRDS v4 gridded (2 km resolution) design rainfall depths (including climate change effects for relevant scenarios). • Sub-catchment rainfall sampled at the sub-catchment centroid from HIRDS v4 gridded (2 km resolution) design rainfall depths (including climate change effects for relevant scenarios). • Tailwater conditions incorporating Sea Level Rise (SLR), Storm Surge and the Mean High-Water Springs (MHWS) tidal cycle.

3.2. Data Sources

This section details the key information regarding the sources of data used to create the model, as shown in Table 2 and Table 3.

3.2.1. Spatial Data

Table 2. Details of spatial data used to build the model.

DATA	DETAILS	DATE SUPPLIED
Topography	KCDC - GroundLasDataset2017.img	1st March 2019
Stormwater asset data	KCDC - KCDC_Stormwater_20200619_gdb	19th June 2020
Land cover	Lynker - Kāpiti_Coast_Landcover_20210527.gdb Koordinates - Landcare Research - Land Cover Database version 5 (LCDB v5)	27th May 2021 N/A
Soil map	Koordinates - The Fundamental Soil Layers New Zealand Soil Classification (FSL) dataset, updated July 2017	N/A
Soil map	Koordinates – LRIS – SMAP Soil Classification, updated August 2021	N/A
Infiltration map	Awa - Derived from field investigation data collection and analysis	2022
Soil compaction	Awa - Derived from GIS desktop investigation	2022
Building footprints	Lynker - Kāpiti_Coast_Landcover_20210527.gdb	27th May 2021
Open channels	KCDC - KCDC_Stormwater_20200619_gdb	19th June 2020
Rainfall	HIRDS - HIRDS v4 gridded (2 km resolution) design rainfall depths	3rd September 2021
Groundwater	T&T – Groundwater level files – • AWA_2130_85H_model_hds_toplayer_50% • AWA_2130_85H+_model_hds_toplayer_50%	20th January 2022

3.2.2. Non-spatial Data

Table 3. Details of non-spatial data used to build the model.

DATA	DETAILS	DATE SUPPLIED
Validation data	KCDC - DETSUM12058.csv – KCDC service requests for period January 2015 to November 2020	23rd November 2020
X-sections (survey)	Jacobs - Wharemauku_E12_NZTM_005.xns11	6th March 2019
Culverts (survey)	Jacobs - Wharemauku_E12_NZTM_005.nwk11	6th March 2019
Tide (validation)	Website - May 2015, December 2021 validation tide data from GWRC live monitoring and research website	N/A

DATA	DETAILS	DATE SUPPLIED
Rainfall (validation)	Website - May 2015, December 2021 validation rainfall data from GWRC live monitoring and research website	N/A
Tide (design)	Design tides generated by AWA	N/A
Network (survey)	KCDC – Manhole Condition Survey	2021
Google Maps - Kāpiti	Street View April 2008 to December 2019	N/A
Aerial Imagery	Service Layer Credits: Eagle Technology, Land Information New Zealand, GEBCO, Community maps contributors	N/A
Soakage Rates	KCDC – Soakage rate data for various locations across the district	2021

3.3. Model Domain

The extent and computational method for each of the key model features are defined in Table 4.

Table 4. Extent and computational method for each of the model's key features.

DATA	DETAILS
Model boundary	• GIS-based drainage analysis was used to define watersheds within the catchment. These watersheds were merged to form the extent of the 2D model domain, as shown in Figure 3.
Overland flow	• The 2D computational grid is discretised into regular 2 m x 2 m square elements. • Overland flow processes are simulated within the TUFLOW 2D model domain. • Surface elevations are based on LiDAR data.
Pipe network	• Represented in 1D using TUFLOW's ESTRY module. • All stormwater drainage sumps, pipes, pump-stations, and manholes in the catchment identified from KCDC's stormwater asset data layer, except for small diameter private connections which discharge to the kerb and channel, are included in the model. • Stormwater assets included in the network are summarised in Section 3.4. • The extent of the pipe network is shown in Figure 4.
Open channels	• The main open channels are modelled using TUFLOW's sub-grid sampling feature (SGS) which represents the channel bed at a 0.5 m resolution. This fine-resolution grid has been interpolated from cross section data from legacy model survey. • All other small open channels and swales are represented in the DEM at a cell resolution of 2 m.

DATA	DETAILS
	• The extent of open channels is shown in Figure 5.
Sub-catchments	• Sub-catchments are used to simulate runoff from steep, hill catchments along the south-eastern extent of the catchment. • Soil Conservation Service (SCS) Curve Number method is used to simulate hydrological losses (SKM, 2011). • The Clark Unit Hydrograph method is used to simulate hydrological routing parameters (SKM, 2011). • The location of the modelled sub-catchments is shown in Figure 6. • Further details are included in Section 3.6.
Rain-on-grid	• Initial loss/continuing loss infiltration model, calculated from field infiltration data and analysis, was applied across the 2D model domain to account for hydrological losses. Parameters are spatially distributed to account for the various land use, soil type and compaction assumptions, as shown in Figure 7 and Figure 8. • The extent of the soil compaction layer is shown in Figure 9. • The extent of the sub-catchment and rain-on-grid domain is shown in Figure 6. • Further details are included in Section 3.6.
Lakes, ponds, and wetlands	• Ponds identified in the aerial imagery are represented in the TUFLOW 2D model domain by excavating the pond extent 500 mm below the outlet structure invert level and applying an initial water surface. • For ponds without an outlet structure, the pond extent is excavated 500 mm below the LiDAR estimate of the pond surface and a 500 mm deep initial water surface applied.

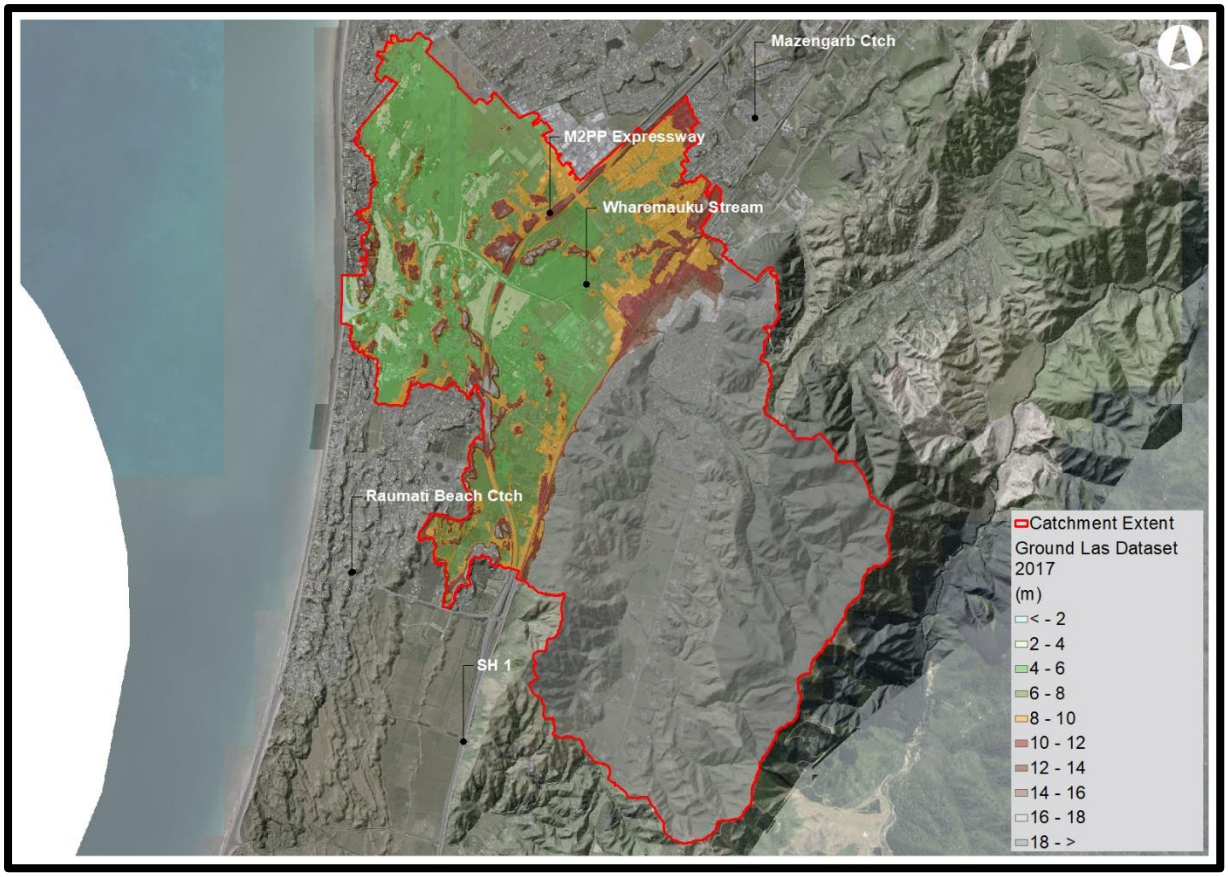


Figure 3. Surface elevation overlaid with model domain (shown in red).

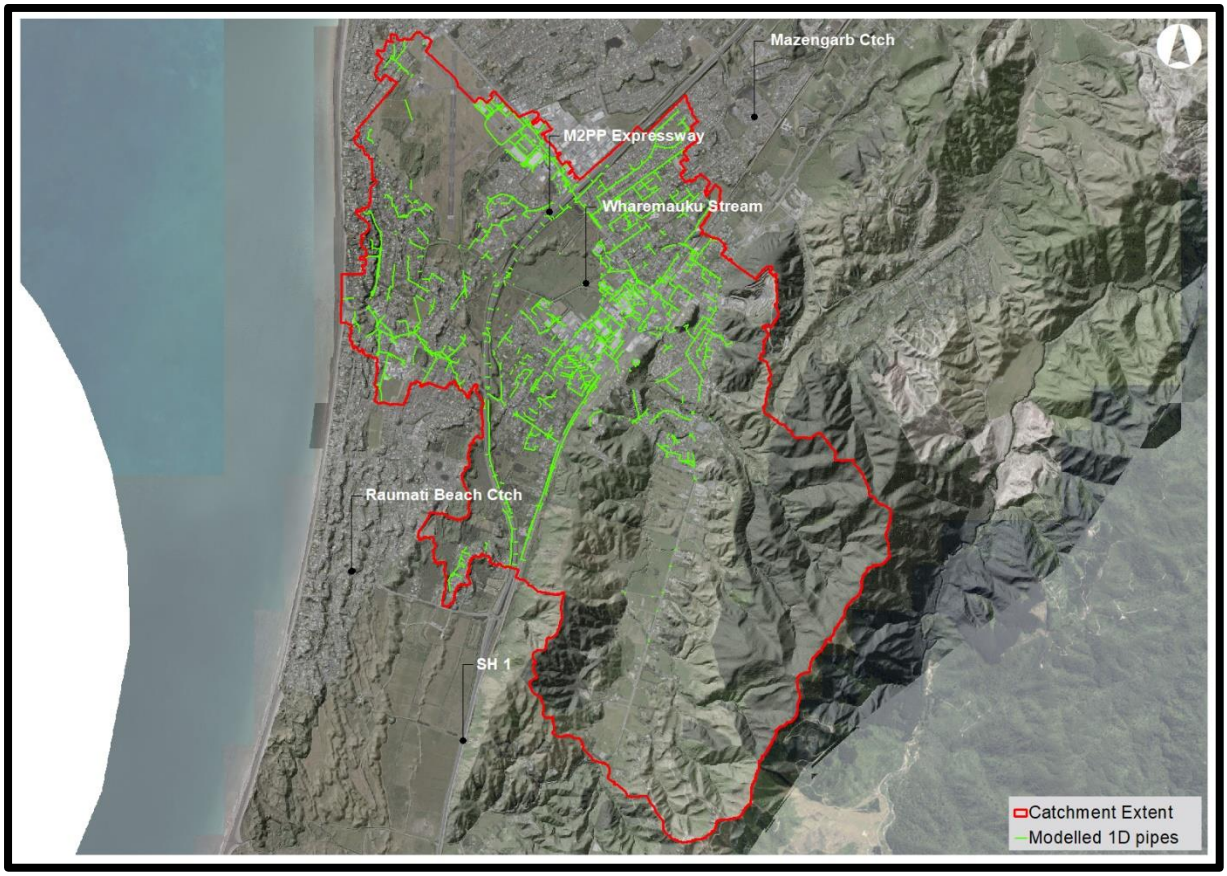


Figure 4. Pipe network extent (shown in green) and model domain (shown in red).

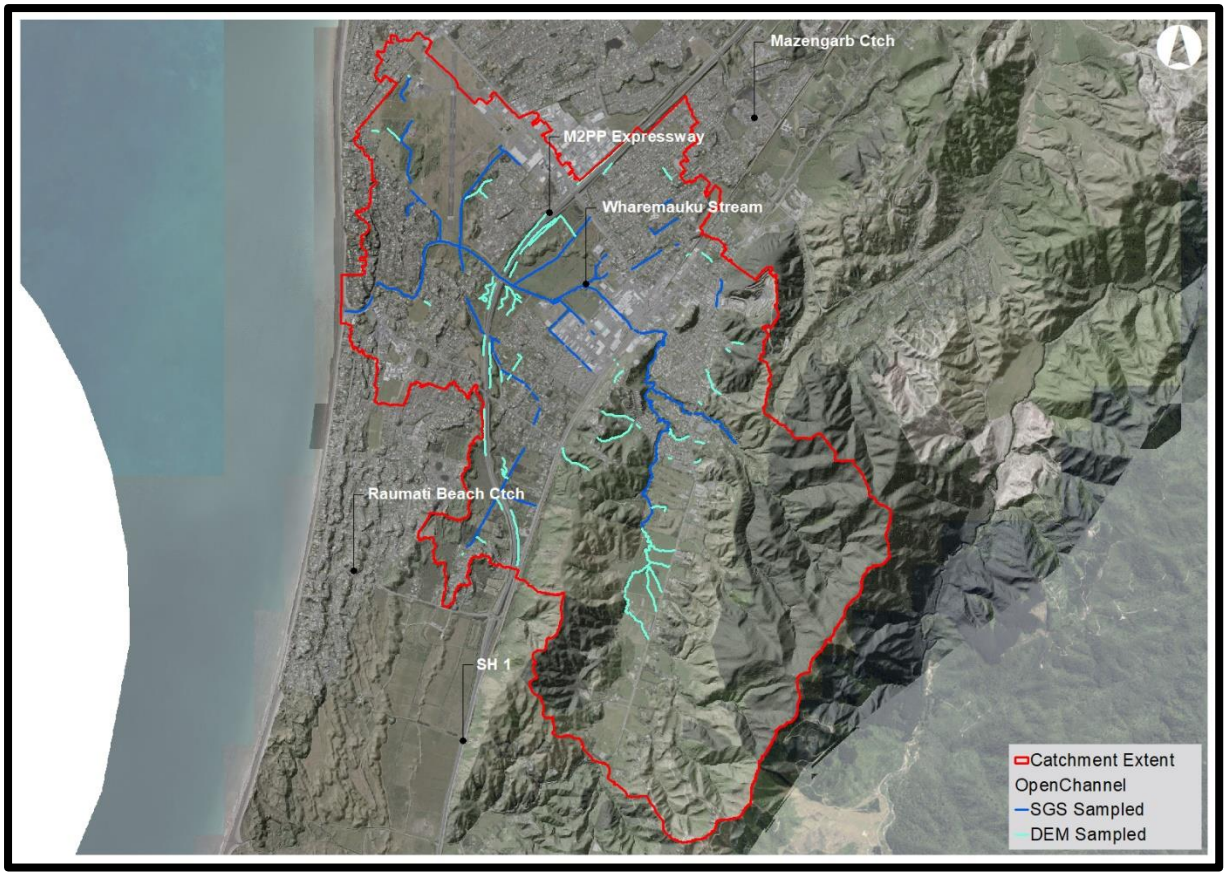


Figure 5. Open channel representation – sub-grid sampling (dark blue) and DEM (light blue).

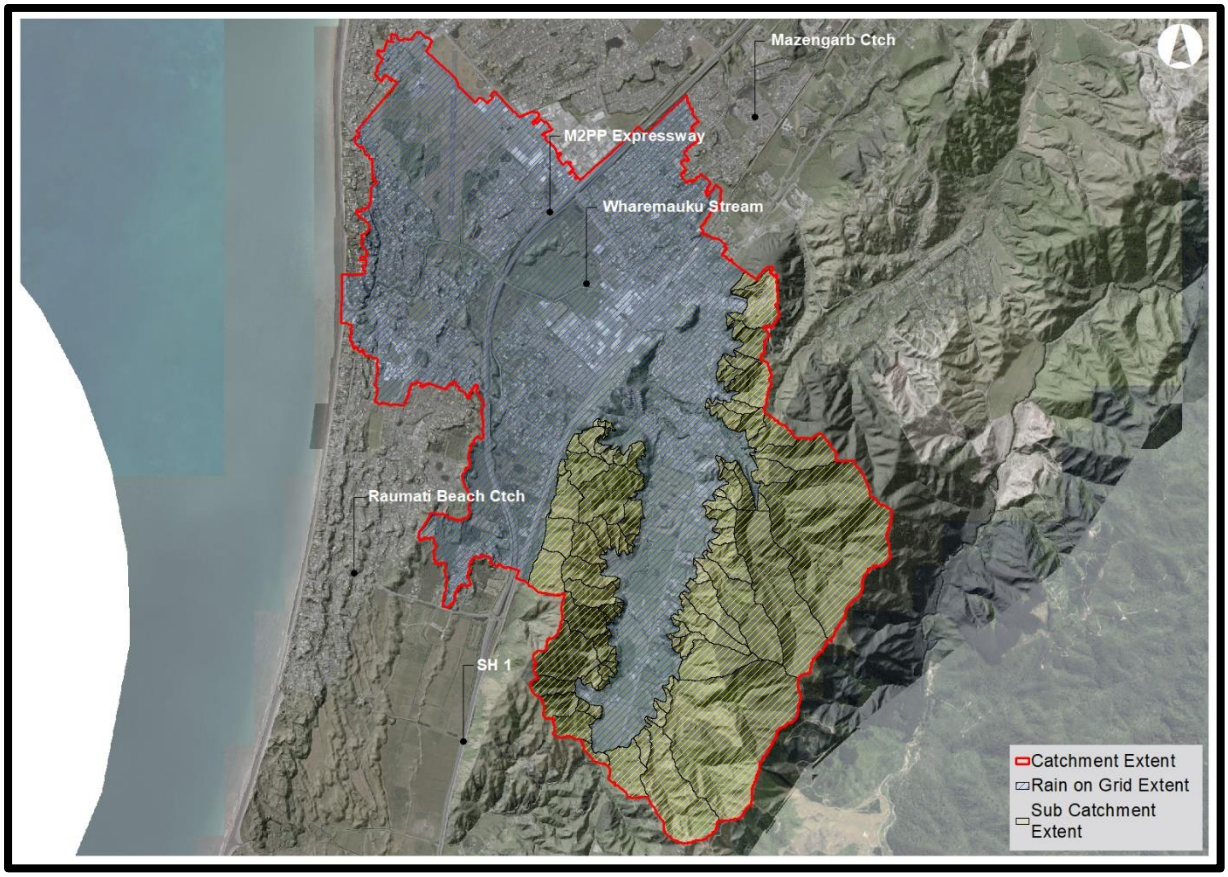


Figure 6. Sub-catchments extent (yellow) and Rain on Grid extent (blue).

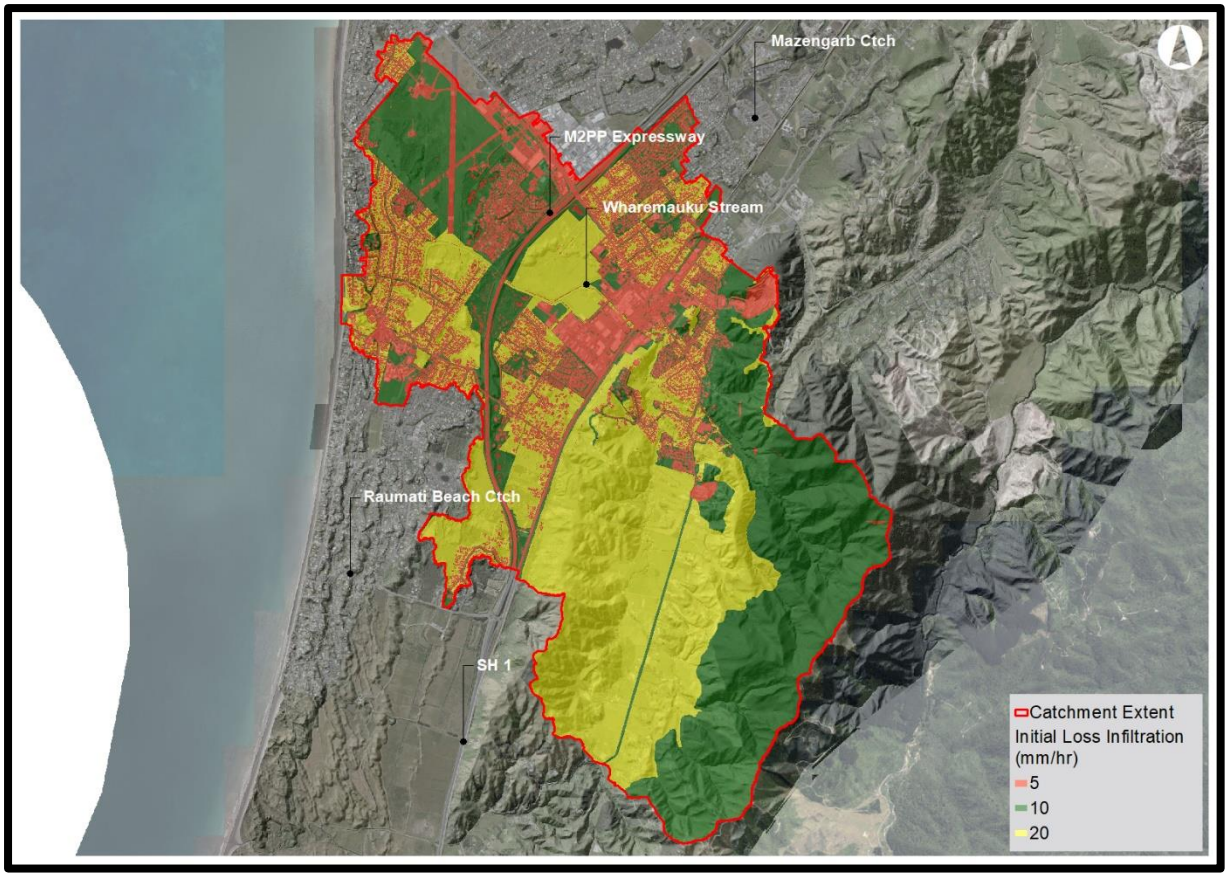


Figure 7. Initial loss infiltration model.

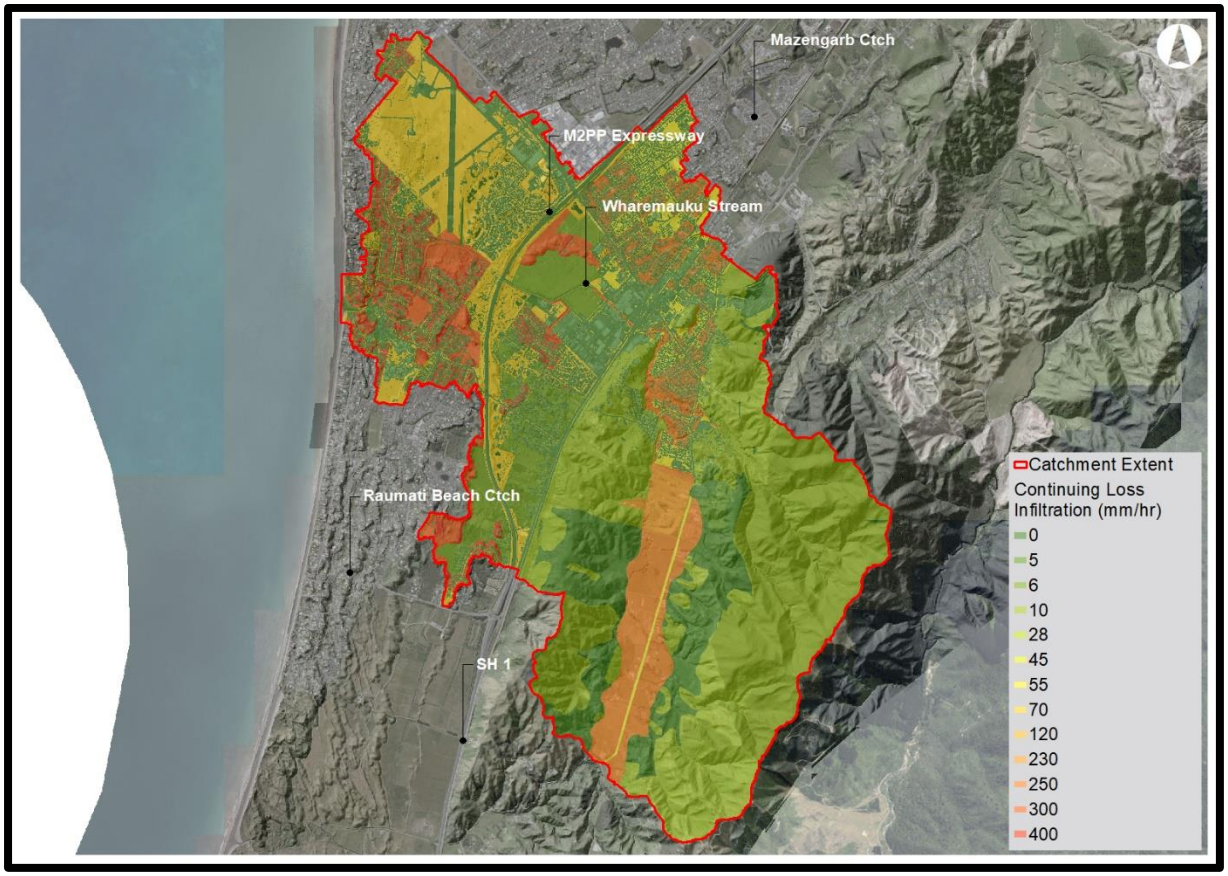


Figure 8 Continuing loss infiltration model.

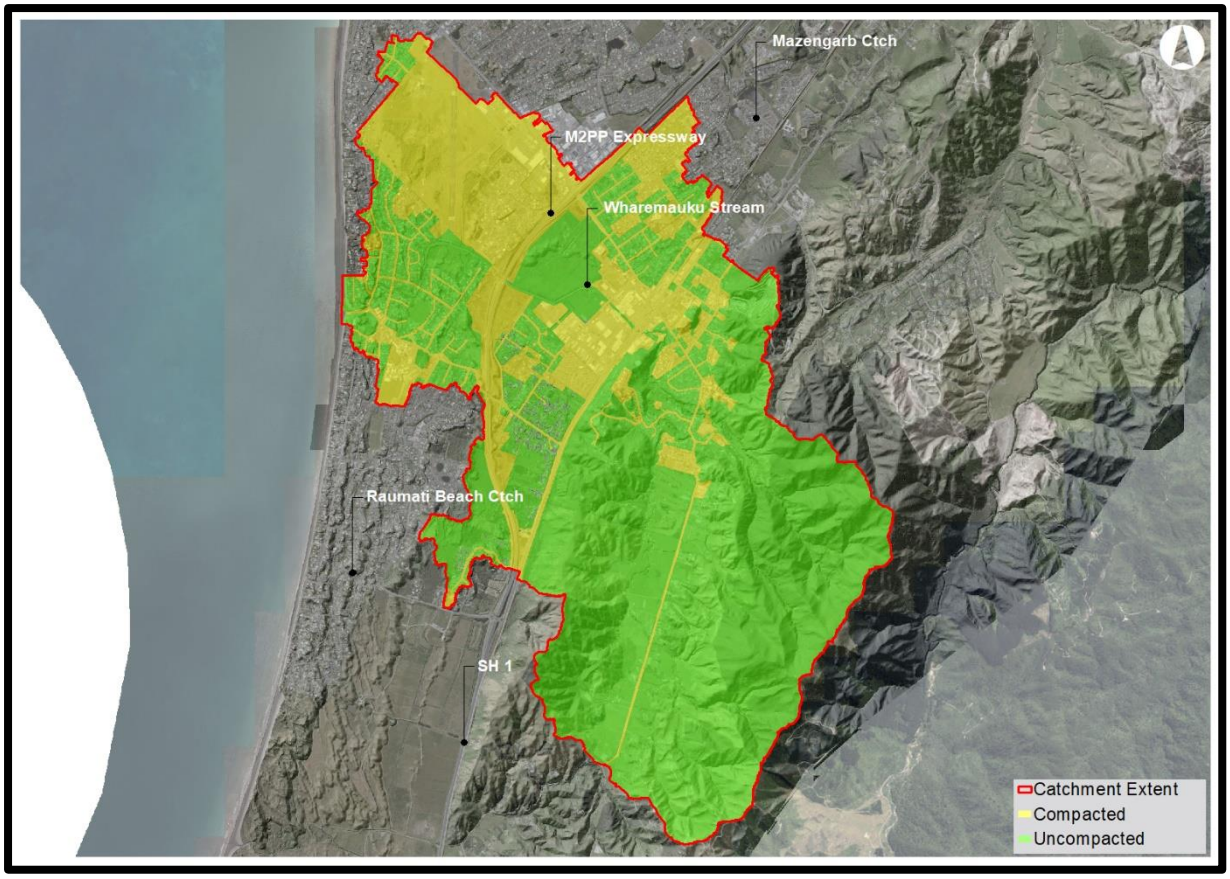


Figure 9. Extent of the soil compaction layer.

3.4. Pipe Network

The 1D network comprises gravity mains which drain to the Wharemauku Stream.

The network includes all stormwater drainage pits, pipes and manholes in the catchment identified from KCDC's stormwater asset data layer, excluding private drainage.

The asset types included in the pipe network model and key information on how they are represented is shown in Table 5.

Table 5. Stormwater asset model representation.

DATA	DETAILS
Pipes	• All pipes in the KCDC_Stormwater_20200619_gdb layer, excluding private drainage, are included in the model. • Sump-lead connections in the KCDC_Stormwater_20200619_gdb layer are included in the model. Small diameter privately owned lateral connections and pipes discharging to the kerb and channel are excluded from the model. • Additional laterals are added to connect sumps to the network where necessary and the diameter assumed. • Parameters specified in the asset database are used where appropriate. Where available, survey data is used to correct anomalies, otherwise network assumptions and engineering judgement are used to

DATA	DETAILS
	interpolate gaps in the data or correct apparent errors in the pipe network.
Inlets	• Inlet structures - ground levels at the structure are adjusted to match the invert level of the connected pipe. • Where invert information is not available, the pipe invert has been adjusted to match the LiDAR. • Inlets are coupled to the 2D surface allowing for the exchange of surface flow into the pipe network.
Outlets	• Outlet structures - ground levels at the structure are adjusted to match the invert level of the connected pipe. • Where invert information is not available, pipe inverts are adjusted to match the LiDAR. • Outlets are coupled to the 2D surface allowing for the exchange of surface flow into the pipe network.
Manholes	• All manholes in the supplied dataset are included in the model, except where they are isolated from other network. • Additional manholes are added to the model to fill gaps in the GIS dataset. • Manhole inverts are assigned the minimum of the connected upstream or downstream pipe invert levels in the first instance. Where pipe inverts are not available, inverts are calculated from the Depth field of the asset data and the LiDAR ground level. Where no depths are specified, inverts are estimated based on the connected pipe diameters and an assumed pipe cover depth of 450 mm or interpolated using engineering judgement to maintain a consistent grade. • Lid levels are set from the LiDAR surface elevation DEM. • Manhole diameters are specified in the asset data. For manholes missing from the asset data, diameters are set to accommodate connected pipes or assumed to be 1050 mm diameter. • Manholes are not coupled to the 2D surface, effectively sealed, so no exchange of surface flow into the manholes occur.
Junctions	• Junctions in the supplied KCDC_Stormwater_20200619_gdb layer are included where sump leads connect to stormwater mains. • Junctions are modelled as circular nodes with parameters to accommodate connected pipes.
Sumps	• Stormwater inlet (sump) discharge-depth relations are based on those defined by WWL (2017) as shown in Table 9. • Lid levels are set from the LiDAR surface elevation DEM. • Upstream inverts of sump leads are set to 450 mm above the sump invert and the sump-lead grade is set to 5%. Where this is not possible, the upstream or downstream inverts are adjusted accordingly. • Sumps are coupled to the 2D surface allowing for the exchange of surface flow into the pipe network. • Sump types have been taken from supplied asset database. Identified sumps, not in the asset database, have had sump type defined using street-view.

DATA	DETAILS
Subsoil drains	• Nova flow pipes are included in the model as standard pipes. • Isolated sections of nova flow pipe are excluded from the model.
Soakage	• All soakage nodes in the supplied dataset are included in the model and categorised as either. • Soak-hole and dimensioned as standard manholes, not coupled to the 2D surface, with connected sumps. • Soak-hole and dimensioned as standard drainage pits represented with a grated lid with/without connected sumps, coupled to the 2D surface. • A soakage rate of 300 mm / hr has been assumed across all identified soakage devices.
Pump stations	• Ihakara Street • Raumati Road
Bridges	• Represented in the 2d Domain by TUFLOWS layered flow constrictions shape (LFCSH). There are up to 3 layers that can have the surface elevation, blockage and loses associated with each layer. A bridge is modelled as having a 0-10% blockage as the first layer (could have piles or not) Second layer is the deck level that is 100% impervious. (Levels taken from old mike model and or DEM or survey). The third layer represents the railing that is generally a 10%-20% blockage. Assuming they are a min of 1.2m high. During blockage scenarios the first layer can be adjusted to represent blockages.

3.5. Key Structures and Assets

Several key culverts and bridges within the Wharemauku catchment demonstrate constraints in the network. The location of these assets is shown in Figure 10 with the dimensions and configuration shown in Table 6.

There are two pump stations within the catchment area. The location of these assets is shown in Figure 11 with the details shown in Table 7.

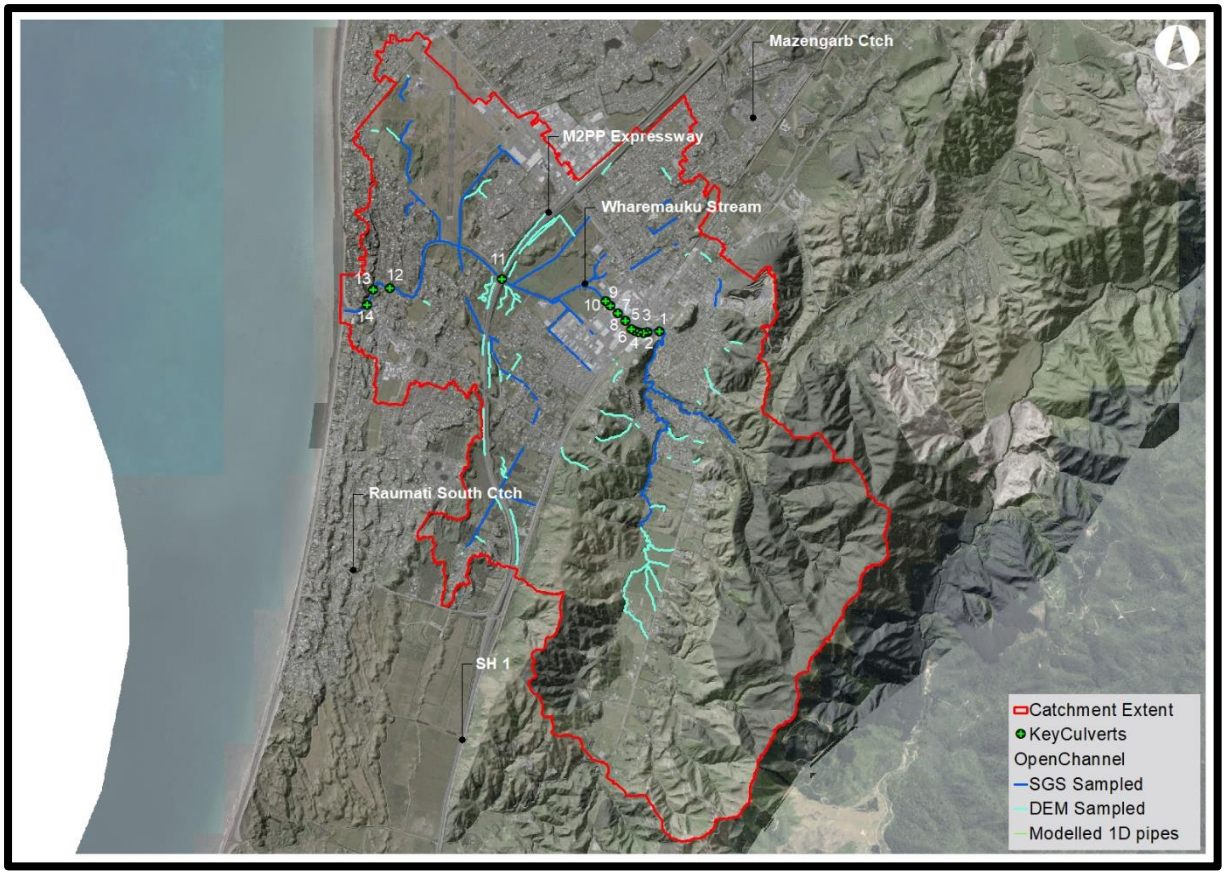


Figure 10. Locations of key open channel structures.

Table 6 Culvert descriptions

CULVERT ID	CULVERT NAME	DIMENSIONS/CONFIGURATION
1	Vera Lane Bridge	TUFLOW LFCSH (underside = 17m RL)
2	Private crossing 1	TUFLOW LFCSH (underside = 14.4m RL)
3	Private crossing 2	TUFLOW LFCSH (underside = 13.4m RL)
4	Epiha Street Bridge	3*(2.15m*1.5m) box culverts
5	NIMT Railway Bridge	TUFLOW LFCSH (underside = 13m RL)
6	Old SH1 Culvert	2*(2.8m*1.6m) box culverts
7	Coastlands Bridge 1	TUFLOW LFCSH (underside = 10.25m RL)
8	Coastlands Bridge 2	TUFLOW LFCSH (underside = 9.75m RL)
9	Coastlands Bridge 3	TUFLOW LFCSH (underside = 8.92m RL)
10	Rimu Rd Bridge	TUFLOW LFCSH (underside = 8.787m RL)
11	SH1 Bridge	Not in model as water does not get that high
12	Alexander Road Bridge	TUFLOW LFCSH (underside = 2.75m RL)
13	Matatua Road Twin Cell Culvert	2*4.7m Armco culverts
14	Matatua Road Bridge	TUFLOW LFCSH (underside = 3.18 RL)

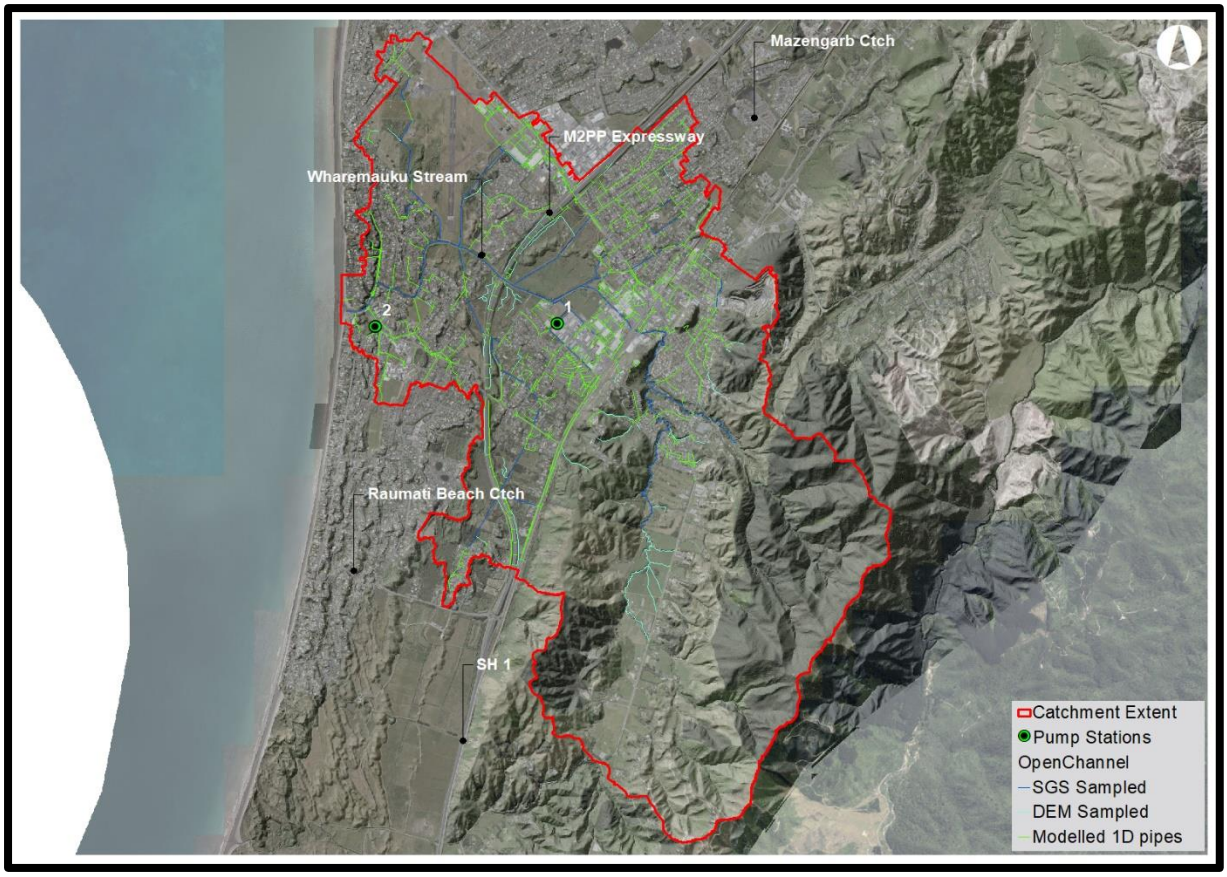


Figure 11 Pump station locations.

Table 7 Pump station details

MODEL ASPECT		DETAILS
Pump-Station	(1) Ihakara Street	**Wet-well Details** • 3.1416 x 1.5m(2) x 4m. **Pump Details** • 2 x Homa K5570, • 22 Kw, • 48 Amps, • Installation date 2005, • Flow rate (260). **Rising main details** • 21.35meters of 600mm PE100 [HDPE], • Static head based on contours 3m [lid - depth - contour at outfall], • Friction loss estimate (assumed), • Estimated flow rate based on above = 260 l/s, • Pump start level 90%, • Pump stop level 10%, • Lid RL from GIS = 5m, • Highest point of rising main from GIS = 4m.
	(2) Raumati Road	**Wet-well Details** • 4m x 5.6m x 5m. **Pump Details** • 3 x Sulzer VUPX 0501, • 28.2 Kw, • (unknown) Amps, • Installation date 2012, • Flow rate (650). **Rising main details** • 3.77meters of 1350mm (assumed), • Static head based – 3.7m, • Friction loss estimate (unknown), • Estimated flow rate based on above = 650 l/s (per pump), • Pump start level 60%, • Pump stop level 20%, • Lid RL from drawings = 5.2m, • Highest point of rising main from drawings = 3.7m.

3.6. Computational Approaches

The computational approaches for the various components are outlined in Table 8, including key hydraulic and hydrological parameters.

Table 8. Computational approaches and key parameters for various aspects of the model.

MODEL ASPECT		DETAILS
Internal model coupling	Overland flow to pipe network	• The model surface is connected to the pipe network via TUFLOW pits. Flow is exchanged according to Q-D relations taken from WWL (2017), as shown in Table 9.
	Open channels to pipe network	• TUFLOW 2D SX link nodes are used to connect pipe inlets and outlets to channel cells. • Instabilities are dampened and, in some cases, eliminated by levelling several cells and connecting the pipe inlet or outlet to them using 2D SX link lines.
Boundary condition application	Model domain	• For design events, rainfall is applied as a 2 km-resolution grid timeseries. The gridded rainfall is based on HIRDS v4 rainfall depths and a centred nested rainfall pattern. • For the validation event, gauged rainfall is applied as Thiessen polygon zones.
	Sub-catchments	• Rainfall is applied to each sub-catchment depending on the zone or grid cell that the sub-catchment's centroid falls within. • Each sub-catchment runoff discharge timeseries is distributed across a 2D Source over Area polygon located along the edge of the model domain where the sub-catchment abuts. • Inflow from hill catchments is calculated outside the TUFLOW model.

<table>
<tr><th>MODEL ASPECT</th><th></th><th>DETAILS</th></tr>
<tr><td rowspan="4">Hydrodynamic parameters</td><td>Resistance</td><td>

Mannings n is spatially distributed across the 2D domain.
The spatial distribution is based on land cover data provided by Lynker in urban areas and Landcare Research's LCDB v5 land cover elsewhere.
A map of the roughness grid used in the model is shown in Figure 12.
Manning's n values applied to different land cover classes are provided in the table below.

<table>
<tr><th>Land cover</th><th>Manning's n</th></tr>
<tr><td>Forest</td><td>0.1</td></tr>
<tr><td>Paved</td><td>0.02</td></tr>
<tr><td>Scrub</td><td>0.2</td></tr>
<tr><td>Maintained grass</td><td>0.03</td></tr>
<tr><td>Channel bed</td><td>0.025</td></tr>
<tr><td>Rural grass</td><td>0.04</td></tr>
<tr><td>Crops</td><td>0.2</td></tr>
<tr><td>Gravel</td><td>0.03</td></tr>
<tr><td>Building</td><td>0.02</td></tr>
</table>
</td></tr>
<tr><td>Flood and dry parameters</td><td>

Default wetting and drying parameters are applied.
Wetting and Drying == ON METHOD B
Cell Wet/Dry Depth == 0.0002

</td></tr>
<tr><td>Map cutoff depth</td><td>

Parameter set to 0.01

</td></tr>
<tr><td>Eddy viscosity</td><td>

Default Wu eddy viscosity formulation used with default coefficients of C3D = 7.0 and C2D = 0.0.

</td></tr>
<tr><td>Initial conditions</td><td>

Ponds are filled to the invert of the outflow, which makes the ponds 500 mm deep at the start of the simulation.
A spatially varying groundwater table has been applied as an initial condition to better represent the total soil storage available through the simulation.

</td></tr>
</table>

<table>
<tr><th>MODEL ASPECT</th><th></th><th>DETAILS</th></tr>
<tr><td rowspan="2">Pipe network hydrodynamic parameters</td><td>Pipe energy losses</td><td>

Most pipes are circular with a few exceptions: generally larger rectangular or irregular pipes. All pipes, including culverts are treated identically by TUFLOW.
Manning's n values applied to different pipe materials are provided in the table below.

<table>
<tr><th>Material</th><th>Manning's n</th></tr>
<tr><td>Plastic/Stone</td><td>0.0125</td></tr>
<tr><td>Concrete</td><td>0.0133</td></tr>
<tr><td>Cement mortar/Asbestos cement</td><td>0.0130</td></tr>
<tr><td>Iron(cast/ductile)/Ceramic/Steel</td><td>0.0143</td></tr>
<tr><td>Iron(wrought)/nova flow/ Galvanised iron</td><td>0.0154</td></tr>
<tr><td>Dummy pipes*</td><td>0.0133</td></tr>
</table>
* Dummy pipes are connected to nodes that represent soakage devices. This is required by the software.

Entry and exit loss coefficients are set to 0.5 and 1.0, respectively.

</td></tr>
<tr><td>Manhole energy losses</td><td>

All manholes use the Engelund loss approach.

Km and K_Bend_Max coefficients are set to 0.25.
</td></tr>
<tr><td>Resistance</td><td>

A Manning's n value of 0.033 has been applied uniformly to the 1D Waikanae River branch at the downstream end of the model. As the river is not a key component of the model, a more sophisticated treatment is not warranted.
Resistance applied to open channels in the 2D domain varies along each channel depending on the land cover estimates: Forest to Channel Bed classifications have been applied corresponding to Manning's n roughness values from 0.1 to 0.025. Roughness has been adjusted as part of validation for the open channels in this catchment as covered in section 5.

</td></tr>
</table>

MODEL ASPECT		DETAILS
2D configuration	Initial conditions	• The initial water level is set automatically to the level of the downstream water level boundary at the start of each simulation.
	Rain-on-grid	• Applied to flat areas of interest for flood mapping. • Spatially and temporally varying rainfall is applied directly to the 2D domain. • Initial loss/continuing loss infiltration model, calculated from field infiltration data and analysis, infiltration parameter sets for a range of land cover and soil types are produced for the whole of Kāpiti, as described by Awa (2021). • A spatially varying groundwater table has been applied as an initial condition to better represent the total soil storage available through the simulation.
Hydrology	Sub-catchment-based	• Applied to steeper rural zones. • Sub-catchments are delineated using a GIS-based drainage analysis, which does not consider hydraulic effects. • Hill sub-catchments are either loaded to the upstream end of cross-drainage pipes under roads or distributed along the sub-catchment boundary with the 2D domain. • The hydrological loss model used is the Clark Unit Hydrograph using the SCS Curve Number method. The following parameters are required for each sub-catchment. • Initial loss calculated as an area-weighted average of 0.0 mm for urban areas and 5.0 mm for all others. • Curve Number based on land use and soil type. A map of CN has been created for the whole of Kāpiti as described in the Kāpiti Flood Hazard Methodology report. • The routing model used is the Clark Unit Hydrograph method. The following parameters are required for each sub-catchment. ◦ Area is taken directly from the sub-catchment area and so assumes that the entire sub-catchment contributes to runoff. ◦ Time of Concentration is calculated according to the approach specified by Cardno (2019). ◦ Storage Coefficient R is calculated from the area-weighted averaged of the Ratio parameter and the Time of Concentration, as described by SKM (2011).

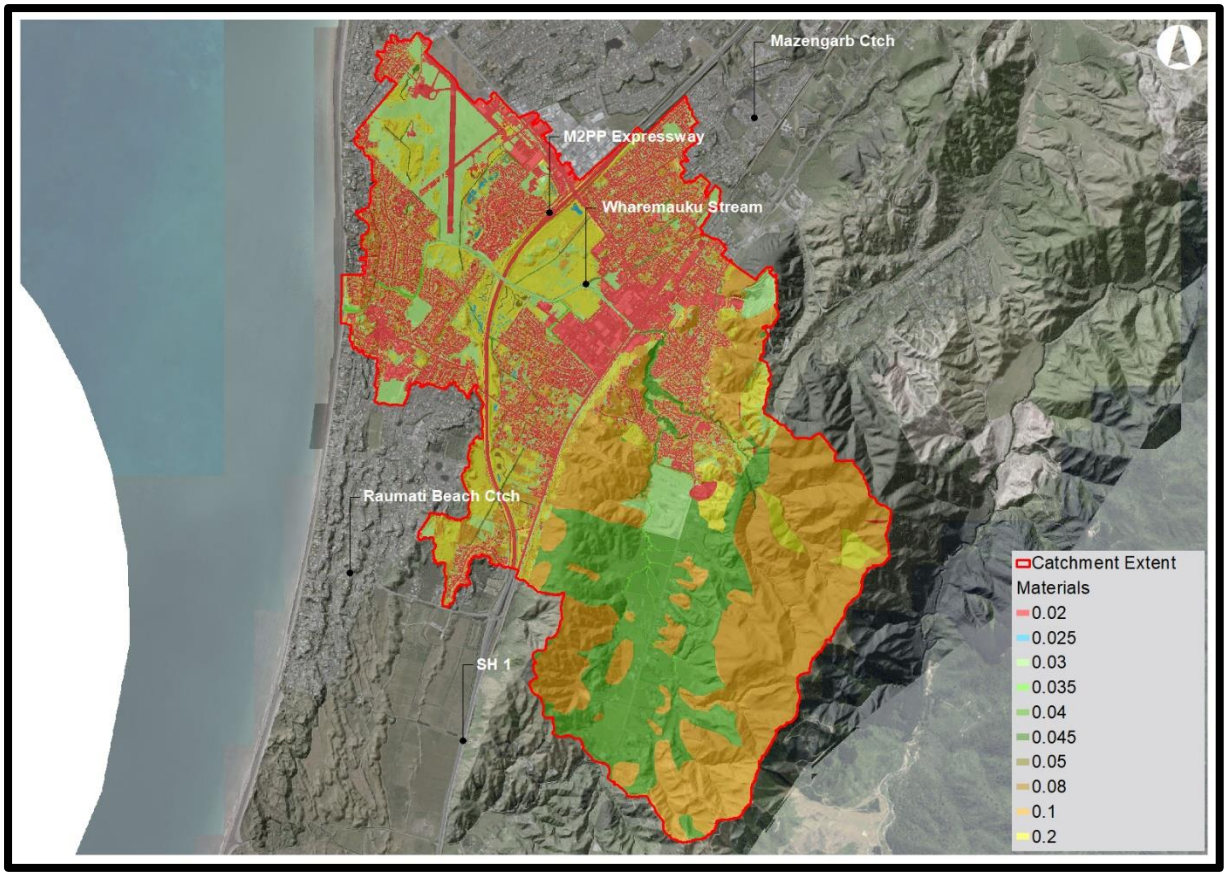


Figure 12. Mannings overland flow resistance parameters applied to the model.

Table 9. Q-D relations taken from WWL (2017).

INLET CONFIGURATION ID	CODE	CATCHPIT TYPE	INLET AREA (M2)	DISCHARGE COEFFICIENT (-)	QDH (M)
1.1	CP	Standard grate, open with single sump	0.122	0.67	0.25
1.2	CP	Standard grate, in-line with single sump	0.122	0.67	0.3
1.3	DCP	Standard grate, in-line with double sump	0.243	0.67	0.3
1.4	CP	Standard grate, recessed with single sump	0.122	0.67	0.3
1.5	CP	Standard kerb-opening, back entry with single sump	0.063	0.67	0.3
1.6	DCP	Standard kerb-opening, back entry with double sump	0.126	0.67	0.3
1.7	CP	Standard combination, in-line with single sump	0.1845	0.55	0.35
1.8	CP	Standard combination, recessed with single sump	0.1845	0.55	0.35
1.9	DCP	Standard combination, in-line with double sump	0.369	0.55	0.35

1.10	DCP	Standard combination, recessed with double sump	0.369	0.55	0.35
2.1	SSPLAY	Single splay, in-line with single sump	0.063	0.67	0.3
2.2	SSPLAY	Single splay, in-line with double sump	0.126	0.67	0.3
3.1	DSPLAY	Double splay, in-line with single sump	0.063	0.67	0.3
3.2	DSPLAY	Double splay, in-line with double sump	0.126	0.67	0.3
4.1	SCP	Super pit, in-line with single sump	0.353	0.62	0.4
4.2	DSCP	Super pit, in-line with double sump	0.705	0.62	0.4
5.1	MCP	Mega pit, in-line or recessed with single sump	0.729	0.55	0.05
5.2	MCP	Mega pit, in-line or recessed with double sump	1.458	0.55	0.05
5.3	MCP	Mega pit grate, open with single sump	0.648	0.67	0.5

3.7. Boundaries

Three different types of boundaries are applied to the TUFLOW model, as shown in Table 10. Hydrographs for the hill sub-catchments are generated externally from TUFLOW and are either:

- connected to Source over Area (SA) polygons along the extent of the boundary which abuts the relevant sub-catchment; or
- connected to the upstream end of cross-drainage culverts which pass under roads.

In the case of flows entering cross-drainage culverts, a storage area-height relationship is applied to the upstream node to account for ponding storage upstream. The node is also connected to the boundary to allow for overtopping flows.

Table 10. TUFLOW model boundaries.

BOUNDARY	DETAILS
Rainfall	• Spatially and temporally varying rainfall is applied across the entire 2D domain. • Externally to the TUFLOW model, rainfall is applied to hill sub-catchments based on the location of the sub-catchment's centroid.
Tide	• Applied at the downstream end of the Wharemauku Stream branch at the coast.
Flow	• Hill sub-catchment runoff is directed into cross-drainage culverts or onto the 2D surface along the south-eastern edge of the 2D domain.

3.8. Model Limitations

Model limitations which should be considered when using the model or interpreting outputs are discussed in Table 11.

Table 11. Limitations of the model.

LIMITATION	DETAILS
Data quality	Some errors, omissions, and anomalies in the GIS asset data were identified through automated error detection and resolved using as-built drawings where available. In the absence of data, engineering judgement was utilised based on terrain and surrounding assets.
Cross section data	Cross-section data for the TUFLOW SGS defined open channels were based on MIKE 11 open channel cross sections extracted from the legacy MIKE FLOOD model. The invert level in the open channel in these locations may have changed over time depending on aggradation or scouring of the channel. There are some key areas where this is a known issue, and this has been managed through sensitivity modelling in these locations.
Sub-catchment discharge effects	Discharges from the hydrological model are loaded onto the TUFLOW 2D surface, via dummy nodes in TUFLOW 1D. If the catchments are too large the point loading of the flow onto the grid could result in water "mounding" at the discharge location. Catchments are delineated to a relatively small size to distribute the discharges across the model and ensure that mounding is not significant.
Grid cell resolution	Some of the finer surface features that influence overland flows and catchment delineation are not fully represented by the resolution of the terrain (2m). Features such as kerb lines are at a sub grid size scale and some preconditioning of the terrain had to be undertaken prior to sub-catchment delineation. This involved cutting kerb lines into the terrain and adding localised high points into the surface at key locations. These edits were applied during sub-catchment delineation and have been carried through into the final model.

3.9. Assumptions

Assumptions made during the model build process are discussed in Table 12.

Table 12. Assumptions made during the model build.

TYPE	ASSUMPTION
Hydrological assumptions	• The hydrological method specified by SKM (2011) reproduces the significant hydrological responses of the hill sub-catchments. • The 2017 LiDAR is a reasonable representation of catchment topography, and minor channels are overwhelmed during flood flows. • While surface infiltration rates will vary the parameters used in the model are a reasonable estimate of mean rates.
Hydraulic assumptions	• The 2017 LiDAR is a reasonable representation of the current state of the catchment. • Manhole lid levels are adequately estimated by the LiDAR. • Pipes and hydraulic structures are sediment free. • Inlets, outlets, and sumps are sediment and blockage free. • Where data is of low quality, engineering-design-based estimates of pipe and manhole inverts and grades are reasonable. • The land cover estimates are sufficiently accurate for use in distributing hydraulic parameters, such as overland flow resistance and infiltration rates.

4. Flow Gauge Model Calibration

4.1. Introduction

Calibration of coastal catchments on the Kāpiti Coast is limited by the lack of available flow gauging stations. For this reason, the Wharemauku Stream is an important source of gauged data. The gauging station (Wharemauku Stream at Coastlands) has a data record sapnning 44 years. The gauging station can be compromised when flows are diverted to the North and/or South at the upstream Epiha Street bridge. This needs to be understood as a data constraint by the modeller.

As this is the only available local gauging station for flow, the calibration of this waterway will be used to quantify runoff parameters from the other hill catchments in the urban hydraulic models. This will include the upper Mazengarb, Paekākāriki and Waikanae Hill catchments alongside the Wharemauku Stream.

Calibration of the Wharemauku catchment models has been previously undertaken in 2009 by SKM and 2001 by Connell Wagner. For comparison, this historic calibration has been compared to other available steep Wellington hill catchments to ensure consistency. The most recently calibration was undertaken in 2011 through the Board of Inquiry, involving several gauged hill catchments, as part of the consent process for Transmission Gully3. This included the Horokiri, Pauatahanui, and Porirua Streams as shown in Table 13.

Table 13: Calibrated Model Parameters (SKM 2009)

Calibrated model parameters						
Catchment Name	Area (km2)	Initial Abstraction (mm)	SCS Curve No	Connected Impervious Area (CIA)	Tc (hr)	Ratio
Horokiri	28.7	5	80	0	2.00	0.65
Pauatahanui	38.3	5	75	0	1.70	0.65
Porirua (1997)	40	4	78	16	2.60	
Wharemauku	5.5	5	79	1	0.80	
Calibrated model parameters						
Maungakawa	1.825	5	73	0.8	0.75	1.39
Wharemauku Valley	5.058	5	72	4.8	1.20	2.23
Suggested model parameters for 50 and 100 year design storm analysis						
Maungakawa	1.825	5	78	0.8	0.75	1.39
Wharemauku Valley	5.058	5	77	4.8	1.20	2.23

4.2. Modelled Catchment Characteristics

There are some significant changes in the hydraulic model form used for this calibration compared to historic assessments. In the 2009 historic calibration, the hydrologic model was defined by two upstream catchments. For this calibration, the upstream system was modelled to allow for a more detailed sub-catchment analysis of inflows. In addition, the modelling of the valley floor provides a

[3] SKM 2011, Transmission Gully Project – Assessment of Hydrology and Stormwater Effects.

much more accurate understanding of catchment storage. The upper Wharemauku catchment sub-catchments are outlined in blue, and the 'rain on grid' valley floor is shown in yellow (Figure 13).

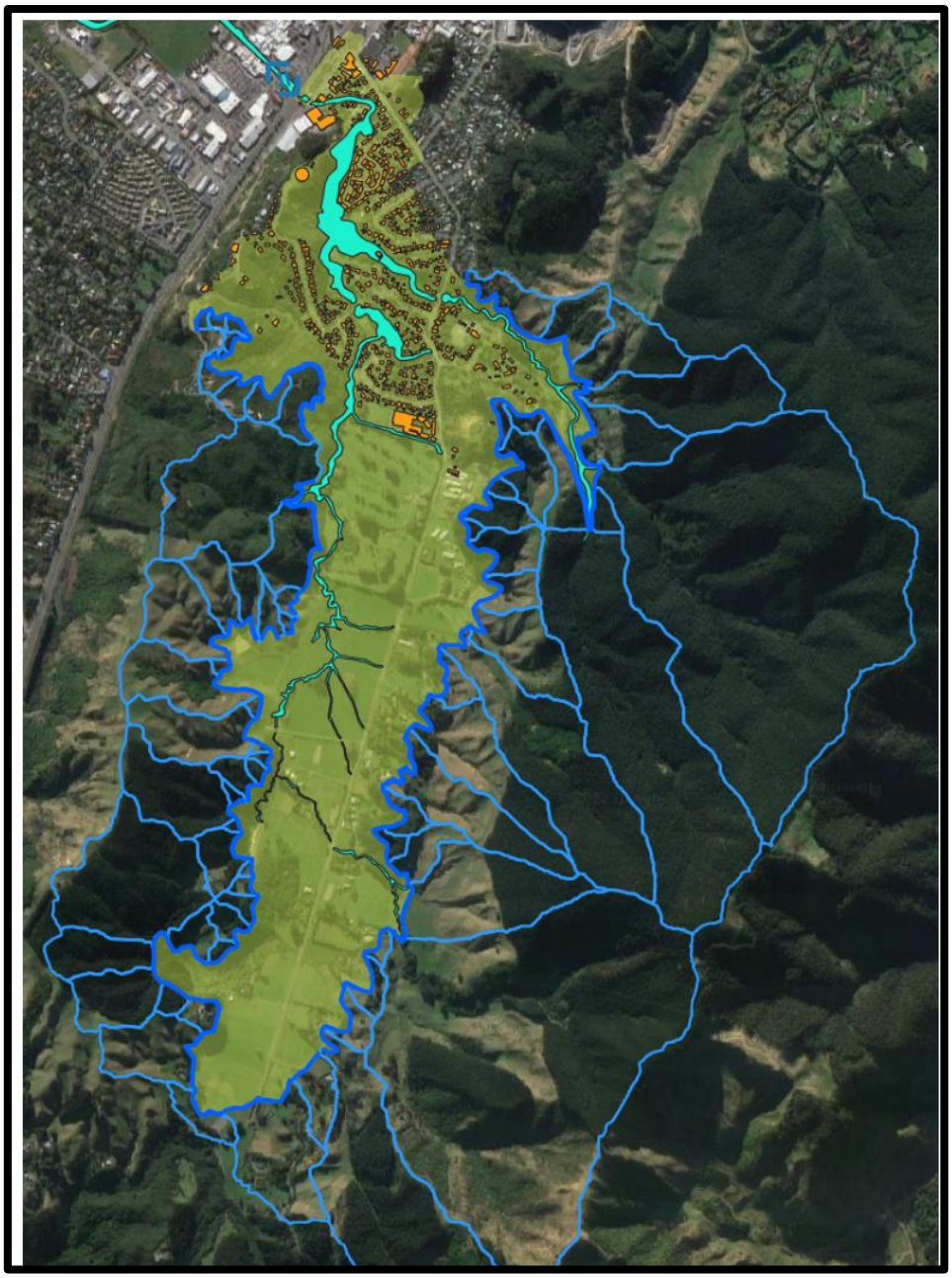


Figure 13. Wharemauku upper catchment extent and partitioning into hill sub-catchments and the 2D valley floor hydrodynamic domain.

Initial catchment characteristics were developed based on historic work completed for Kāpiti District Council and can be summarised in Table 14 for each soil typology.

Table 14. Soil typology of kāpiti hill catchments

	Soil Type	Curve Number
1	**Loose Dune Sands**	
	Assumed soil type A.	45
2	**Gravel Silt Loams**	
	Pasture	69
	Urban Gardens*	61
	Bush	48
	Assumes soil type B. In some cases testing will show gravel soils to have higher infiltration capacities than this in which case soil type A should be assumed.	
3	**Residential Inland Dune sands**	
	Assumes soil type B and accounts for construction compactions.	61
4	**Greywacke Argillite Steepland Soils**	
	Pasture	79
	Urban	74
	Bush	65

*Excludes connected impervious areas as covered in section 2.2.3.
**Awa created additional CN's based on site specific soils and land use types.

HYDROLOGICAL METHODOLOGY FOR UPPER CATCHMENT

The unit Clark hydrograph method of flood estimation was first proposed by Sherman (1932) and has since found wide application for both design and estimation of actual floods where a hydrograph and reasonable accuracy are required (Maidment, 1992). Unit Hydrographs are defined by the runoff resulting from uniform units of rainfall depth over an entire catchment. The difference between rainfall volumes and runoff volumes in the unit hydrograph model is expressed as losses to the system, which can relate to a variety of forms such as evapotranspiration, and storage within vegetation, the soil, and undrained depressions. The key components for the development of a unit hydrograph model are therefore rainfall depth relationships, rainfall losses, and catchment characteristics. Each of these items have been separately discussed through the remainder of this chapter and are covered considerably more comprehensively in Hoggan (1996).

$$Q=\frac{(P-I_a)^2}{P-I_a+S}$$

Where
Q = accumulated Runoff (mm)
P = accumulated Rainfall (mm)
I_a = initial Abstraction
S = potential maximum retention after runoff begins (mm)
CN = curve number, percent of runoff

Table 15: Initial vs final sub-catchment model parameter values

Model version	V0	V12
Area	100% area per catchment	Split catchments Fast (25%) Slow (75%) per catchment
Ia	Varying across catchments	Set to constant 5mm
CN	Varying across catchments	All CNs below 90 were increased by 8
Time of Concentration	Calculated using Wellington waters tc	Doubled
Ratio	Varying across catchments	Split catchments Fast (0.95) Slow (0.3)

Refer to Appendix A for final subcatchment characteristics.

4.3. Flow Gauging Station

The flow gauge, pictured in Figure 14, is a concrete trapezoidal structure situated immediately downstream of the State Highway.



Figure 14. Wharemauku flow gauging station site

As commonly seen with urban flow gauging stations, the site is compromised, particularly in high flows. This needs to be considered when considering calibration of an extreme event flow. In particular the upstream culverts at Epiha Street, NIMT Railway and Old State Highway 1 all restrict high flows to some degree, diverting flows to both the North and South (Figure 15).

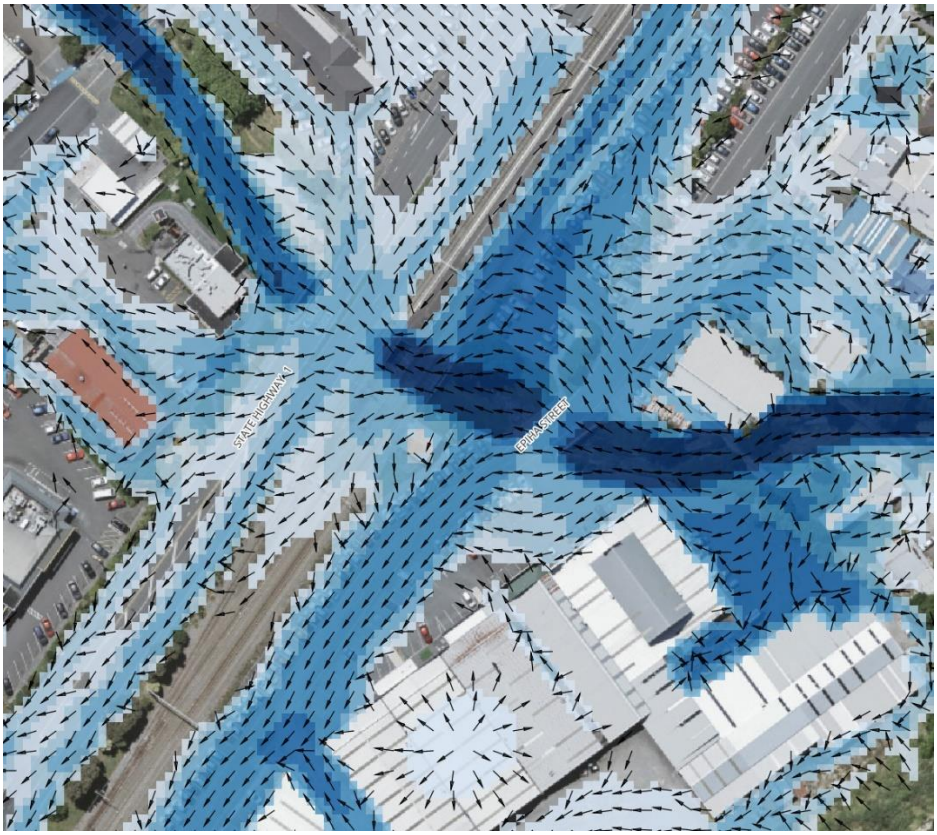


Figure 15. Flooding around the Epiha Street, NIMT Railway and Old State highway culverts, 2030 100yr Event

4.4. Rainfall

Rainfall will typically be the most significant variable in the calibration of any hydraulic model, as is the case for Kāpiti.

SKM (2011) completed an assessment of rainfall depths across the district for varying return period rainfall events. There is a noticeably strong orographic rainfall effect into the hills of Kāpiti that needs to be understood (Figure 16).

As the starting point for calibration runs, rainfall has been scaled up by 20% to account for orographic effects (based on SKM 2011). In this case scaling was applied to the Paraparaumu rain gauge site.

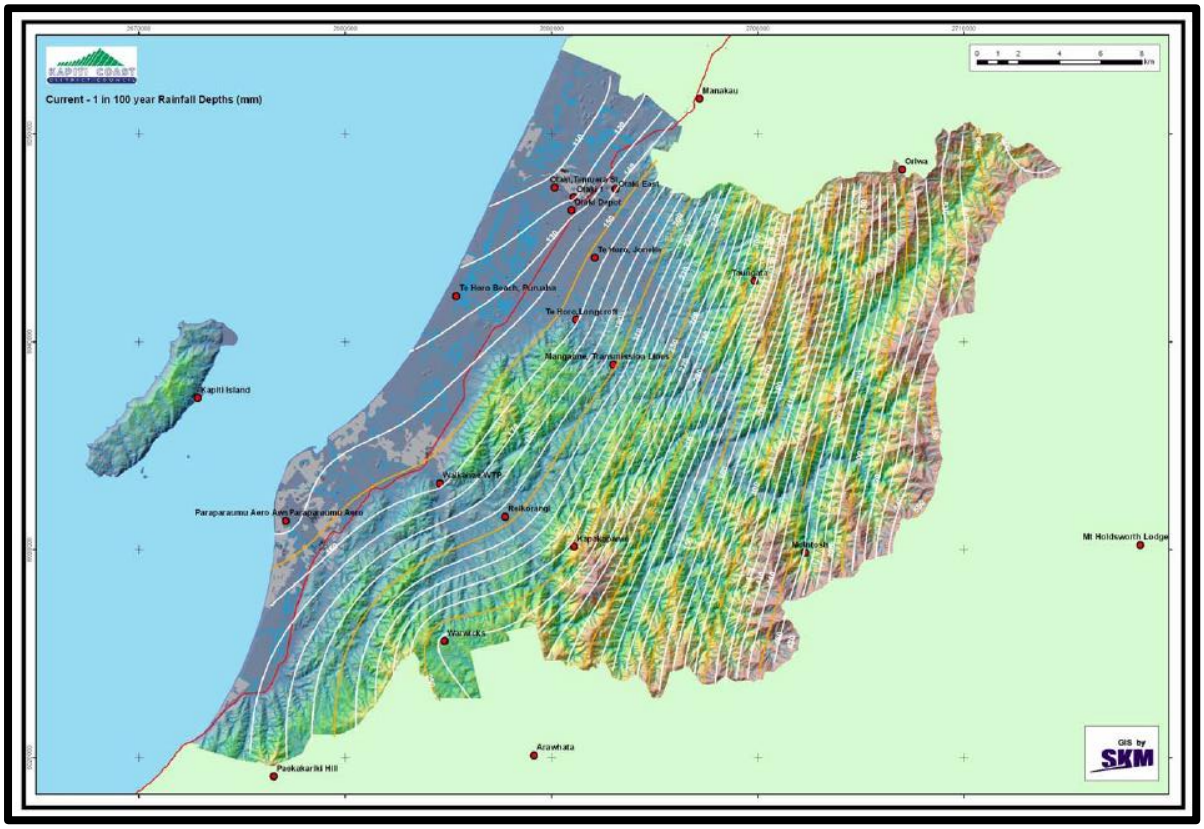


Figure 16. KCDC 1 in 100-year rainfall isohyets

4.5. Event Selection

Additional gauged data has been generated since the last calibration that used the Wharemauku Stream. This includes some significant flood events that were useful to this calibration exercise. The following events were chosen to undertake the calibration and validation runs.

The model was calibrated to the following events.

- 14th May 2015
- 6th December 2021

4.5.1. May 2015 Event

The gauged and simulated discharge for the May 2015 event is shown in Figure 17. The observed gauge data, represented by the black line, shows there is little baseflow at the gauge directly before the flow event the baseflow, sitting at around 200 L/s. This suggests that baseflow can be a minor flow component in some cases, and that most of the rain falling on the catchment during a storm event should appear in the gauge record during and shortly after the event (stormflow).

Simulated discharge at the Coastlands weir flow gauge was altered over 12 iterations by adjusting the hydrology, and hydraulic model characteristics. The simulated discharge, represented as the green line in Figure 17, matches the gauged discharge well for both peak and volume, without recourse to unusual or extreme parameter values.

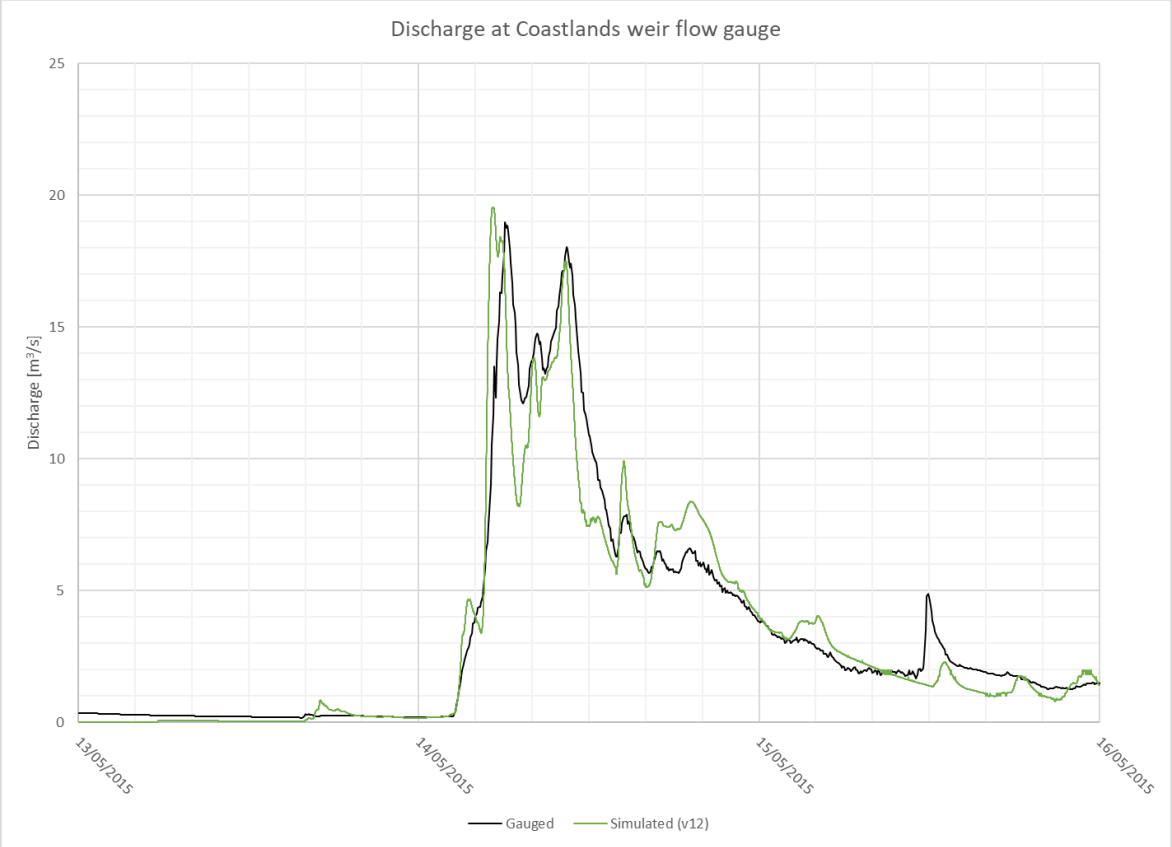


Figure 17. Calibrated simulation discharge versus gauged discharge May 2015

4.5.2. December 2021 Event

The gauged and simulated discharges for the December 2021 event are shown in Figure 18. As per the May 2015 calibration, the observed flows (black line) show there is little baseflow at the gauge directly before the flow event, this time sitting around 150 L/s.

Following refinement of model parameters, again over 12 iterations, the simulated discharge (green line) matches the gauged discharge well for both peak and volume. The model may be under-predicting the receding tail, which is likely an artefact of sediment accumulation and vegetation growth in the gauging structure, and the inability of the model to release water stored in the soil (through sub-catchment CN losses or 2D infiltration) back into the open channels. This water in the model is effectively lost from the system, but does not have a significant bearing on the overall flood estimation.

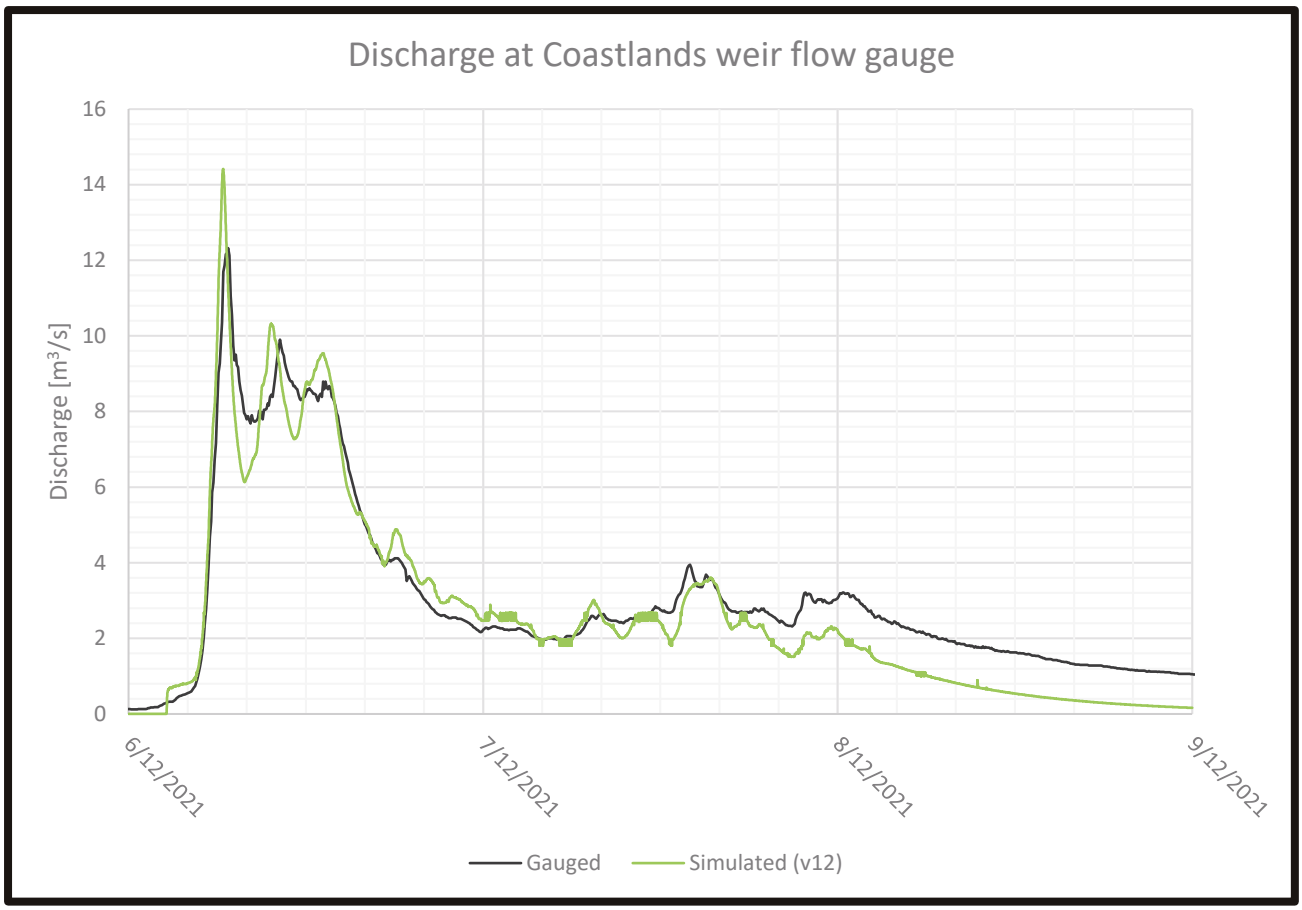


Figure 18. Calibrated simulation discharge versus gauged discharge December 2021

4.6. Validation

Three attempts were made to validate the calibrated model using the following storm events:

- 20th October 1998
- 17th June 2002
- 30th April 2008

4.6.1. October 1998 Event

The gauged and simulated discharge for the 1998 event is shown in Figure 19. The gauged flow data shown by the black line shows there is a baseflow of around 400L/s before the peak storm flow which reaches around 20 m^3/s. This confirms that baseflow can be ignored as most of the rain falling on the catchment during an event should appear in the gauge record during and shortly after the event (within a week).

Discharge at the Coastlands weir flow gauge has been simulated for the final calibration configuration and parameters. The validation event discharge for the twelfth iteration (v12) model is plotted with the gauged discharge as green and black lines respectively in Figure 19.

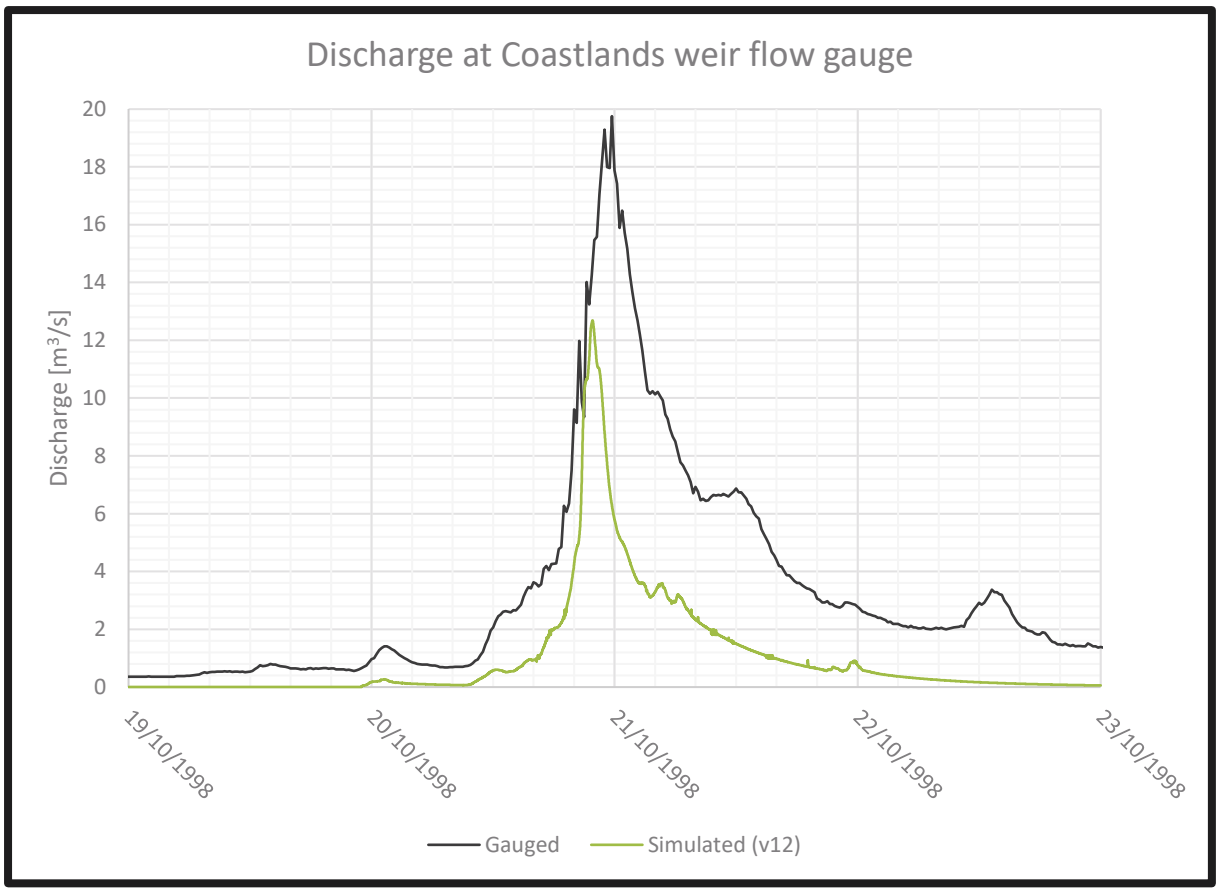


Figure 19. Calibrated simulation discharge versus gauged discharge October 1998

The simulated discharge under predicts both peak and volume for this event. The open channel aggraded by over 1m through Rimu Rd in this event. This aggradation would have been partly caused by the undersized culvert under Rimu Road with flood waters backing all the way up to the gauging station.

On this basis we cannot helpfully validate against this event with gauged flows not representing the actual flood peaks. Following these floods the Rimu Road armco culvert was quickly replaced with a bridge, and while there has been some aggradation through Coastlands in large events since, nothing like the 1998 event, when bed levels rose by over 1m, has been experienced again.

4.6.2. June 2002 Event

The gauged and simulated discharge for the June 2002 event is shown in Figure 20. The black line shows that observed baseflow before the storm event is around 150L/s, again confirming that baseflow can be ignored when modelling catchment flood response.

The validation event discharge for the twelfth iteration (v12) model that contains the final calibration configuration and parameters is plotted as the green line in Figure 20. The gauged discharge as represented by the black line.

Given the catchment has been calibrated for larger events, it is expected that for smaller storms like the June 2002 event, there would be an overestimation of peak flows in the model. This is due to reduced antecedent conditions in the catchment with more extreme rainfall events. As seen in Figure 20, the

simulated discharge over-predicts the peak flow for this event. Hence we can be satisfied with these validation results.

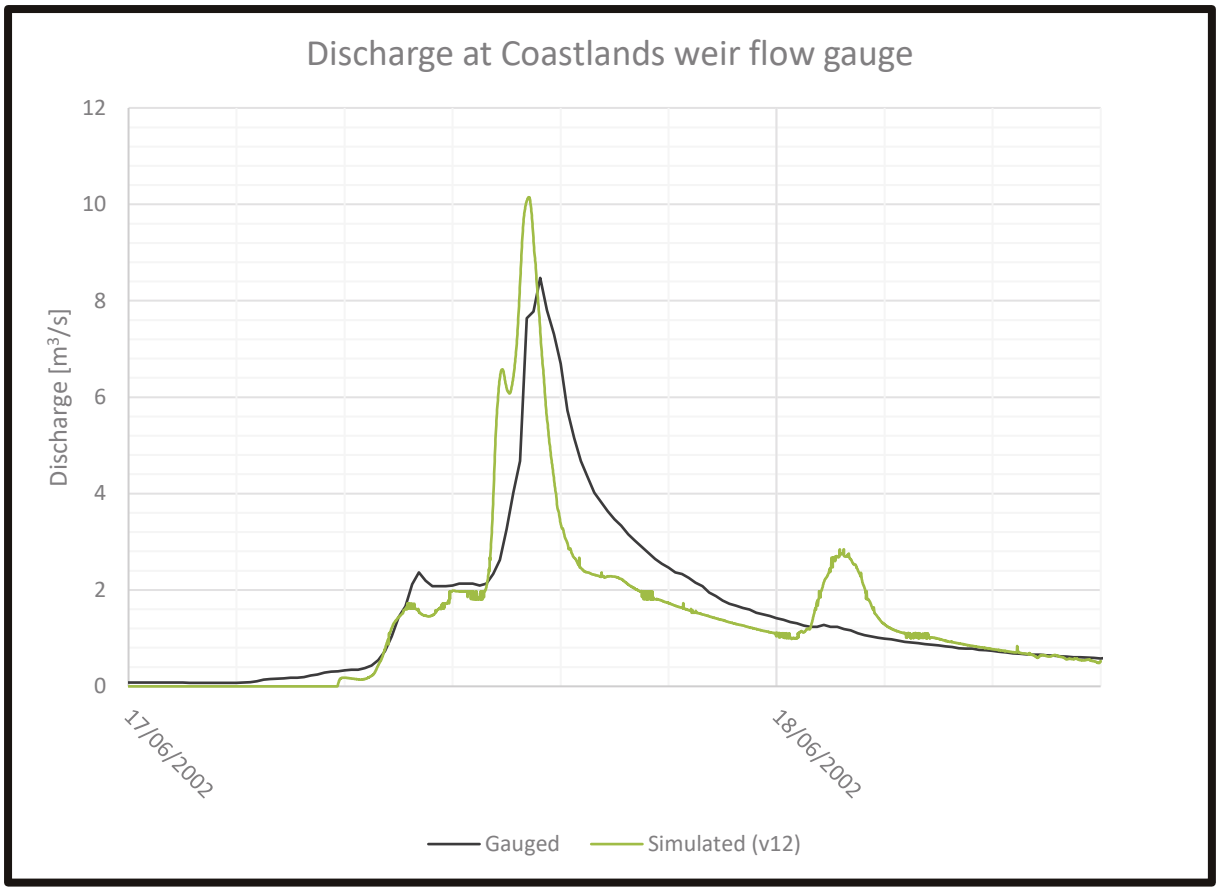


Figure 20. Calibrated simulation discharge versus gauged Discharge June 2002.

4.6.3. April 2008 Event

The gauged and simulated discharge for the April 2008 event is shown in Figure 21. The black line shows that observed baseflow before the storm event is around 100L/s. The validation event discharge based on the twelfth iteration (v12) model is shown in green.

Again the simulated discharge over-predicts the peak and volume for this event. This would be expected as our calibration is for much larger events in which we would expect higher moisture and more saturated soils, resulting in larger overland flow. The simulation is therefore considered a reasonable validation of the calibrated model.

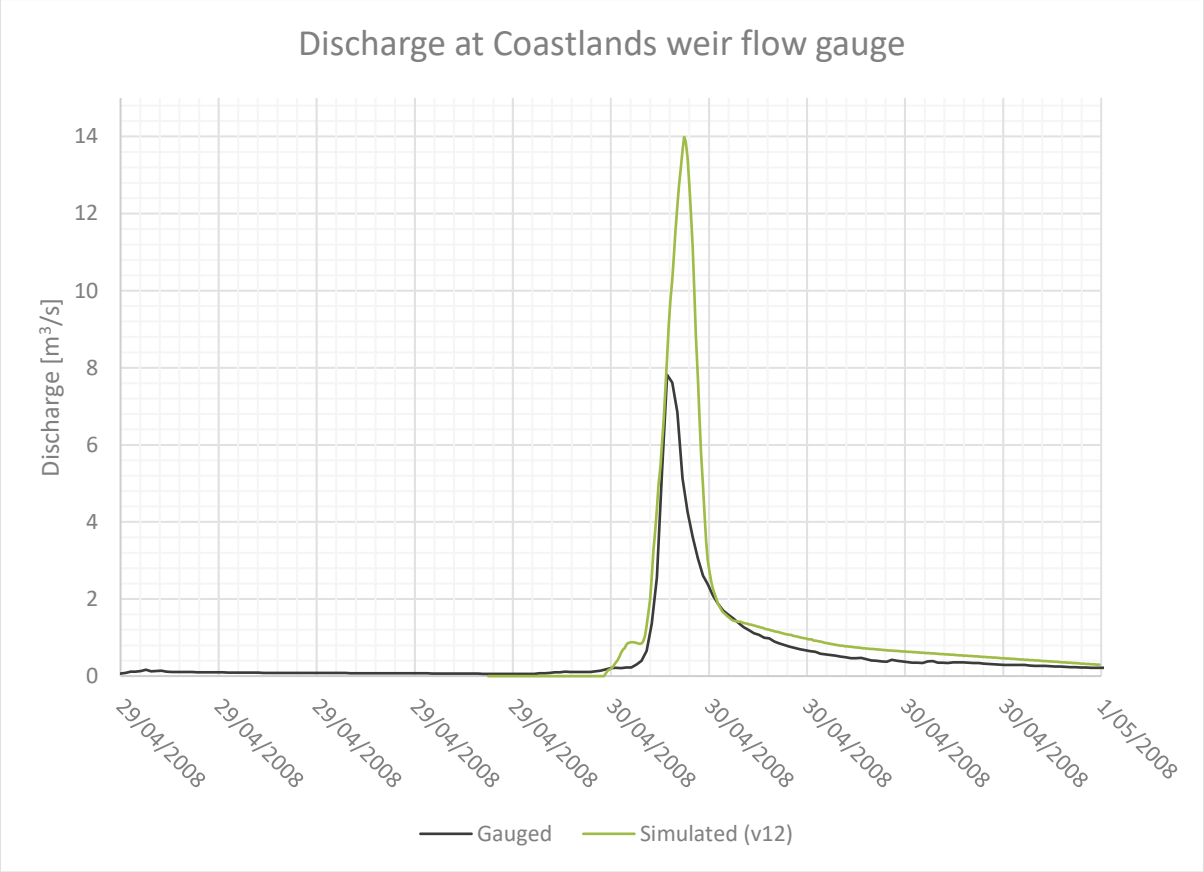


Figure 21. Calibrated Simulation Discharge versus Gauged Discharge April 2008

5. Model Summary

5.1. Results Comparison

While the legacy MIKE FLOOD Wharemauku Catchment model (2014) followed a different model build methodology to the recent TUFLOW modelling, it is worth undertaking a high-level comparison of the modelling results. The two models should be the same order of magnitude when comparing the 2115 100-YR ARI rainfall event (MIKEFLOOD) to the 2130 100-YR ARI rainfall event (TUFLOW).

The peak water level comparison at various locations is shown in Figure 22 - Figure 27. It is worth noting the MIKEFLOOD model does not represent flooding in the 1D channels in these figures.

There is general agreement in peak flood levels between the two models over a majority of the catchment. The TUFLOW model (rain-on-grid) shows ponding within isolated depressions in the bathymetry. These are not captured in the MIKE FLOOD model as the sub-catchment hydrology has been loaded directly to the network or open channels with only larger isolated catchments loaded into the bathymetry surface.

It is likely the ponding within isolated depressions, along with infiltration grid, is mitigating the increased rainfall intensity associated with the (TUFLOW 2130) compared to (MIKE FLOOD 2115).

There are two main areas of difference in flood levels located in the upper catchment.

The M2PP expressway and associated stormwater network and storage areas have changed the ponding around the expressway, especially in the areas identified as A and B where the filling of the expressway has displaced the storage on the floodplain. This has been represented in the TUFLOW model. In the upper Wharemauku catchment around Valley Road, the MIKE FLOOD sub-catchment hydrographs were released into the model in the areas identified as A and B. In the TUFLOW model the rain-on-grid methodology is applied to the valley floor, the sub-catchment discharges are released around the valley showing the extent of flows within the valley floor. This is shown in Figure 28 and Figure 29.

Having reviewed the results, our conclusion is that the differences between the MIKE FLOOD and TUFLOW models are a result of the increased detail in the new TUFLOW model. This includes the rain-on-grid methodology, along with a significant improvement in the quality of the network data. Flood storage is more widely distributed in the TUFLOW model and there is a significantly greater level of connectivity in the local networks. This has improved the quality of understanding of local flooding. The 100YR-ARI 2130 peak depth results are shown in Appendix B.

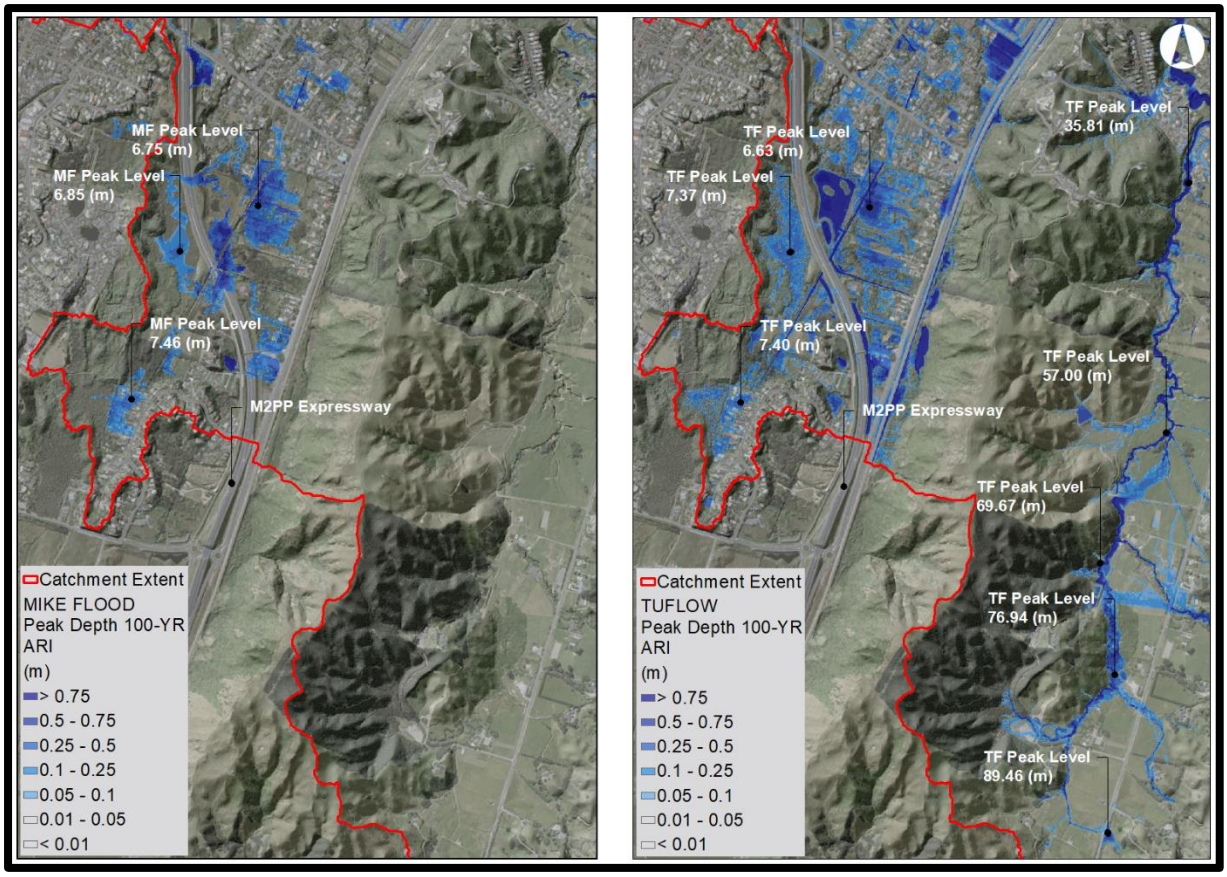


Figure 22. Wharemauku sheet 1 – peak water level results compare MIKE FLOOD verses TUFLOW.

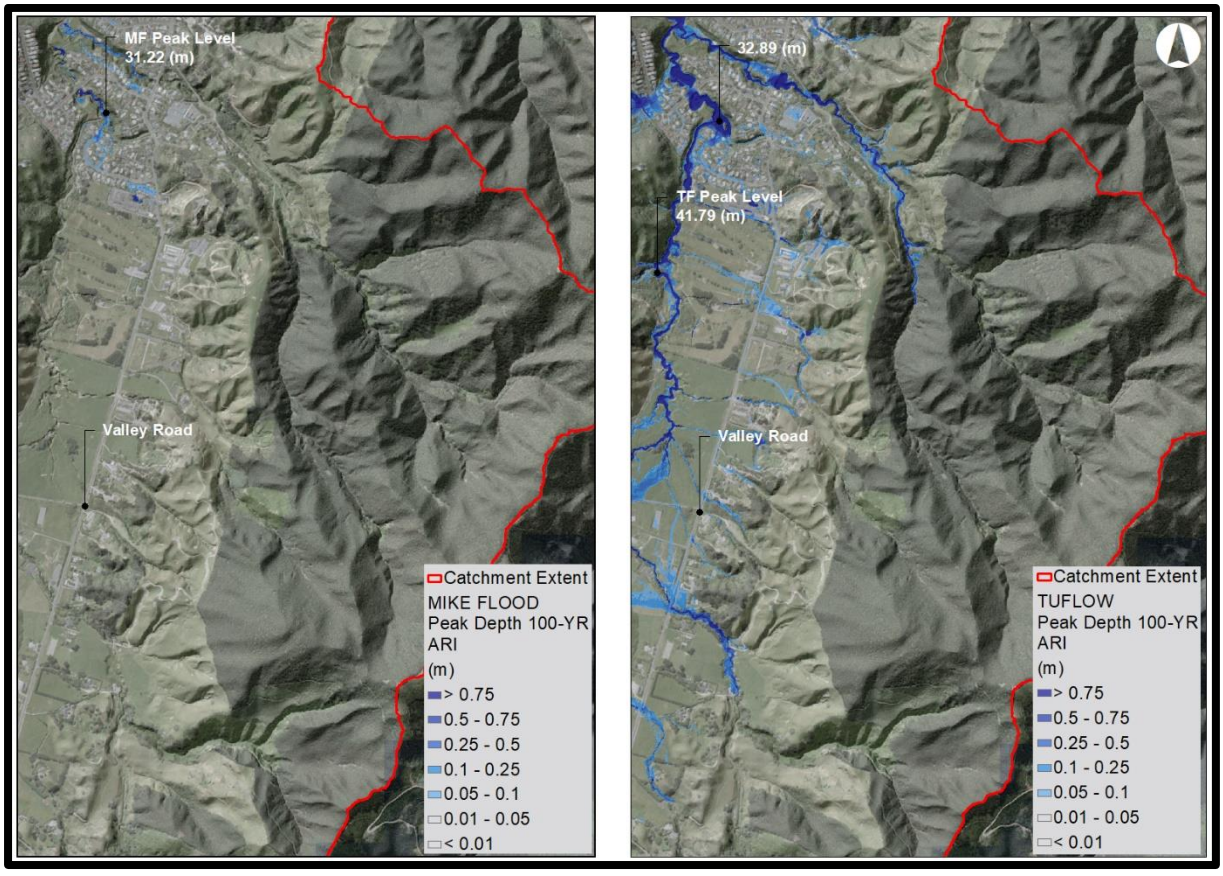


Figure 23. Wharemauku sheet 2 – peak water level results compare MIKE FLOOD verses TUFLOW.

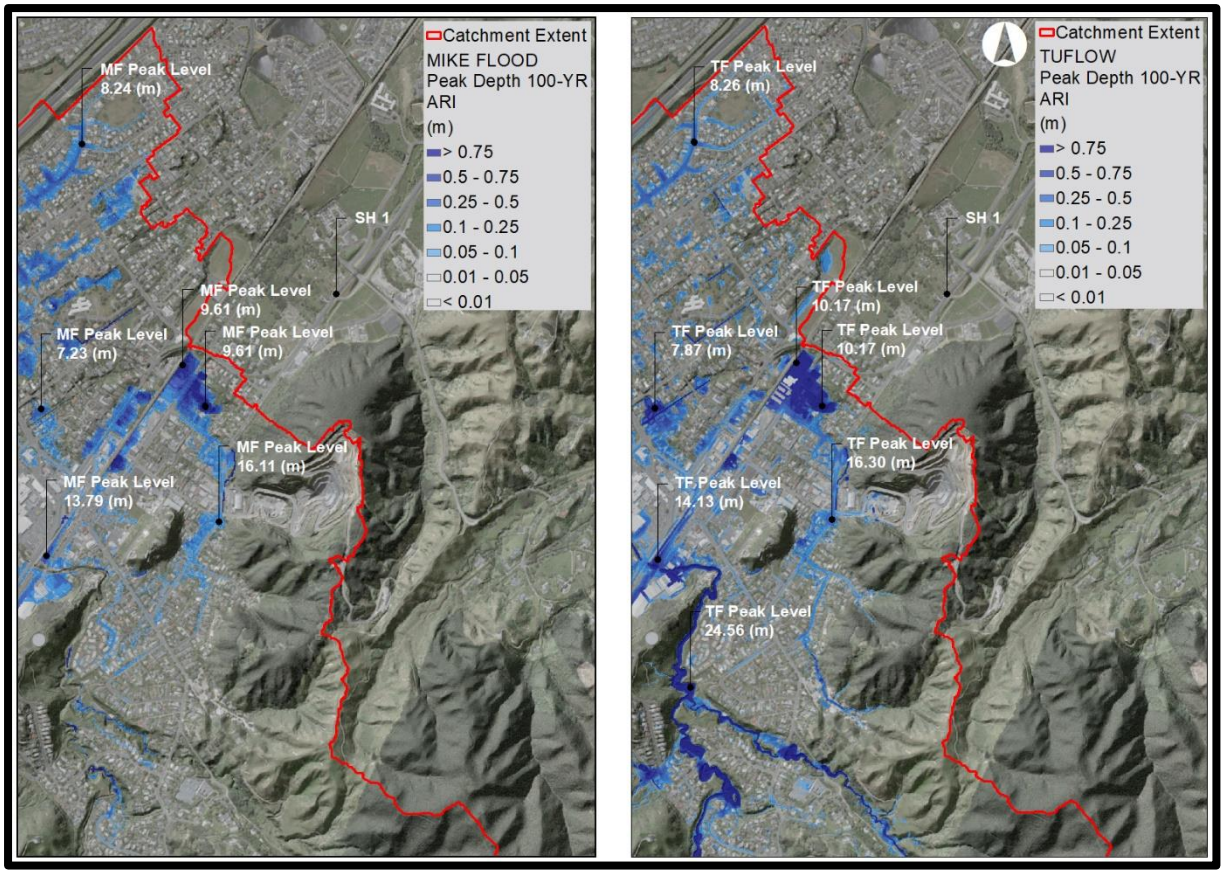


Figure 24. Wharemauku sheet 3 – peak water level results compare MIKE FLOOD verses TUFLOW.

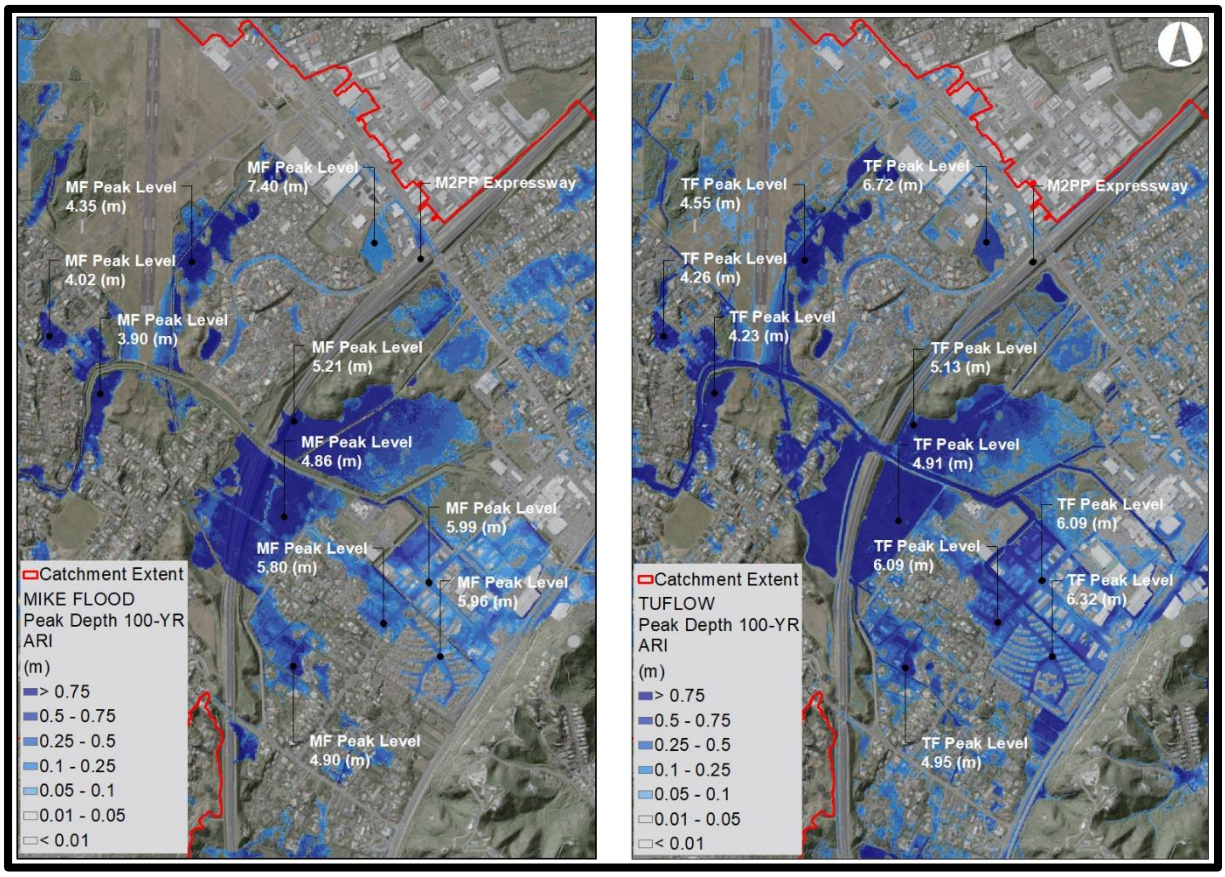


Figure 25. Wharemauku sheet 4 – peak water level results compare MIKE FLOOD verses TUFLOW.

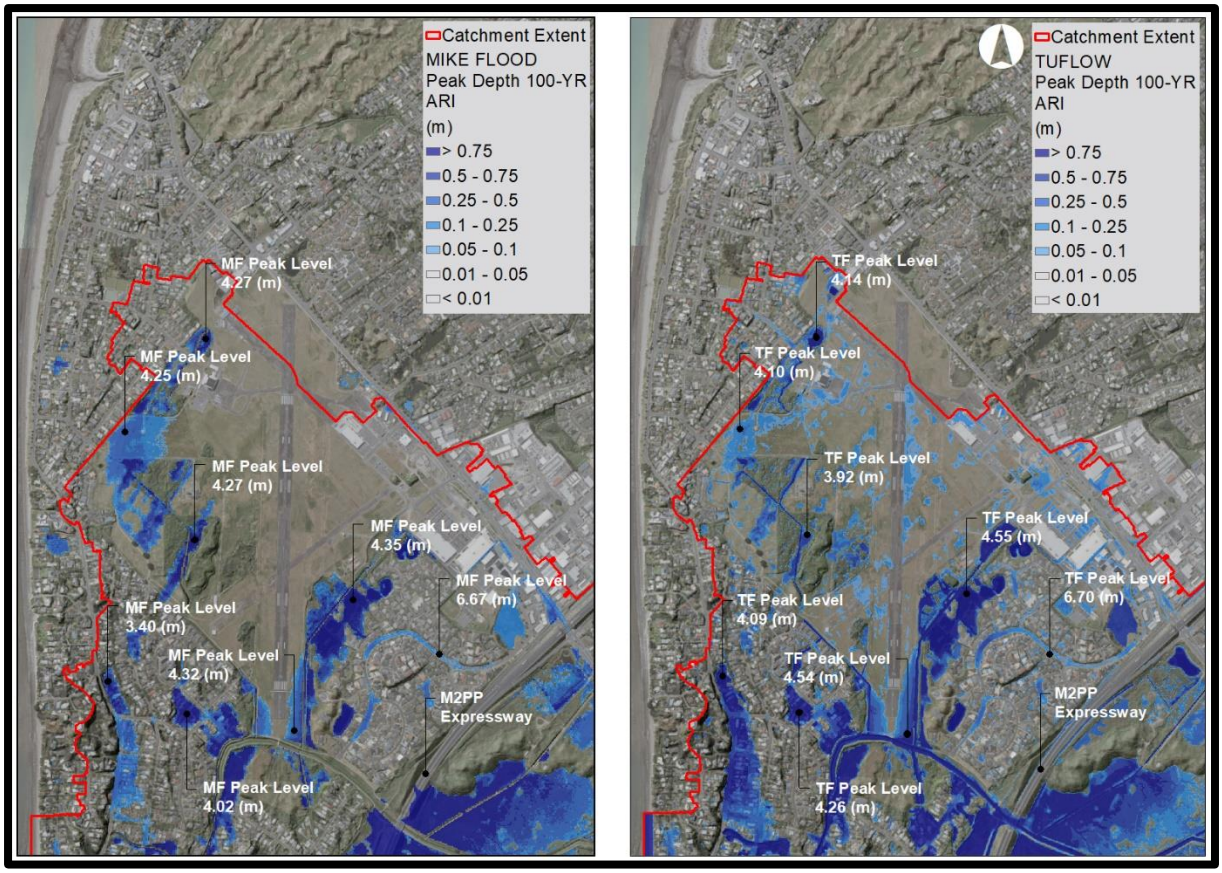


Figure 26. Wharemauku sheet 5 – peak water level results compare MIKE FLOOD verses TUFLOW.

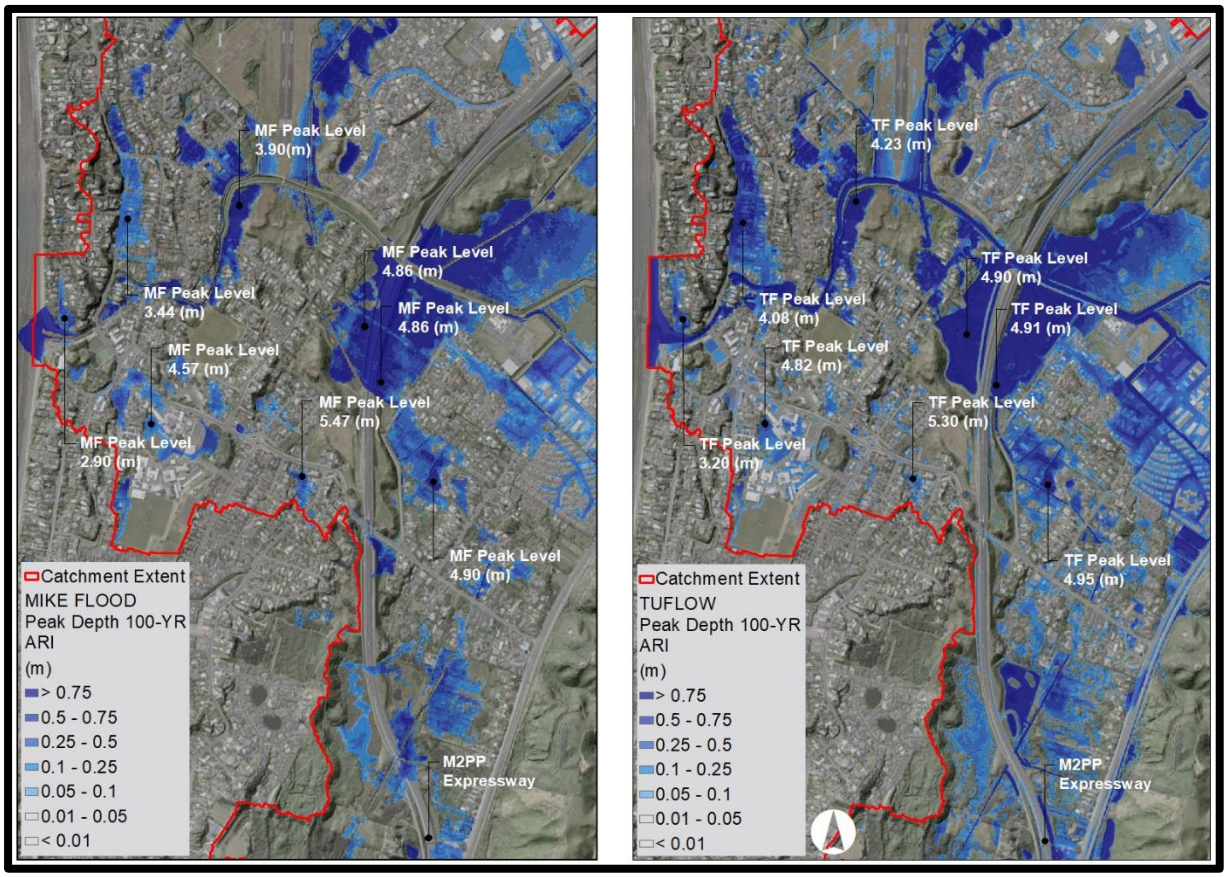


Figure 27. Wharemauku sheet 6 – peak water level results compare MIKE FLOOD verses TUFLOW.

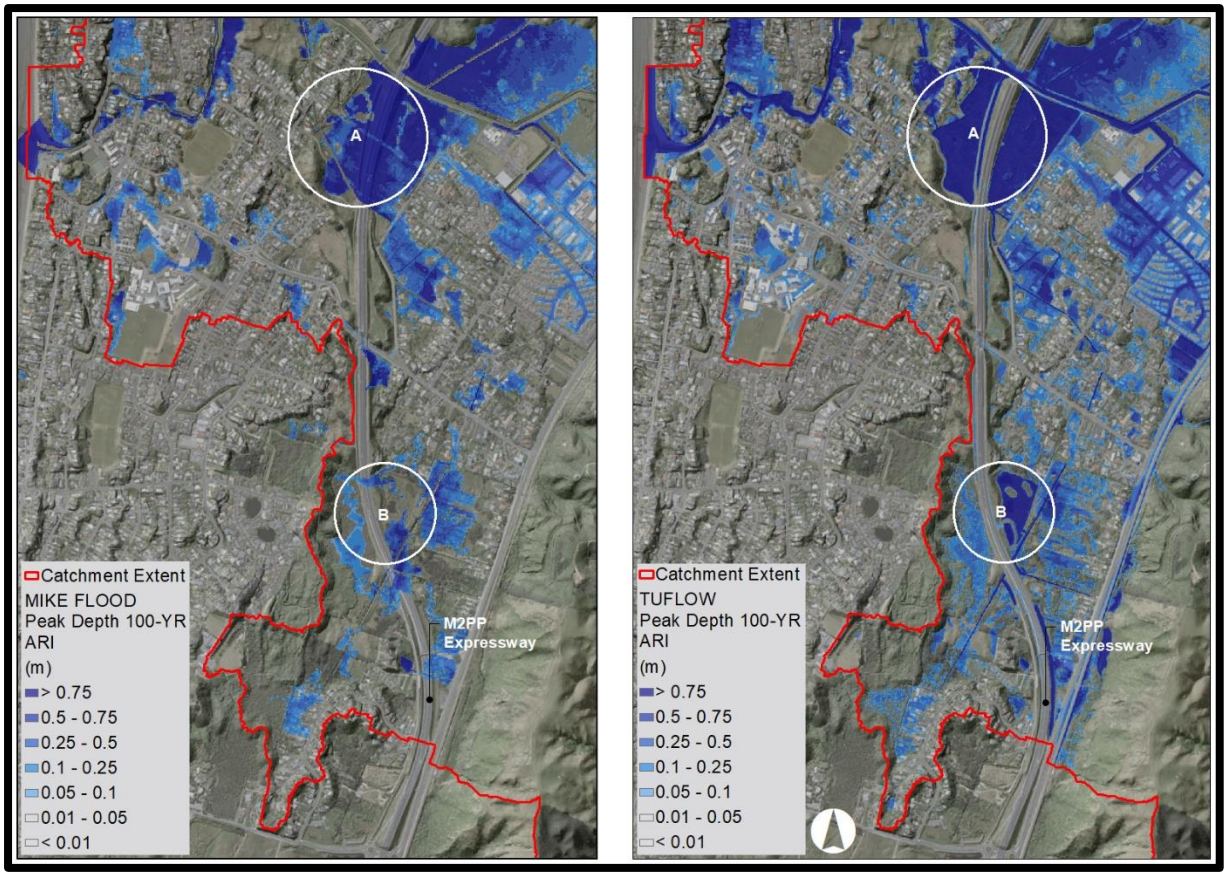


Figure 28. Difference in ponding as a result of modelling methodology (MIKE FLOOD verses TUFLOW).

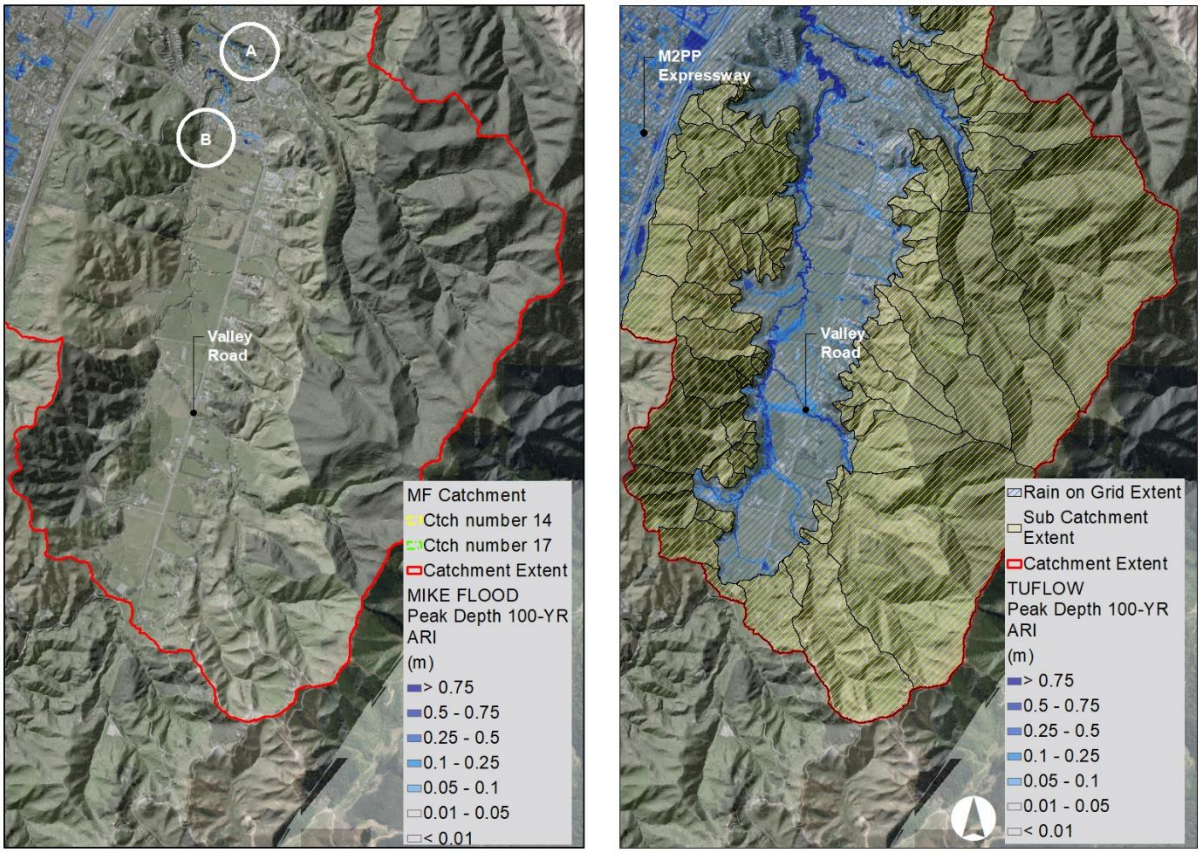


Figure 29 Difference in ponding as a result of modelling methodology (MIKE FLOOD verses TUFLOW).

6. Wider Model Validation

6.1. Introduction

To ensure confidence in the Wharemauku hydraulic model build, a process of validation has been undertaken against two historic rainfall events with comparisons made between modelled predictions and actual observations of the event in the field.

This calibration process allows for the hydrologic parameters in the model to be revised to better reflect local conditions. It also provides a check on the construction of the model as it can highlight areas where flooding may have been recorded where it is not represented by the model and vice versa.

6.2. Flood Events

The Wharemauku model has been validated against two significant historic rainfall events.

- May 2015
- December 2021

The basis for the validation has come from several sources including.

- KCDC flood incidence database
- Observations
- Public reports
- Field observations

To understand the nature of these two rainfall events, historic rainfall and ground water data was collated and analysed. Three rainfall gauges were analysed, Paraparaumu Aero, Te Horo, and Waikanae Water Treatment Plant (Figure 31). This rainfall gauge data was sourced from Cliflo and captured ~80 years of rainfall data, as shown in Table 16.

Table 16. Gauging station period

GAUGE STATION	PERIOD OF DATA COLLECTED
Paraparaumu Aero EWS (E04995)	1996 - 2023
Te Horo Wetland at Shoveler Lagoon	2009 - 2023
Waikanae Treatment Plant	1995 - 2023

6.2.1. May 2015

On 14-15 May 2015 there was a significant rainfall event which affected much of Kāpiti Coast. This was a high intensity event with 6-, 12-, and 24-hour peak rainfall depths all more than the 100-year ARI at the Paraparaumu Aerodrome, as shown in Table 17.

Table 17. May 2015 peak rainfall, return period at Paraparaumu EWS (E04995).

TIME (HRS)	PEAK RAINFALL (MM)	RETURN PERIOD (ARI)[4]
1	31 (0430 14/5 – 0530 14/5)	20
2	42 (0405 14/5 – 0605 14/5)	20
6	91 (0405 14/5 – 1005 14/5)	100+
12	120 (0220 14/5 – 1420 14/5)	100+
24	153 (0220 14/5 – 0220 15/5)	100+
48	163 (2320 13/5 – 2320 15/5)	60-80
72	182 (2200 11/5 – 2200 14/5)	80

The rainfall depths at the three key gauging sites are shown in Figure 30. The storm lasted approximately 28 hours and had a total depth of 91mm (Te Hapua) to 157mm (Paraparaumu Airport). The location of the three rain gauges is shown in Figure 31.

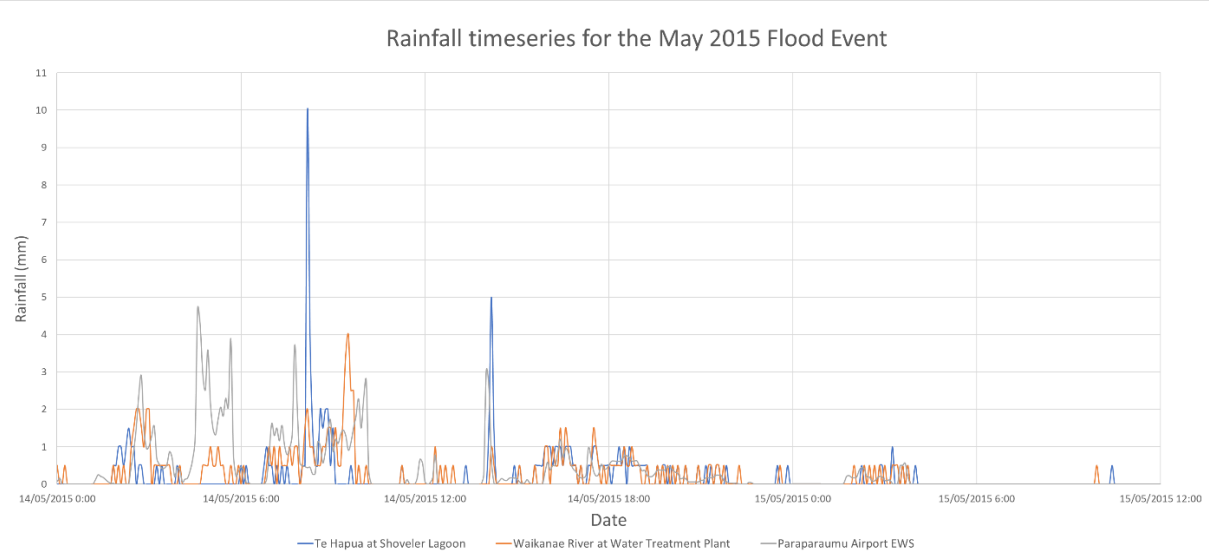


Figure 30. Rainfall depths at three gauging stations.

[4] Return period (ARI) are based on NIWA HIRDS V4.

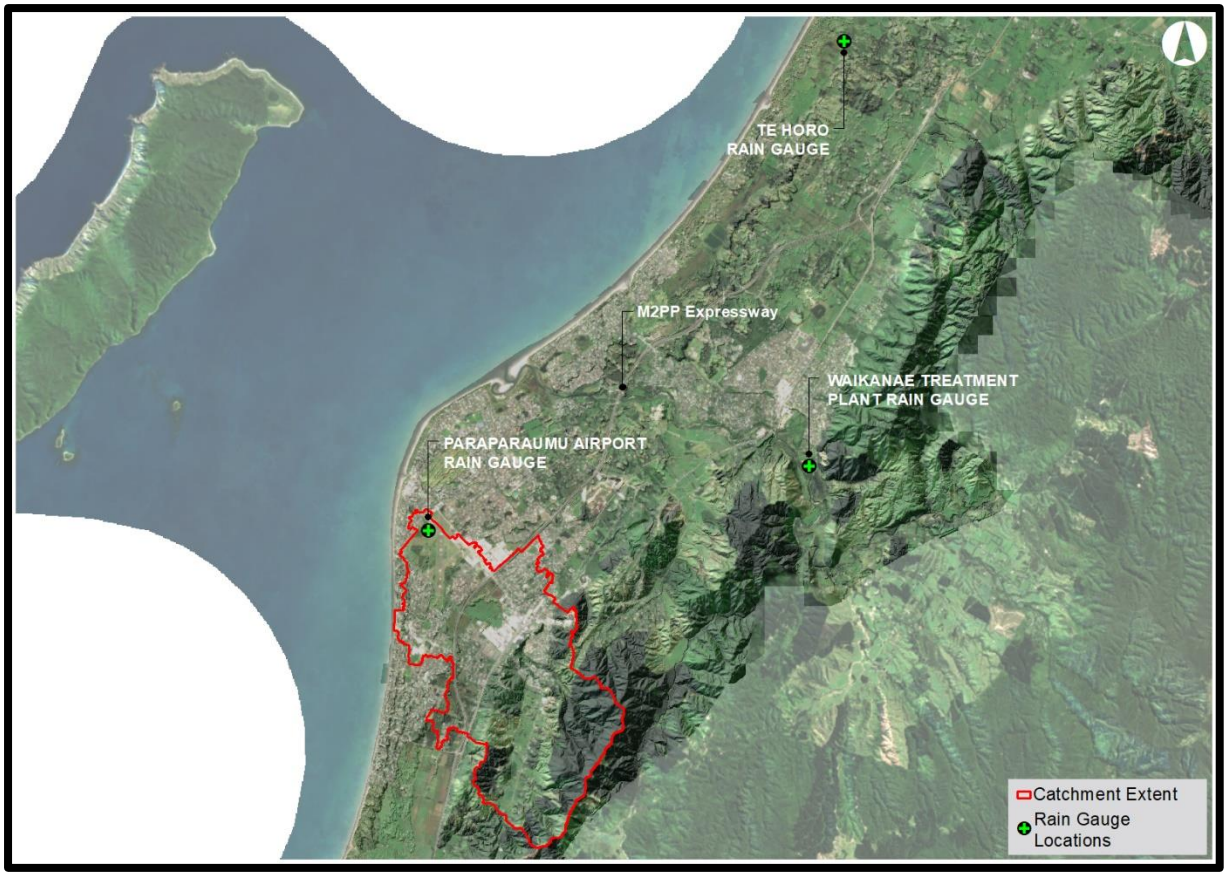


Figure 31. Rain gauge locations.

This rainfall event was significant enough to generate several flooding complaints to Kāpiti Coast District Council, these are spatially recorded in the incidence database as shown in Figure 32. The records for this event are descriptive in nature, "*flooding entering garage at number 27*", and largely do not include photographic evidence showing flood depth and extent.

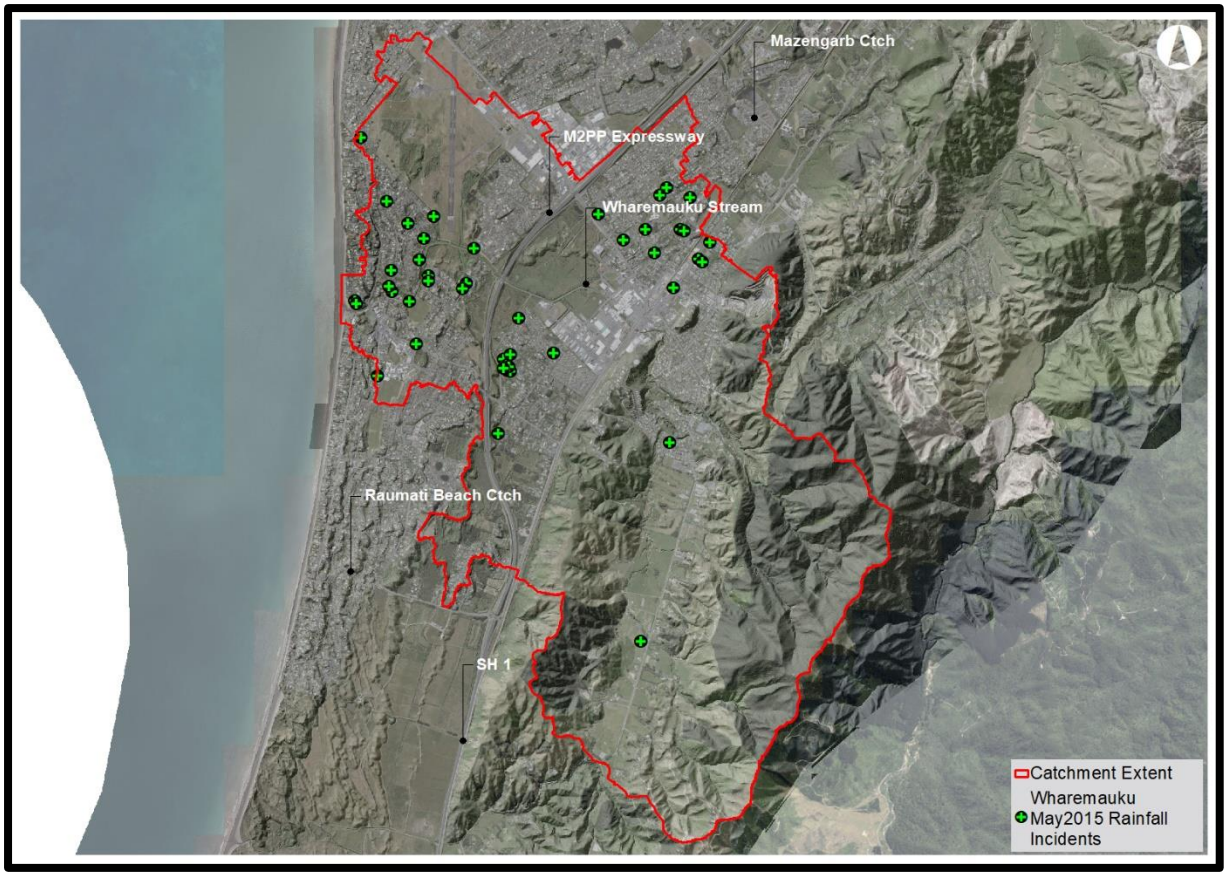


Figure 32. May 2015 Council complaints database locations.

6.2.2. December 2021

On the 5th-8th of December 2021 there was a significant rainfall event which affected much of Kāpiti Coast. This was a moderate intensity event, with very high volume over the longer time periods with 6hr-, 12-, 24-, 48-, and 72-hour peak rainfall depths in the order of 20-40 year ARI at the Paraparaumu Aerodrome as shown in Table 18. This rain fell after a long period of wet weather which meant catchments had high antecedent conditions (which for much of Kāpiti responds to high groundwater levels).

Table 18. Dec 2021 Peak rainfall, return period at Paraparaumu EWS (E04995).

TIME (HR)	PEAK RAINFALL (MM)	RETURN PERIOD (ARI)
1	18 (0500 6/12 – 0600 6/12)	2-5
2	29 (0425 6/12 – 0625 6/12)	5
6	63 (0410 6/12 – 1010 6/12)	10-20
12	96 (0155 6/12 – 1355 6/12)	30
24	111 (0100 6/12 – 0100 7/12)	20
48	144 (2100 5/12 – 2100 7/12)	30
72	148 (1755 5/12 – 1755 8/12)	20

The rainfall depths at the three key gauging sites are shown in Figure 33. The storm lasted approximately 52 hours and had a total depth of 143mm (Paraparaumu EWS) to 168mm (Waikanae River at Water Treatment Plant) depending on rain gauge location.

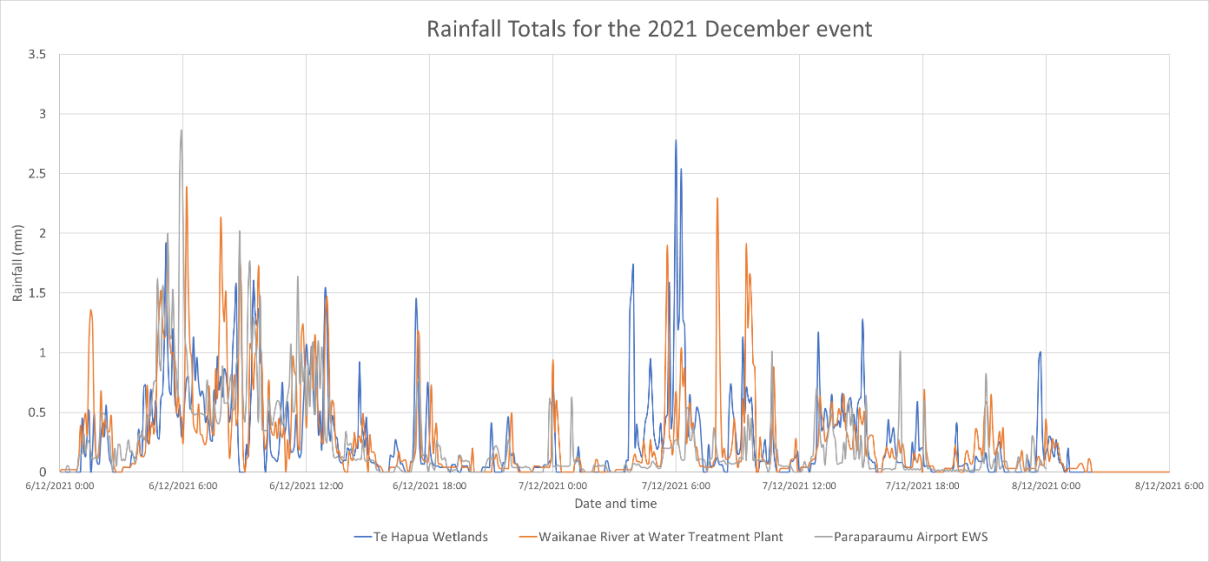


Figure 33. Rainfall depths at three gauging stations.

While not as significant as the 2015 event, the 2021 event was significant enough to generate several flooding complaints to the Council which are spatially recorded in the incidence database as shown in Figure 34.

There was also work undertaken by council consultants to gather time stamped photographic evidence for model validation/calibration. While the evidence collected was not exhaustive, nor was it collected at the peak of the storm, it does provide a sound basis for validation of the model.

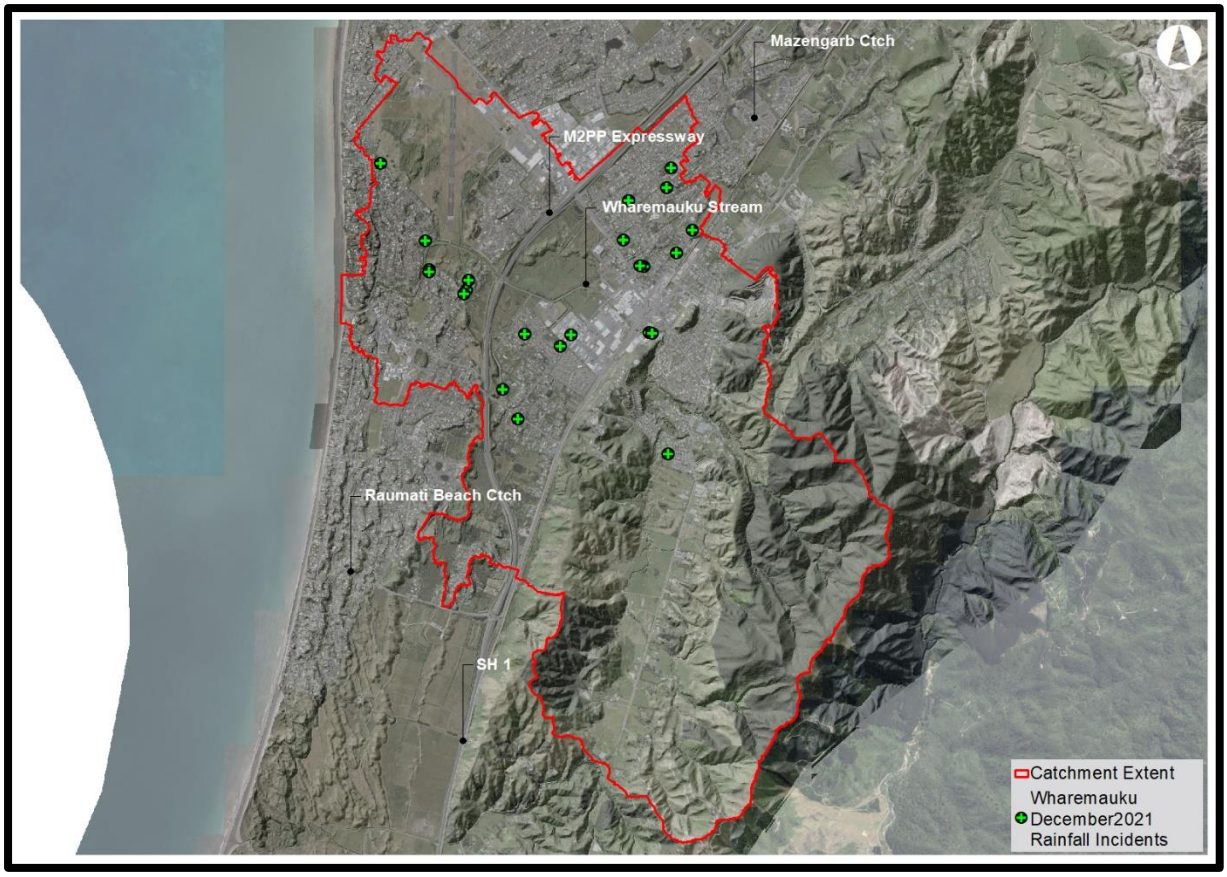


Figure 34. December 2021 Council complaints database locations.

For each recorded complaint there is varying levels of information recorded in the incident database system. An example of an affected property showing caller description and modelled peak flood depth for the 2015 rainfall event is shown in Figure 35 - Figure 37.

An example of an affected property showing caller description, modelled peak flood depth and photographic evidence of flooding for the 2021 rainfall event is shown in Figure 38 - Figure 41.

As part of the model validation, each of the complaints has been investigated to ensure the flooding can be explained and replicated by the model.

REPORTED FLOOD INCIDENT (MAY 2015 EVENT)	
Affected properties	30A, 30B, 30C, 30E, 30F, 40A, and 46 Rata Road
Caller description	Stream going past house on left hand side has risen very quickly and feeder drains are not able to keep up. Sections are flooded up to a foot in parts. There is another creek that is up as well. In 11 years never experienced anything like this previous. Flooding on properties which are all down long driveways off Rata Road. The flooding is due to very overgrown open stormwater drain (near the old timber yard). This is causing the flooding on these properties. This open drain needs clearing.
Description of modelled flooding	The open channel along the back of 40C Rata Road is flooding the nearby properties.
MODEL RESULT	

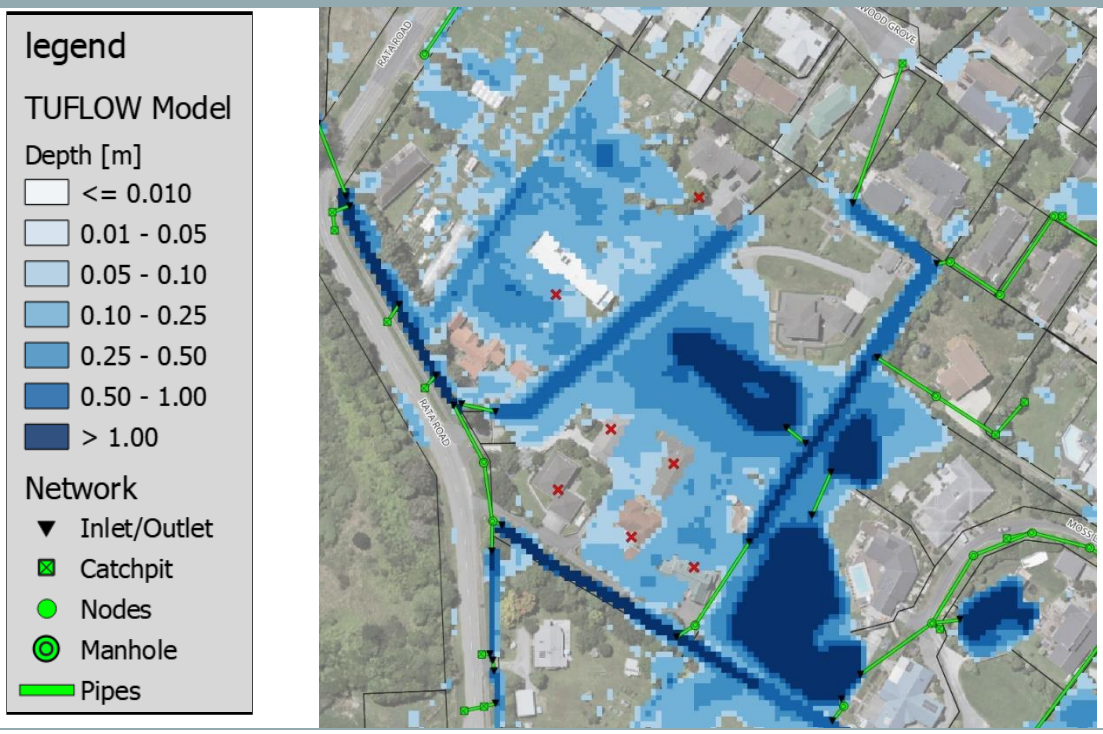


Figure 35. Wharemauku model results.

REPORTED FLOOD INCIDENT (MAY 2015 EVENT)	
Affected properties	7 Warrimoo Street
Caller description	Adam has requested some sandbags as the flooding is getting quite bad. He is going to call the fire service for some pumps as well.
Description of modelled flooding	Flooding ponding at the rear of the property as it's a low point.
MODEL RESULT	

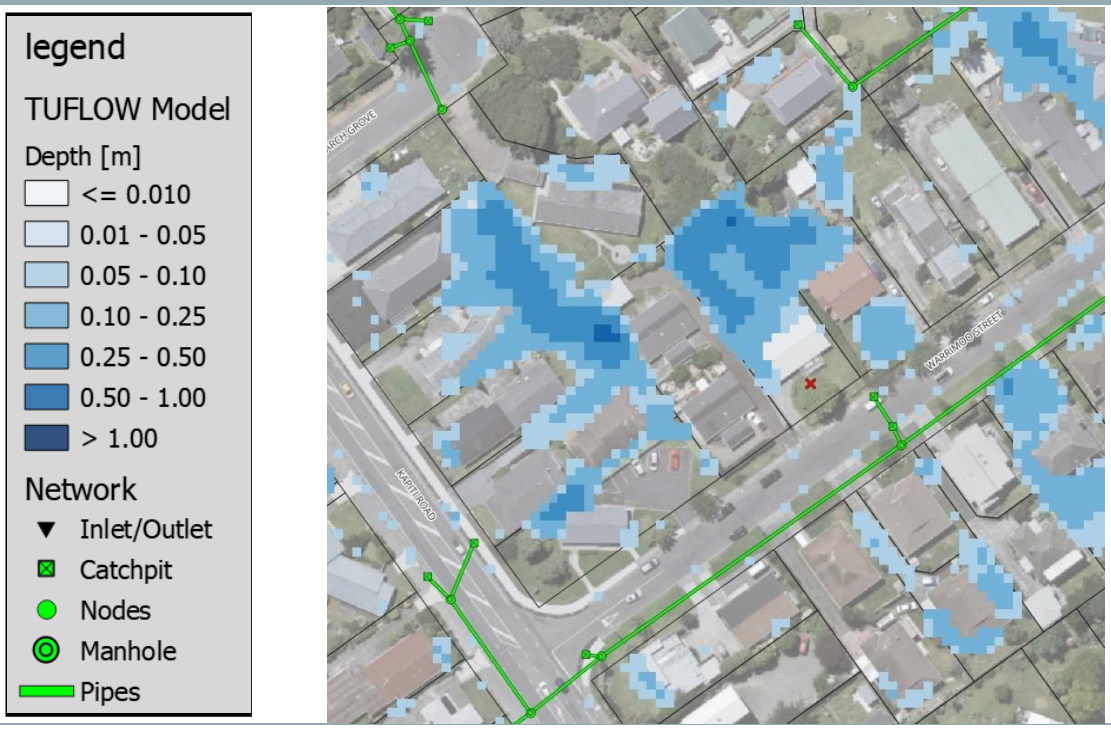


Figure 36. Wharemauku model results.

REPORTED FLOOD INCIDENT (MAY 2015 EVENT)	
Affected properties	29 Raumati Road
Caller description	Sandbags for this address please. Thanks.
Description of modelled flooding	Flooding ponding at the rear of the property as it's a low point.
MODEL RESULT	

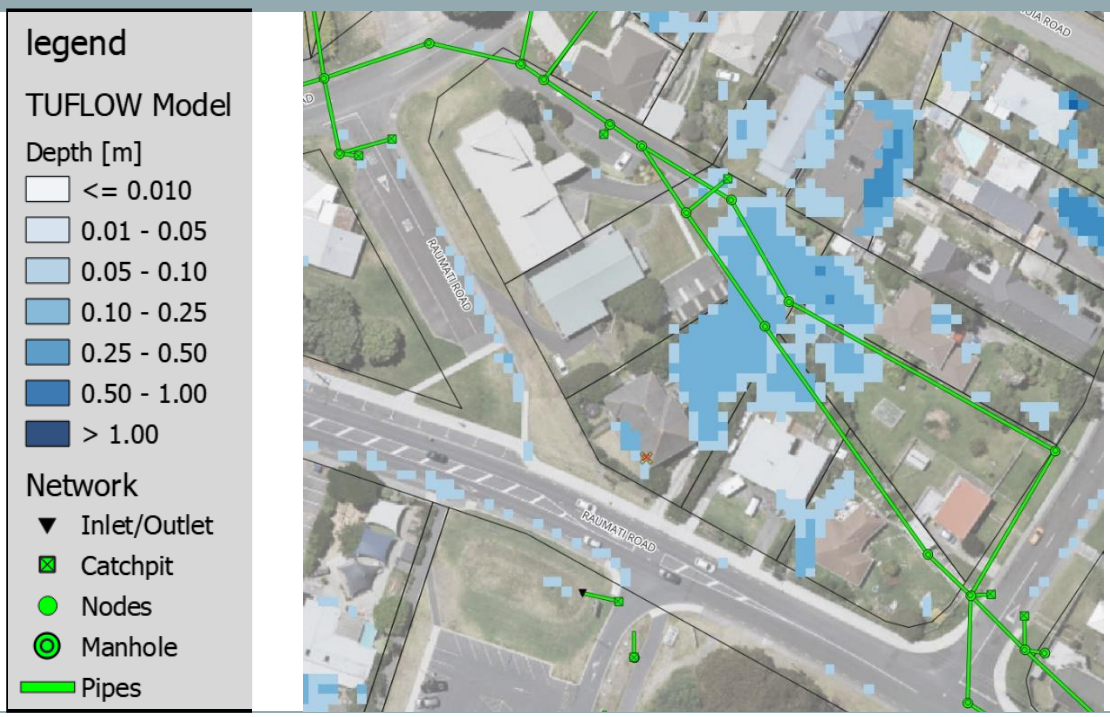
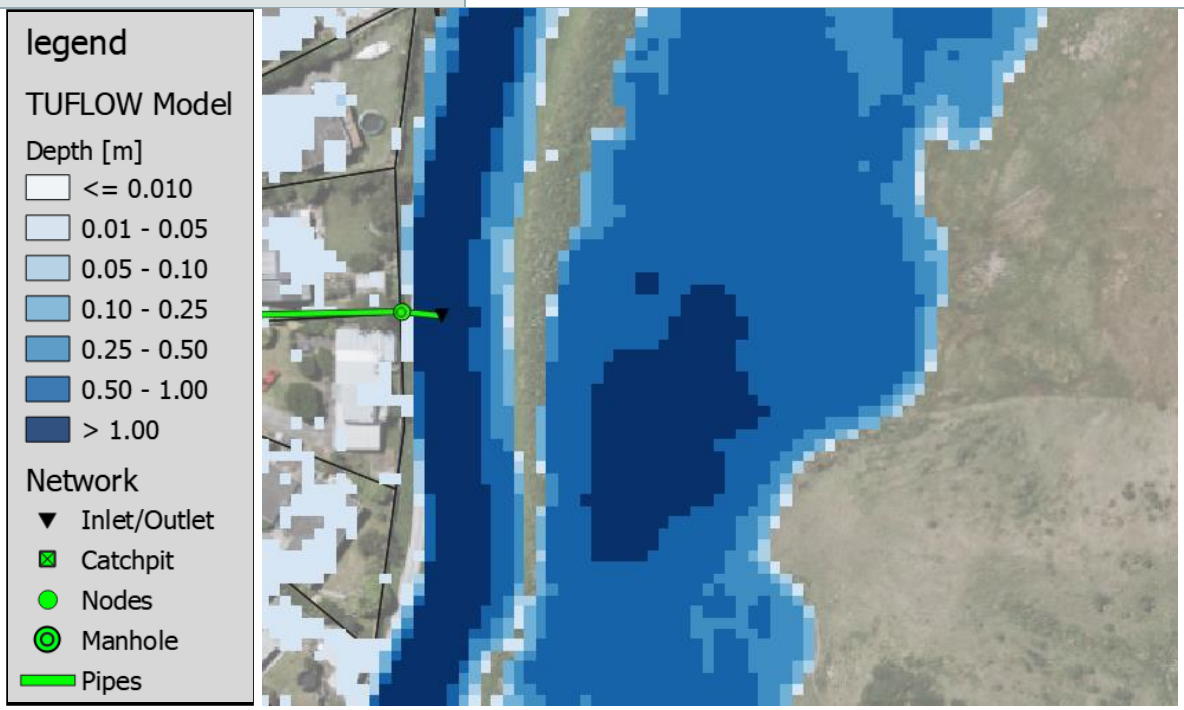


Figure 37. Wharemauku model results.

REPORTED FLOODING REPRODUCED IN THE MODEL (DEC 2021 EVENT)	
Affected properties	19 and 21 Moa Road
Description of modelled flooding	Sections flooding from Wharemauku Stream.

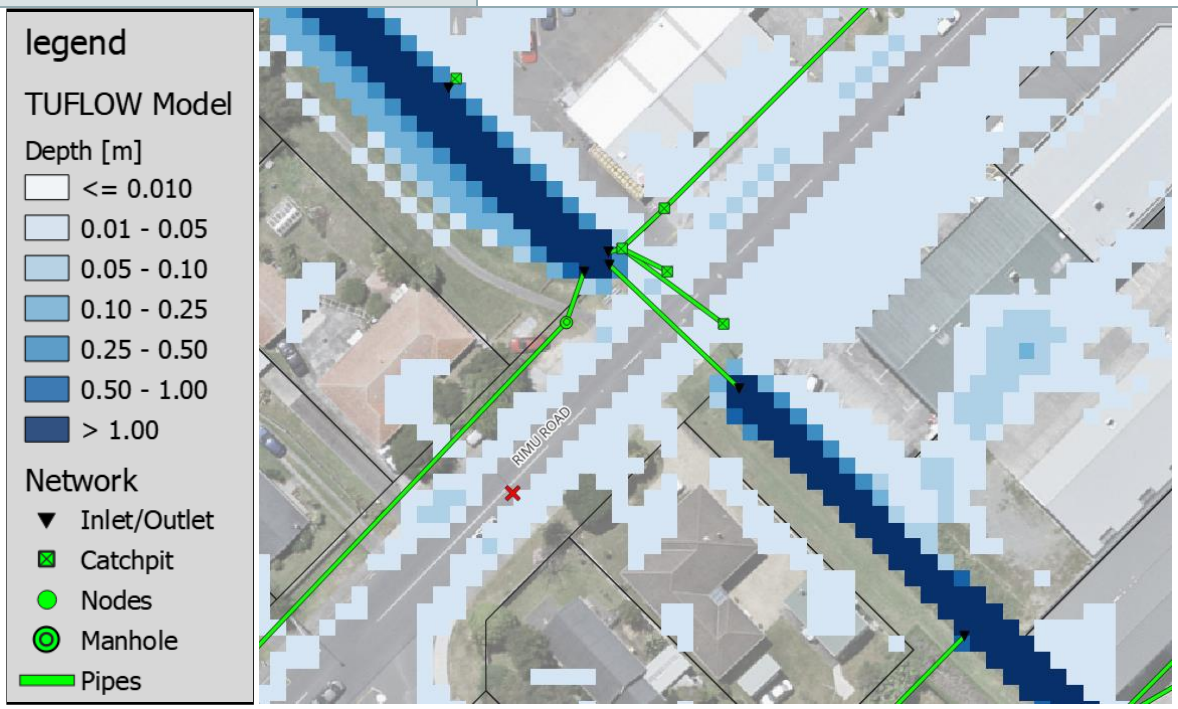


PHOTOGRAPHIC EVIDENCE (DEC 2021 EVENT)



Figure 38. Wharemauku Stream flooding – Moa Road

REPORTED FLOODING REPRODUCED IN THE MODEL (DEC 2021 EVENT)	
Affected properties	101 Rimu Road
Description of modelled flooding	Street Flooding.

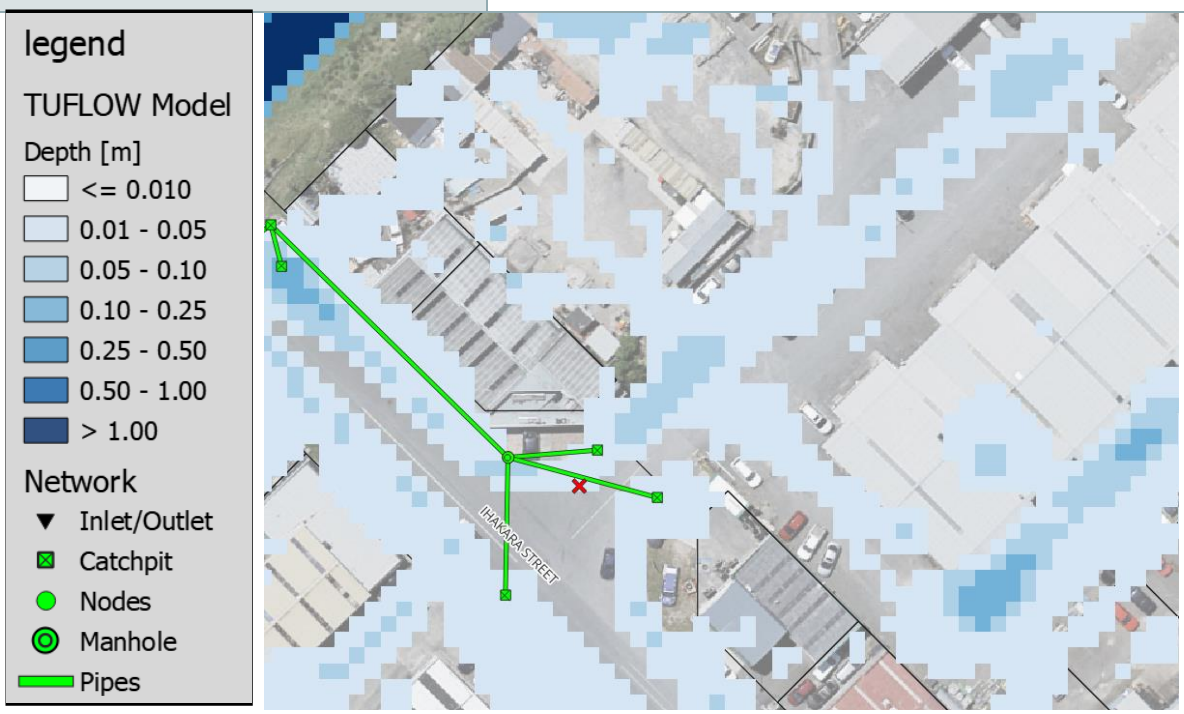


PHOTOGRAPHIC EVIDENCE (DEC 2021 EVENT)



Figure 39. Wharemauku Stream flooding – Rimu Road

REPORTED FLOODING REPRODUCED IN THE MODEL (DEC 2021 EVENT)	
Affected properties	Ihakara Street
Description of modelled flooding	Street Flooding.

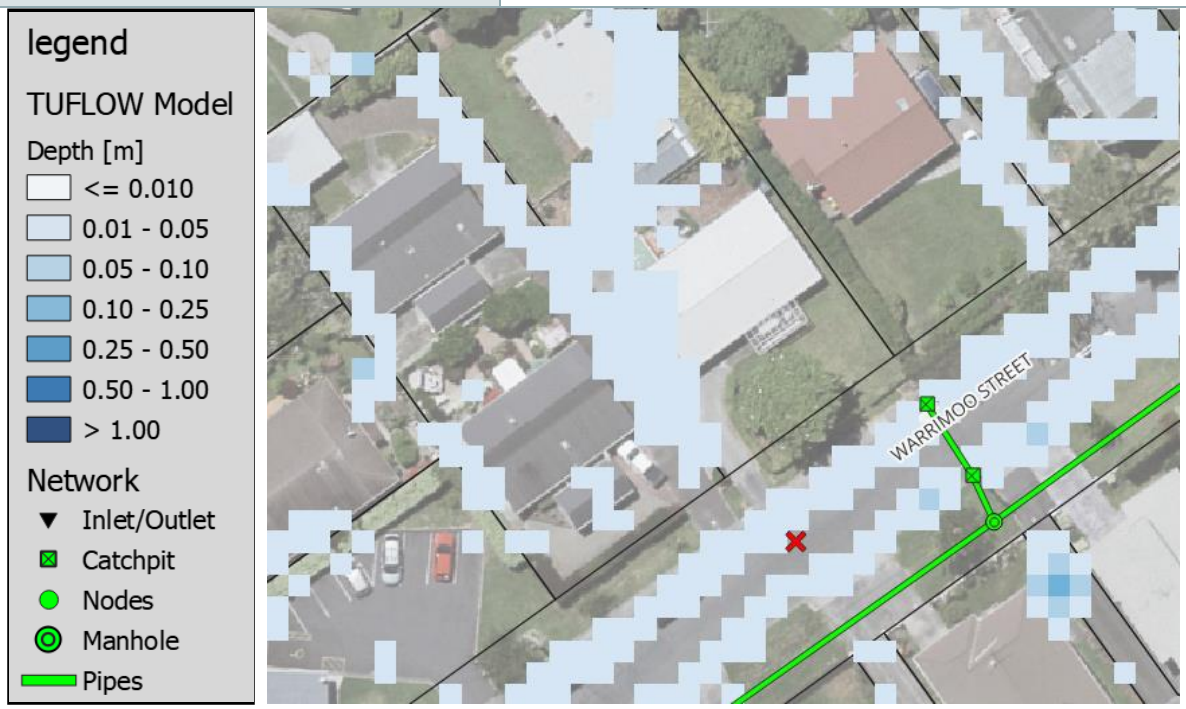


PHOTOGRAPHIC EVIDENCE (DEC 2021 EVENT)



Figure 40. Ihakara Street Flooding

REPORTED FLOODING REPRODUCED IN THE MODEL (DEC 2021 EVENT)	
Affected properties	7 Warrimoo Street
Description of modelled flooding	Section Flooding.



PHOTOGRAPHIC EVIDENCE (DEC 2021 EVENT)

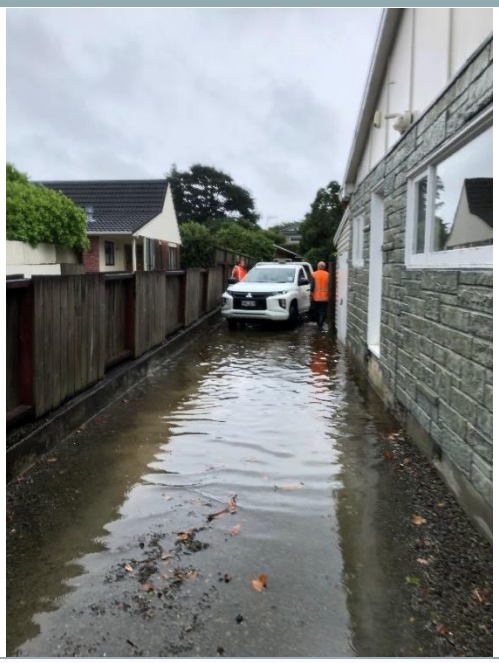


Figure 41. Warrimoo Street Flooding

6.3. Validation

Calibration, validation, and verification are detailed in (Section 2) of the Flood Hazard Methodology report.

The Wharemauku model has been validated using available historic data, including the discharge gauge at the coastland's weir, and achieved a good validation.

Validation of the Wharemauku catchment is based on recorded historic flood complaints. Council holds flood complaints going back to 2015, however these are largely not matched to photographic evidence. For the December 2021 flood event photographic evidence was collected and this provided additional context for model validation.

Validation is an iterative process for the Wharemauku hill sub catchments. The 2D part of the catchment validated well the first time, aligning with model results and recorded flooding. This validation process was based on the first validated model, the Mazengarb.

Rainfall – The transition to a rain on grid methodology required some adjustment of the infiltration parameters to match the measured local soil infiltration rates, as discussed in (Section 3) of the Kāpiti Flood Hazard Methodology report.

Roughness - The roughness of the stream corridors was updated from a constant roughness value of 0.03 across all stream corridors to classified roughness values for each individual stream corridor ranging from 0.025 to 0.08. This update was applied to better reflect the unique characteristics of each stream reach and was based on site walkover and aerial data.

Tidal Boundary - The tidal data was adjusted by shifting the timeseries data back 25 minutes. This was necessary as the available tidal data sourced at the Mana Cruising Club gauge in Porirua had a significant timing difference with the Waikanae River harbour mouth resulting in delayed flood results.

Network Improvements – In some area's networks were not functioning as expected and/or had missing data. These areas were investigated and resolved and then re-tested in the model.

Digital Elevation Model – In some cases there were areas where earthworks have been undertaken since the last version of the LiDAR (2017) was secured by the Council. Where these were identified, the DEM was updated to include these anomalies.

7. Recommendations

The model validation has provided confidence in the way the model performs for the Wharemauku Catchment. It is worth noting that some areas of groundwater flooding in the catchment are expected to worsen over time with climate change and several low-lying sites with no formal drainage will be affected by this.

The model has been developed to a high level of detail using GIS and DEM data supplied by KCDC, supplemented with as-built data and engineering judgement were deemed necessary.

7.1.1. Recommendations

The following recommendations regarding the model build are suggested.

- Continued development and maintenance of the model is recommended as additional information on stormwater network assets become available.
- The model should be updated to the latest 2021 LiDAR data.
- The model should be updated from Wellington vertical datum 1953 to New Zealand VD2016 as the use of the more recent vertical datum will become more prevalent in the future.
- The model should be audited periodically as modelling software and best practice methodologies evolve.
- Flood incident data, such as surveyed flood levels, should be collected across the catchment during large storm events.
- Measured data, such as stream and pipe network flow gauging, should be carried out within the catchment and used in future model validations.
- Some improvements could be made to the groundwater model to the benefit of the model. This is particularly the case around some existing urban waterways that are not well represented in the groundwater model.

8. References

Akan, O. A. (1993). *Urban Stormwater Hydrology: A Guide to Engineering Calculations*. Copyright 1993 CRC Press LLC, ISBN 0-87762-967-6.

Arcement, G. J. & Schneider, V. R. (1989). *Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains*. United States Geological Survey Water-Supply Paper 2339. Prepared in cooperation with the United States Department of Transportation, Federal Highway Administration.

Auckland Regional Council. (1999). *Guidelines for stormwater runoff modelling in the Auckland Region*. Prepared by Beca Carter Hollings & Ferner Ltd on behalf of Auckland Regional Council, Technical Publication No. 108, ISSN 1172-6415, April 1999.

Awa Environmental Ltd. (2022). *Soil Infiltration Summary Report.* Prepared for Kāpiti Coast District Council and Greater Wellington Regional Council.

BMT. (2018). *TUFLOW Classic/HPC User Manual, Build 2018-03-AD*. Software manual.

Bay of Plenty Regional Council. (2021). *Bay of Plenty Hydraulic Modelling Guidelines*. Prepared for Bay of Plenty Regional Council by Awa Environmental Ltd., XXX 2021.

Bell, R. G. & Allis, M. J. (2021). Update on sea-level rise projections for Wellington City: Supporting the 2020–2021 District Plan process. Prepared by NIWA for Wellington City Council, March 2021.

Bodeker, G., Cullen, N., Katurji, M., McDonald, A., Morgenstern, O., Noone, D., Renwick, J., Revell, L. & Tait, A. (2022). *Aotearoa New Zealand climate change projections guidance: Interpreting the latest IPCC WG1 report findings*. Prepared for the Ministry for the Environment, Report number CR 501, 51p.

Burby, R. J., Deyle, R. E., Godschalk, D. R., & Olshansky, R. B. (2000). *Creating Hazard Resistant Communities Through Land Use Planning.*

Cardno (NZ) Ltd. (2019). *Reference Guide for Design Storm Hydrology: Standardised Parameters for Hydrological Modelling.* Prepared for Wellington Water Limited. Available from: https://www.wellingtonwater.co.nz/assets/Resources/Developing/Reference-Guide-for-Design-Storm-Hydrology-April-2019.pdf

Carey-Smith, T., & Henderson, R., Singh S. (2018). *High Intensity Rainfall Design System Version 4*. Prepared by NIWA for Envirolink, August 2018.

de Lange, W. (2013). *Kāpiti Coast coastal hazard assessment*. Department of Earth and Ocean Sciences, The University of Waikato. Downloaded 9th November 2021 from https://www.Kāpiticoast.govt.nz/media/29764/Kāpiti-coast-coastal-hazard-assessment.pdf.

Greater Wellington Regional Council. (2021). *Flood Hazard Modelling Standard*. Prepared for Greater Wellington Regional Council by Cardno NZ, 6th May 2021.

Hydrology and Risk Consulting (HARC). (2023). *Kāpiti Coast District Council Flood and Stormwater Study. Joint probability analysis of coastal and catchment and flooding Draft A*. Prepared for Kāpiti Coast District Council.

Johnson, A. I. (1967). *Specific yield: compilation of specific yields for various materials*. USGS Numbered Series. DOI: 10.3133/wsp1662D. U.S. Government Printing Office, Washington, D.C. Available at https://www.geographynotes.com/aquifer/how-to-calculate-the-specific-yield-of-an-aquifer-groundwater/6810

Land Information New Zealand. (2021). *New Zealand Nautical Almanac*. 2021/22 Edition, NZ 204.

Lane E., Gorman R., Plew D., & Stephens, S. (2012). *Assessing the storm inundation hazard for coastal margins around the Wellington region*. Prepared by NIWA for Greater Wellington Regional Council, Kāpiti Coast District Council and Wellington City Council, November 2012.

Martell, C. (2015). *Greater Wellington Regional Council Flood Assessment Review – The inclusion of freeboard in flood risk mapping.* Awa Environmental.

McFadgen, B. (1997). *Archaeology of the Wellington Conservancy: Kāpiti-Horowhenua, A prehistoric and palaeoenvironmental study*.

Ministry for the Environment. (2017). *Coastal Hazards and Climate Change: Guidance for Local Government*. Ministry for the Environment, Crown copyright New Zealand 2017, Publication number: ME 1341. December 2017.

Ministry for the Environment. (2018). *Climate Change Projections for New Zealand.* Ministry for the Environment, Crown copyright New Zealand 2018, Publication number: ME 1385. September 2018.

Ministry for the Environment. (2022). *Interim guidance on the use of new sea-level rise projections*. Wellington: Ministry for the Environment. Crown copyright New Zealand 2022. Publication number: ME 1667. Published August 2022.

NIWA. (2012). *Joint-probability of storm tide and waves on the open coast of Wellington*. Prepared for Greater Wellington Regional Council. July 2011 (minor edits July 2012).

NIWA. (2018a). *High Intensity Rainfall Design, Version 4*. Report prepared for Envirolink, August 2018.

NIWA, (2018b). *Update on relative sea-level rise and vertical land motion: Wellington region*. Prepared for Greater Wellington Regional Council, December 2018.

Pit R., Lantrip J., & Harrison R. (1999). *Infiltration Through Disturbed Urban Soils and Compost-Amended Soil Effects on Runoff Quality and Quantity – Research Report*. Report EPA/600/R-00/016 December 1999, Office of Research and Development Washington, DC 20460, United States Environmental Protection Agency.

Rawls, W. J., Brakesiek, D., & Miller, N. (1983). *Green-Ampt infiltration parameters from soils data*. Journal of Hydraulic Engineering, vol 109, 62-71.

Sayers, P. (2012). *Flood Risk – Planning, design and management of flood defence infrastructure*.

Sherman, L.K., 1932. 'Stream flow from rainfall by the unit hydrograph method'. *Engineering News Record*, 108, 501–505.

SKM (2011a). *Appendix 1 – Updated Isohyet Based Calculation of Design Peakflows*. Report appendix produced on behalf of Kāpiti Coast District Council, 11th October 2011.

SKM (2011b). *Statement of Evidence of Craig Murray Martell (Hydrology) for the NZ Transport Agency and Porirua City Council.* Prepared for Porirua City Council and NZ Transport Agency.

Stephens, S., Gorman, R., & Lane, E. (2012). *Joint-probability of storm tide and waves on the open coast of Wellington*. Prepared by NIWA for Greater Wellington Regional Council. July 2011 (minor edits July 2012).

Stockdon, H. F., Holman, R. A., Howd, P. A, Sallenger, A. H. (2006). *Empirical parameterization of setup, swash and runup*. Coastal Engineering 53(7): 573-588.

Tanaka, H. & Tinh, N.X. (2008). Wave set-up at river mouths in Japan. Journal of water Resources and Environmental Engineering, no.23; p5-12.

Tauranga City Council. (2017). *Guidelines for Stormwater Modelling using MIKE FLOOD*. Guidelines prepared by DHI for Tauranga City Council, July 2017.

Todd, D., MacDonald, K., & Debski, D. (2021). *Kāpiti Coast Coastal Hazard Susceptibility and Vulnerability Assessment Volume 1: Methodology*. Report produced by Jacobs for Kāpiti Coast District Council. Document No. IS355300-NC-RPT-003, June 2021.

Tonkin & Taylor. (2016). *Risk Based Approach to Natural Hazards under the RMA*. Prepared for the Ministry for the Environment.

TUFLOW. (2018). *TUFLOW 1D/2D Fixed Grid Hydraulic Modelling. TUFLOW Classic/HPC User Manual Build 2018-03-AD*. Available from https://downloads.tuflow.com/_archive/TUFLOW/Releases/2018-03/TUFLOW%20Manual.2018-03.pdf

United States Department of Agriculture. (1986). *Urban Hydrology for Small Watersheds, Technical Release 55*. Conservation Engineering Division, Natural Resources Conservation Service, United States Department of Agriculture, June 1986.

Wellington Water Limited. (2017). *Regional Stormwater Hydraulic Modelling Specifications, version 5*. Wellington Water Limited, December 2017.

Appendix A – Wharemauku Hill Subcatchment Characteristics

ID	Name	Area[m^2]	Sampling	Ia[mm]	CN	T_c[hr]	Ratio	Easting[m]	Northing[m	Fraction	Total_Area	Base_T_c[h
0	Stream2D0_fast	81940.74	centroid/nearest	5	83.85	0.388	0.95	1768194.819	5466424.282	0.25	81940.49	0.194
1	Stream2D1_fast	63126.744	centroid/nearest	5	81.58	0.412	0.95	1768283.532	5466724.691	0.25	63126.494	0.206
2	Stream2D10_fast	2332.484	centroid/nearest	5	78	0.358	0.95	1768580.448	5467625.127	0.25	2332.234	0.179
3	Stream2D11_fast	3152.564	centroid/nearest	5	78	0.424	0.95	1768684.782	5467605.751	0.25	3152.314	0.212
4	Stream2D12_fast	2716.521	centroid/nearest	5	78	0.342	0.95	1768674.222	5467561.088	0.25	2716.271	0.171
5	Stream2D13_fast	768.327	centroid/nearest	5	78	0.262	0.95	1768643.313	5467518.625	0.25	768.077	0.131
6	Stream2D14_fast	540.304	centroid/nearest	5	78	0.244	0.95	1768618.096	5467518.719	0.25	540.054	0.122
7	Stream2D15_fast	167904.965	centroid/nearest	5	78.57	0.496	0.95	1768683.698	5467055.541	0.25	167904.715	0.248
8	Stream2D16_fast	41288.297	centroid/nearest	5	79.44	0.374	0.95	1768867.116	5466869.238	0.25	41288.047	0.187
9	Stream2D17_fast	62458.562	centroid/nearest	5	87	0.44	0.95	1768502.497	5466652.702	0.25	62458.312	0.22
10	Stream2D18_fast	29907.243	centroid/nearest	5	86.68	0.414	0.95	1768620.016	5466750.45	0.25	29906.993	0.207
11	Stream2D19_fast	17009.937	centroid/nearest	5	87	0.354	0.95	1768727.854	5466723.713	0.25	17009.687	0.177
12	Stream2D2_fast	66911.102	centroid/nearest	5	80.15	0.378	0.95	1768339.44	5467011.729	0.25	66910.852	0.189
13	Stream2D20_fast	9977.234	centroid/nearest	5	86.983	0.352	0.95	1768796.865	5466652.518	0.25	9976.984	0.176
14	Stream2D21_fast	2532.498	centroid/nearest	5	87	0.278	0.95	1768855.43	5466624.555	0.25	2532.248	0.139
15	Stream2D22_fast	5500.79	centroid/nearest	5	87	0.288	0.95	1768857.701	5466697.761	0.25	5500.54	0.144
16	Stream2D23_fast	65790.905	centroid/nearest	5	85.05	0.41	0.95	1768491.404	5466426.553	0.25	65790.655	0.205
17	Stream2D24_fast	2512.501	centroid/nearest	5	86.51	0.296	0.95	1768635.293	5466478.201	0.25	2512.251	0.148
18	Stream2D25_fast	2660.513	centroid/nearest	5	87	0.308	0.95	1768748.23	5466344.2	0.25	2660.263	0.154
19	Stream2D26_fast	63334.633	centroid/nearest	5	86.53	0.43	0.95	1768535.672	5466258.128	0.25	63334.383	0.215
20	Stream2D27_fast	1716.42	centroid/nearest	5	87	0.262	0.95	1768761.373	5466203.615	0.25	1716.17	0.131
21	Stream2D28_fast	2532.5	centroid/nearest	5	87	0.278	0.95	1768772.855	5466170.118	0.25	2532.25	0.139
22	Stream2D29_fast	3968.643	centroid/nearest	5	86.57	0.28	0.95	1768753.042	5466130.264	0.25	3968.393	0.14
23	Stream2D3_fast	6784.947	centroid/nearest	5	78.01	0.316	0.95	1768303.938	5467258.982	0.25	6784.697	0.158
24	Stream2D30_fast	11593.404	centroid/nearest	5	79	0.3	0.95	1768681.043	5466119.721	0.25	11593.154	0.15
25	Stream2D31_fast	3000.549	centroid/nearest	5	78	0.282	0.95	1768676.283	5466052.032	0.25	3000.299	0.141
26	Stream2D32_fast	79368.287	centroid/nearest	5	78.44	0.46	0.95	1768478.244	5466066.268	0.25	79368.037	0.23
27	Stream2D33_fast	24482.698	centroid/nearest	5	83.3	0.624	0.95	1768632.318	5465834.964	0.25	24482.448	0.312
28	Stream2D34_fast	1632.413	centroid/nearest	5	78	0.268	0.95	1768677.701	5465943.167	0.25	1632.163	0.134
29	Stream2D35_fast	1720.421	centroid/nearest	5	85.89	0.298	0.95	1768722.321	5465798.433	0.25	1720.171	0.149
30	Stream2D36_fast	4236.671	centroid/nearest	5	83.64	0.298	0.95	1768707.138	5465743.691	0.25	4236.421	0.149
31	Stream2D37_fast	161820.815	centroid/nearest	5	79.35	0.51	0.95	1768344.931	5465763.108	0.25	161820.565	0.255
32	Stream2D38_fast	44244.824	centroid/nearest	5	78.07	0.37	0.95	1768221.424	5465519.641	0.25	44244.574	0.185
33	Stream2D39_fast	49853.376	centroid/nearest	5	80.74	0.378	0.95	1768289.044	5465370.455	0.25	49853.126	0.189
34	Stream2D4_fast	65166.846	centroid/nearest	5	78	0.454	0.95	1768482.206	5467271.323	0.25	65166.596	0.227
35	Stream2D40_fast	7733.033	centroid/nearest	5	77.22	0.286	0.95	1768471.53	5465363.171	0.25	7732.783	0.143
36	Stream2D41_fast	17394	centroid/nearest	5	86.72	0.312	0.95	1768553.723	5465583.387	0.25	17393.75	0.156
37	Stream2D42_fast	4308.681	centroid/nearest	5	85.94	0.29	0.95	1768635.36	5465530.909	0.25	4308.431	0.145
38	Stream2D43_fast	11013.349	centroid/nearest	5	83.93	0.324	0.95	1768657.561	5465627.116	0.25	11013.099	0.162
39	Stream2D44_fast	7653.011	centroid/nearest	5	81.63	0.308	0.95	1768699.65	5465682.94	0.25	7652.761	0.154
40	Stream2D45_fast	115726.604	centroid/nearest	5	84.8	0.618	0.95	1769892.763	5468596.27	0.25	115726.354	0.309
41	Stream2D46_fast	14573.569	centroid/nearest	5	79.81	0.286	0.95	1769770.842	5468755.606	0.25	14573.319	0.143
42	Stream2D47_fast	10781.231	centroid/nearest	5	76.75	0.342	0.95	1769711.427	5468391.976	0.25	10780.981	0.171
43	Stream2D48_fast	48716.632	centroid/nearest	5	78.5	0.382	0.95	1769835.513	5468275.49	0.25	48716.382	0.191
44	Stream2D49_fast	23094.346	centroid/nearest	5	77.91	0.328	0.95	1769739.683	5468124.001	0.25	23094.096	0.164
45	Stream2D5_fast	14713.747	centroid/nearest	5	78	0.336	0.95	1768423.183	5467445.585	0.25	14713.497	0.168
46	Stream2D50_fast	17941.892	centroid/nearest	5	78	0.324	0.95	1769650.223	5468010.932	0.25	17941.642	0.162
47	Stream2D51_fast	9729.145	centroid/nearest	5	78	0.318	0.95	1769591.794	5468084.568	0.25	9728.895	0.159
48	Stream2D52_fast	88188.183	centroid/nearest	5	74.6	0.404	0.95	1769834.847	5467929.566	0.25	88187.933	0.202
49	Stream2D53_fast	30951.09	centroid/nearest	5	72.73	0.3	0.95	1769620.925	5467685.697	0.25	30950.84	0.15
50	Stream2D54_fast	34831.384	centroid/nearest	5	75.8	0.35	0.95	1769832.875	5467623.874	0.25	34831.134	0.175
51	Stream2D55_fast	86052.251	centroid/nearest	5	82.81	0.368	0.95	1769473.059	5465988.741	0.25	86052.001	0.184
52	Stream2D56_fast	92664.833	centroid/nearest	5	83.31	0.36	0.95	1769516.12	5466145.348	0.25	92664.583	0.18

53	Stream2D57_fast	14057.563	centroid/nearest	5	79.83	0.352	0.95	1769421.443	5466416.412	0.25	14057.313	0.176
54	Stream2D58_fast	212643.48	centroid/nearest	5	80.57	0.51	0.95	1769778.192	5466111.073	0.25	212643.23	0.255
55	Stream2D59_fast	66730.353	centroid/nearest	5	86.09	0.342	0.95	1769655.496	5466521.425	0.25	66730.103	0.171
56	Stream2D6_fast	13009.534	centroid/nearest	5	78	0.396	0.95	1768786.691	5467352.67	0.25	13009.284	0.198
57	Stream2D60_fast	20498.133	centroid/nearest	5	86.77	0.316	0.95	1769608.743	5466721.054	0.25	20497.883	0.158
58	Stream2D61_fast	27922.816	centroid/nearest	5	86.9	0.338	0.95	1769604.285	5466866.247	0.25	27922.566	0.169
59	Stream2D62_fast	2912.521	centroid/nearest	5	86.9	0.29	0.95	1769477.621	5466932	0.25	2912.271	0.145
60	Stream2D63_fast	18773.98	centroid/nearest	5	87.01	0.406	0.95	1769571.139	5466980.582	0.25	18773.73	0.203
61	Stream2D64_fast	4780.69	centroid/nearest	5	87.15	0.298	0.95	1769573.808	5467064.911	0.25	4780.44	0.149
62	Stream2D65_fast	34735.423	centroid/nearest	5	83.51	0.406	0.95	1769667.117	5467118.192	0.25	34735.173	0.203
63	Stream2D66_fast	10697.325	centroid/nearest	5	79.37	0.324	0.95	1768570.221	5465317.984	0.25	10697.075	0.162
64	Stream2D67_fast	59478.308	centroid/nearest	5	85.6	0.548	0.95	1768406.974	5465199.583	0.25	59478.058	0.274
65	Stream2D68_fast	98769.961	centroid/nearest	5	77.67	0.388	0.95	1768832.77	5464849.942	0.25	98769.711	0.194
66	Stream2D69_fast	289915.836	centroid/nearest	5	79.38	0.606	0.95	1769213.154	5464656.688	0.25	289915.586	0.303
67	Stream2D7_fast	11489.393	centroid/nearest	5	78	0.396	0.95	1768687.201	5467371.573	0.25	11489.143	0.198
68	Stream2D70_fast	14505.646	centroid/nearest	5	82.9	0.302	0.95	1769085.281	5465280.586	0.25	14505.396	0.151
69	Stream2D71_fast	12301.428	centroid/nearest	5	74.59	0.314	0.95	1769137.258	5465396.037	0.25	12301.178	0.157
70	Stream2D72_fast	4972.725	centroid/nearest	5	76.46	0.356	0.95	1769171.468	5465538.569	0.25	4972.475	0.178
71	Stream2D73_fast	130316.325	centroid/nearest	5	83.03	0.464	0.95	1769511.6	5465716.927	0.25	130316.075	0.232
72	Stream2D74_fast	23758.49	centroid/nearest	5	86.35	0.35	0.95	1769319.103	5465862.711	0.25	23758.24	0.175
73	Stream2D75_fast	6568.875	centroid/nearest	5	78.12	0.3	0.95	1769209.853	5465885.954	0.25	6568.625	0.15
74	Stream2D76_fast	12497.435	centroid/nearest	5	79.97	0.324	0.95	1769256.694	5465978.908	0.25	12497.185	0.162
75	Stream2D77_fast	23810.578	centroid/nearest	5	78	0.432	0.95	1768896.875	5467355.844	0.25	23810.328	0.216
76	Stream2D78_fast	5520.759	centroid/nearest	5	81	0.288	0.95	1769574.032	5467291.493	0.25	5520.509	0.144
77	Stream2D79_fast	6604.854	centroid/nearest	5	84.29	0.292	0.95	1769650.11	5467292.788	0.25	6604.604	0.146
78	Stream2D8_fast	8045.056	centroid/nearest	5	78	0.322	0.95	1768612.087	5467434.406	0.25	8044.806	0.161
79	Stream2D80_fast	52944.946	centroid/nearest	5	82.14	0.338	0.95	1769985.199	5467234.433	0.25	52944.696	0.169
80	Stream2D81_fast	30727.03	centroid/nearest	5	84.04	0.414	0.95	1769772.346	5467078.185	0.25	30726.78	0.207
81	Stream2D82_fast	61025.658	centroid/nearest	5	79.55	0.352	0.95	1769994.724	5467526.289	0.25	61025.408	0.176
82	Stream2D83_fast	4496.666	centroid/nearest	5	72.3	0.318	0.95	1769528.237	5467795.297	0.25	4496.416	0.159
83	Stream2D84_fast	3760.594	centroid/nearest	5	77.38	0.292	0.95	1769649.54	5468450.521	0.25	3760.344	0.146
84	Stream2D85_fast	113378.081	centroid/nearest	5	78.86	0.4	0.95	1770222.518	5467380.584	0.25	113377.831	0.2
85	Stream2D86_fast	433350.471	centroid/nearest	5	78.09	0.59	0.95	1770045.365	5466274.215	0.25	433350.221	0.295
86	Stream2D87_fast	9881.132	centroid/nearest	5	77.88	0.284	0.95	1769912.119	5466981.091	0.25	9880.882	0.142
87	Stream2D88_fast	888023.578	centroid/nearest	5	77.3	0.696	0.95	1770447.53	5466724.117	0.25	888023.328	0.348
88	Stream2D89_fast	20558.117	centroid/nearest	5	74.01	0.32	0.95	1769731.196	5467753.488	0.25	20557.867	0.16
89	Stream2D9_fast	2644.515	centroid/nearest	5	78	0.33	0.95	1768626.053	5467622.014	0.25	2644.265	0.165
90	Stream2D90_fast	25542.733	centroid/nearest	5	82.63	0.346	0.95	1768965.255	5465044.584	0.25	25542.483	0.173
91	Stream2D91_fast	889041.607	centroid/nearest	5	78.33	0.602	0.95	1769649.309	5465161.784	0.25	889041.357	0.301
92	Stream2D92_fast	18714.13	centroid/nearest	5	78.34	0.47	0.95	1768577.66	5464976.592	0.25	18713.88	0.235
93	Stream2D93_fast	28571.128	centroid/nearest	5	78	0.458	0.95	1768542.391	5467494.111	0.25	28570.878	0.229
94	Stream2D0_slow	81941.24	centroid/nearest	5	83.85	0.388	0.3	1768194.819	5466424.282	0.75	81940.49	0.194
95	Stream2D1_slow	63127.244	centroid/nearest	5	81.58	0.412	0.3	1768283.532	5466724.691	0.75	63126.494	0.206
96	Stream2D10_slow	2332.984	centroid/nearest	5	78	0.358	0.3	1768580.448	5467625.127	0.75	2332.234	0.179
97	Stream2D11_slow	3153.064	centroid/nearest	5	78	0.424	0.3	1768684.782	5467605.751	0.75	3152.314	0.212
98	Stream2D12_slow	2717.021	centroid/nearest	5	78	0.342	0.3	1768674.222	5467561.088	0.75	2716.271	0.171
99	Stream2D13_slow	768.827	centroid/nearest	5	78	0.262	0.3	1768643.313	5467518.625	0.75	768.077	0.131
100	Stream2D14_slow	540.804	centroid/nearest	5	78	0.244	0.3	1768618.096	5467518.719	0.75	540.054	0.122
101	Stream2D15_slow	167905.465	centroid/nearest	5	78.57	0.496	0.3	1768683.698	5467055.541	0.75	167904.715	0.248
102	Stream2D16_slow	41288.797	centroid/nearest	5	79.44	0.374	0.3	1768867.116	5466869.238	0.75	41288.047	0.187
103	Stream2D17_slow	62459.062	centroid/nearest	5	87	0.44	0.3	1768502.497	5466652.702	0.75	62458.312	0.22
104	Stream2D18_slow	29907.743	centroid/nearest	5	86.68	0.414	0.3	1768620.016	5466750.45	0.75	29906.993	0.207
105	Stream2D19_slow	17010.437	centroid/nearest	5	87	0.354	0.3	1768727.854	5466723.713	0.75	17009.687	0.177
106	Stream2D2_slow	66911.602	centroid/nearest	5	80.15	0.378	0.3	1768339.44	5467011.729	0.75	66910.852	0.189

107	Stream2D20_slow	9977.734	centroid/nearest	5	86.98	0.352	0.3	1768796.865	5466652.518	0.75	9976.984	0.176
108	Stream2D21_slow	2532.998	centroid/nearest	5	87	0.278	0.3	1768855.43	5466624.555	0.75	2532.248	0.139
109	Stream2D22_slow	5501.29	centroid/nearest	5	87	0.288	0.3	1768857.701	5466697.761	0.75	5500.54	0.144
110	Stream2D23_slow	65791.405	centroid/nearest	5	85.05	0.41	0.3	1768491.404	5466426.553	0.75	65790.655	0.205
111	Stream2D24_slow	2513.001	centroid/nearest	5	86.51	0.296	0.3	1768635.293	5466478.201	0.75	2512.251	0.148
112	Stream2D25_slow	2661.013	centroid/nearest	5	87	0.308	0.3	1768748.23	5466344.2	0.75	2660.263	0.154
113	Stream2D26_slow	63335.133	centroid/nearest	5	86.53	0.43	0.3	1768535.672	5466258.128	0.75	63334.383	0.215
114	Stream2D27_slow	1716.92	centroid/nearest	5	87	0.262	0.3	1768761.373	5466203.615	0.75	1716.17	0.131
115	Stream2D28_slow	2533	centroid/nearest	5	87	0.278	0.3	1768772.855	5466170.118	0.75	2532.25	0.139
116	Stream2D29_slow	3969.143	centroid/nearest	5	86.57	0.28	0.3	1768753.042	5466130.264	0.75	3968.393	0.14
117	Stream2D3_slow	6785.447	centroid/nearest	5	78.01	0.316	0.3	1768303.938	5467258.982	0.75	6784.697	0.158
118	Stream2D30_slow	11593.904	centroid/nearest	5	79	0.3	0.3	1768681.043	5466119.721	0.75	11593.154	0.15
119	Stream2D31_slow	3001.049	centroid/nearest	5	78	0.282	0.3	1768676.283	5466052.032	0.75	3000.299	0.141
120	Stream2D32_slow	79368.787	centroid/nearest	5	78.44	0.46	0.3	1768478.244	5466066.268	0.75	79368.037	0.23
121	Stream2D33_slow	24483.198	centroid/nearest	5	83.3	0.624	0.3	1768632.318	5465834.964	0.75	24482.448	0.312
122	Stream2D34_slow	1632.913	centroid/nearest	5	78	0.268	0.3	1768677.701	5465943.167	0.75	1632.163	0.134
123	Stream2D35_slow	1720.921	centroid/nearest	5	85.89	0.298	0.3	1768722.321	5465798.433	0.75	1720.171	0.149
124	Stream2D36_slow	4237.171	centroid/nearest	5	83.64	0.298	0.3	1768707.138	5465743.691	0.75	4236.421	0.149
125	Stream2D37_slow	161821.315	centroid/nearest	5	79.35	0.51	0.3	1768344.931	5465763.108	0.75	161820.565	0.255
126	Stream2D38_slow	44245.324	centroid/nearest	5	78.07	0.37	0.3	1768221.424	5465519.641	0.75	44244.574	0.185
127	Stream2D39_slow	49853.876	centroid/nearest	5	80.74	0.378	0.3	1768289.044	5465370.455	0.75	49853.126	0.189
128	Stream2D4_slow	65167.346	centroid/nearest	5	78	0.454	0.3	1768482.206	5467271.323	0.75	65166.596	0.227
129	Stream2D40_slow	7733.533	centroid/nearest	5	77.22	0.286	0.3	1768471.53	5465363.171	0.75	7732.783	0.143
130	Stream2D41_slow	17394.5	centroid/nearest	5	86.72	0.312	0.3	1768553.723	5465583.387	0.75	17393.75	0.156
131	Stream2D42_slow	4309.181	centroid/nearest	5	85.94	0.29	0.3	1768635.36	5465530.909	0.75	4308.431	0.145
132	Stream2D43_slow	11013.849	centroid/nearest	5	83.93	0.324	0.3	1768657.561	5465627.116	0.75	11013.099	0.162
133	Stream2D44_slow	7653.511	centroid/nearest	5	81.63	0.308	0.3	1768699.65	5465682.94	0.75	7652.761	0.154
134	Stream2D45_slow	115727.104	centroid/nearest	5	84.8	0.618	0.3	1769892.763	5468596.27	0.75	115726.354	0.309
135	Stream2D46_slow	14574.069	centroid/nearest	5	79.81	0.286	0.3	1769770.842	5468755.606	0.75	14573.319	0.143
136	Stream2D47_slow	10781.731	centroid/nearest	5	76.75	0.342	0.3	1769711.427	5468391.976	0.75	10780.981	0.171
137	Stream2D48_slow	48717.132	centroid/nearest	5	78.5	0.382	0.3	1769835.513	5468275.49	0.75	48716.382	0.191
138	Stream2D49_slow	23094.846	centroid/nearest	5	77.91	0.328	0.3	1769739.683	5468124.001	0.75	23094.096	0.164
139	Stream2D5_slow	14714.247	centroid/nearest	5	78	0.336	0.3	1768423.183	5467445.585	0.75	14713.497	0.168
140	Stream2D50_slow	17942.392	centroid/nearest	5	78	0.324	0.3	1769650.223	5468010.932	0.75	17941.642	0.162
141	Stream2D51_slow	9729.645	centroid/nearest	5	78	0.318	0.3	1769591.794	5468084.568	0.75	9728.895	0.159
142	Stream2D52_slow	88188.683	centroid/nearest	5	74.6	0.404	0.3	1769834.847	5467929.566	0.75	88187.933	0.202
143	Stream2D53_slow	30951.59	centroid/nearest	5	72.73	0.3	0.3	1769620.925	5467685.697	0.75	30950.84	0.15
144	Stream2D54_slow	34831.884	centroid/nearest	5	75.8	0.35	0.3	1769832.875	5467623.874	0.75	34831.134	0.175
145	Stream2D55_slow	86052.751	centroid/nearest	5	82.81	0.368	0.3	1769473.059	5465988.741	0.75	86052.001	0.184
146	Stream2D56_slow	92665.333	centroid/nearest	5	83.31	0.36	0.3	1769516.12	5466145.348	0.75	92664.583	0.18
147	Stream2D57_slow	14058.063	centroid/nearest	5	79.83	0.352	0.3	1769421.443	5466416.412	0.75	14057.313	0.176
148	Stream2D58_slow	212643.98	centroid/nearest	5	80.57	0.51	0.3	1769778.192	5466111.073	0.75	212643.23	0.255
149	Stream2D59_slow	66730.853	centroid/nearest	5	86.09	0.342	0.3	1769655.496	5466521.425	0.75	66730.103	0.171
150	Stream2D6_slow	13010.034	centroid/nearest	5	78	0.396	0.3	1768786.691	5467352.67	0.75	13009.284	0.198
151	Stream2D60_slow	20498.633	centroid/nearest	5	86.77	0.316	0.3	1769608.743	5466721.054	0.75	20497.883	0.158
152	Stream2D61_slow	27923.316	centroid/nearest	5	86.9	0.338	0.3	1769604.285	5466866.247	0.75	27922.566	0.169
153	Stream2D62_slow	2913.021	centroid/nearest	5	86.9	0.29	0.3	1769477.621	5466932	0.75	2912.271	0.145
154	Stream2D63_slow	18774.48	centroid/nearest	5	87.01	0.406	0.3	1769571.139	5466980.582	0.75	18773.73	0.203
155	Stream2D64_slow	4781.19	centroid/nearest	5	87.15	0.298	0.3	1769573.808	5467064.911	0.75	4780.44	0.149
156	Stream2D65_slow	34735.923	centroid/nearest	5	83.51	0.406	0.3	1769667.117	5467118.192	0.75	34735.173	0.203
157	Stream2D66_slow	10697.825	centroid/nearest	5	79.37	0.324	0.3	1768570.221	5465317.984	0.75	10697.075	0.162
158	Stream2D67_slow	59478.808	centroid/nearest	5	85.6	0.548	0.3	1768406.974	5465199.583	0.75	59478.058	0.274
159	Stream2D68_slow	98770.461	centroid/nearest	5	77.67	0.388	0.3	1768832.77	5464849.942	0.75	98769.711	0.194
160	Stream2D69_slow	289916.336	centroid/nearest	5	79.38	0.606	0.3	1769213.154	5464656.688	0.75	289915.586	0.303

161	Stream2D7_slow	11489.893	centroid/nearest	5	78	0.396	0.3	1768687.201	5467371.573	0.75	11489.143	0.198
162	Stream2D70_slow	14506.146	centroid/nearest	5	82.9	0.302	0.3	1769085.281	5465280.586	0.75	14505.396	0.151
163	Stream2D71_slow	12301.928	centroid/nearest	5	74.59	0.314	0.3	1769137.258	5465396.037	0.75	12301.178	0.157
164	Stream2D72_slow	4973.225	centroid/nearest	5	76.46	0.356	0.3	1769171.468	5465538.569	0.75	4972.475	0.178
165	Stream2D73_slow	130316.825	centroid/nearest	5	83.03	0.464	0.3	1769511.6	5465716.927	0.75	130316.075	0.232
166	Stream2D74_slow	23758.99	centroid/nearest	5	86.35	0.35	0.3	1769319.103	5465862.711	0.75	23758.24	0.175
167	Stream2D75_slow	6569.375	centroid/nearest	5	78.12	0.3	0.3	1769209.853	5465885.954	0.75	6568.625	0.15
168	Stream2D76_slow	12497.935	centroid/nearest	5	79.97	0.324	0.3	1769256.694	5465978.908	0.75	12497.185	0.162
169	Stream2D77_slow	23811.078	centroid/nearest	5	78	0.432	0.3	1768896.875	5467355.844	0.75	23810.328	0.216
170	Stream2D78_slow	5521.259	centroid/nearest	5	81	0.288	0.3	1769574.032	5467291.493	0.75	5520.509	0.144
171	Stream2D79_slow	6605.354	centroid/nearest	5	84.29	0.292	0.3	1769650.11	5467292.788	0.75	6604.604	0.146
172	Stream2D8_slow	8045.556	centroid/nearest	5	78	0.322	0.3	1768612.087	5467434.406	0.75	8044.806	0.161
173	Stream2D80_slow	52945.446	centroid/nearest	5	82.14	0.338	0.3	1769985.199	5467234.433	0.75	52944.696	0.169
174	Stream2D81_slow	30727.53	centroid/nearest	5	84.04	0.414	0.3	1769772.346	5467078.185	0.75	30726.78	0.207
175	Stream2D82_slow	61026.158	centroid/nearest	5	79.55	0.352	0.3	1769994.724	5467526.289	0.75	61025.408	0.176
176	Stream2D83_slow	4497.166	centroid/nearest	5	72.3	0.318	0.3	1769528.237	5467795.297	0.75	4496.416	0.159
177	Stream2D84_slow	3761.094	centroid/nearest	5	77.38	0.292	0.3	1769649.54	5468450.521	0.75	3760.344	0.146
178	Stream2D85_slow	113378.581	centroid/nearest	5	78.86	0.4	0.3	1770222.518	5467380.584	0.75	113377.831	0.2
179	Stream2D86_slow	433350.971	centroid/nearest	5	78.09	0.59	0.3	1770045.365	5466274.215	0.75	433350.221	0.295
180	Stream2D87_slow	9881.632	centroid/nearest	5	77.88	0.284	0.3	1769912.119	5466981.091	0.75	9880.882	0.142
181	Stream2D88_slow	888024.078	centroid/nearest	5	77.3	0.696	0.3	1770447.53	5466724.117	0.75	888023.328	0.348
182	Stream2D89_slow	20558.617	centroid/nearest	5	74.01	0.32	0.3	1769731.196	5467753.488	0.75	20557.867	0.16
183	Stream2D9_slow	2645.015	centroid/nearest	5	78	0.33	0.3	1768626.053	5467622.014	0.75	2644.265	0.165
184	Stream2D90_slow	25543.233	centroid/nearest	5	82.63	0.346	0.3	1768965.255	5465044.584	0.75	25542.483	0.173
185	Stream2D91_slow	889042.107	centroid/nearest	5	78.33	0.602	0.3	1769649.309	5465161.784	0.75	889041.357	0.301
186	Stream2D92_slow	18714.63	centroid/nearest	5	78.34	0.47	0.3	1768577.66	5464976.592	0.75	18713.88	0.235
187	Stream2D93_slow	28571.628	centroid/nearest	5	78	0.458	0.3	1768542.391	5467494.111	0.75	28570.878	0.229

Appendix B – 100YR-ARI 2130 peak depth results

Model Outputs / Flood Map disclaimer:

Note: Kāpiti Coast District Council's current suite of flood hazard models [legacy models] for the District Plan and flood hazard mapping are under review. The work has been designed to incorporate updated climate change and groundwater conditions for the district, recent development and major roading projects into the models and aligns with wider resilience work underway. The models have been extended to include Te Kowhai and Muaupoko catchments. Council intends engaging with those in areas which may be affected from September 2024. Ultimately, model outputs will be tested for use in future district plan work which will consider any necessary changes to land use and subdivision controls in areas which may be affected. In the meantime, the new base models are available for use to scenario test proposed development [subject to Council's agreement] or for guidance [subject to this disclaimer].

Until a flood hazard Plan Change is publicly notified, the existing rules in the operative District Plan still apply to any area that is identified in the current flood hazard overlays. The updated model outputs cannot be considered the most up to date flood hazard information [in a statutory sense] until directly affected properties have been engaged with, and all output maps and model-build reports are finalised.

- Kāpiti Coast District Council's flood maps and new model outputs are compiled using an assessment of the best available information.
- The design storms used to generate outputs in the new models are based on HIRDS v4 datasets, provided by NIWA.
- The new model outputs reflect flooding originating from Kāpiti Coast District Council's urban drainage network [piped and minor watercourses within urban areas] only, and as such may not represent flooding originating from any of the watercourses administered by Greater Wellington Regional Council [GWRC] (Our models do cover the Mangapouri Stream in particular). The current flood hazard maps stitch together outputs from KCDC legacy models and GWRC models for rivers under its administration. The Watercourses' Agreement attributes the administration of the following watercourses to GWRC:
    - Waikanae River, and its tributaries above the SH bridge
    - Waimeha Stream
    - Mangaone Stream and drains
    - Pahiko Drains
    - Otaki River and tributaries
    - Ngatoko Stream
    - Mangapouri Stream and tributaries
    - Waitohu Stream and tributaries
    - Ngatotara Drain

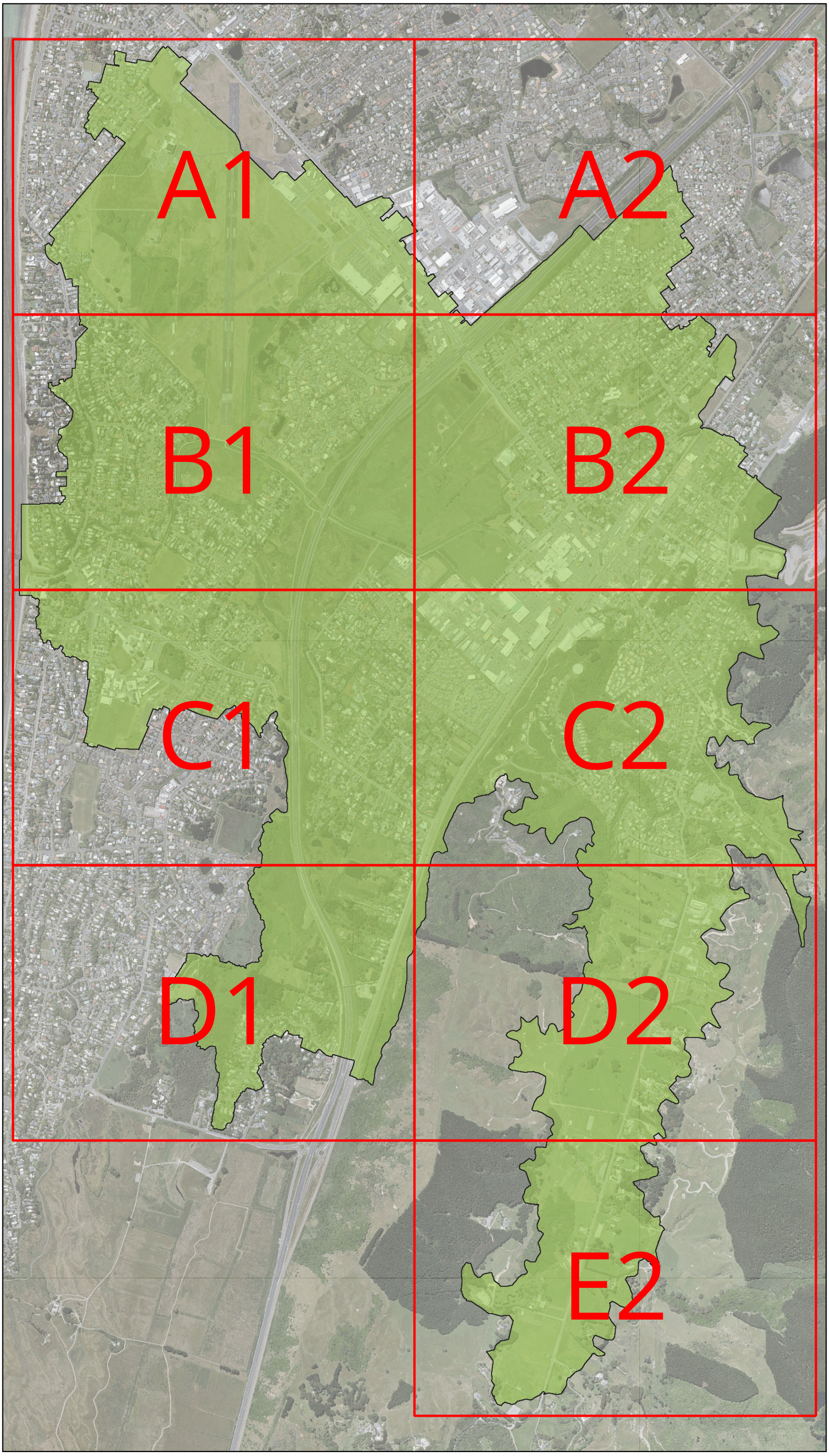
  Where a proposal occurs within Greater Wellington Regional Council's flood model extent, its written approval should be sort. Although the outputs from GWRC models are incorporated within the District Plan flood hazard maps, KCDC holds none of the supporting information. Both Councils have a duty under the Resource Management Act to avoid and mitigate natural

hazards - territorial authorities have a duty to control the effects of use, development or protection of land; Regional Councils have a duty to control the use of land.

- When using these model outputs or flood maps, users should be aware that the results may be subject to change at the discretion of Kāpiti Coast District Council. This is a natural outworking of models being updated over time with new data. Checking with the Council that the District Plans represent the latest information is an important step in the planning process.
- To the fullest extent permitted by applicable law, neither Kāpiti Coast District Council nor any of its members, officers, associates, consultants, employees, affiliates, servants, agents or other representatives shall be liable for loss or damage arising out of, or in connection with, the use of, or the inability to use, the information contained in these maps and/or electronic files including, but not limited to, indirect or consequential loss or damages, loss of data, income, profit, or opportunity, loss of, or damage to, property and claims of third parties, even if Kāpiti Coast District Council has been advised of the possibility of such loss or damages, or such loss or damages were reasonably foreseeable.
- The flood information contained within these plans has been derived from information and techniques available at the time of the study. It is provided to assist in reducing the flood risk for development in the area. However, the agencies and individuals involved in the assessment of the flood hazard assume no responsibility for any action by any agency or individual that is based on the information provided.

Wharemauku Page Reference

For Flood Extent, Hazard, and Depth Maps



Prepared by:
Awa Environmental Ltd
For:
Kapiti Coast District Council

1 Ghuznee St, Te Aro
Wellington 6011
www.awa.kiwi

0 250 m

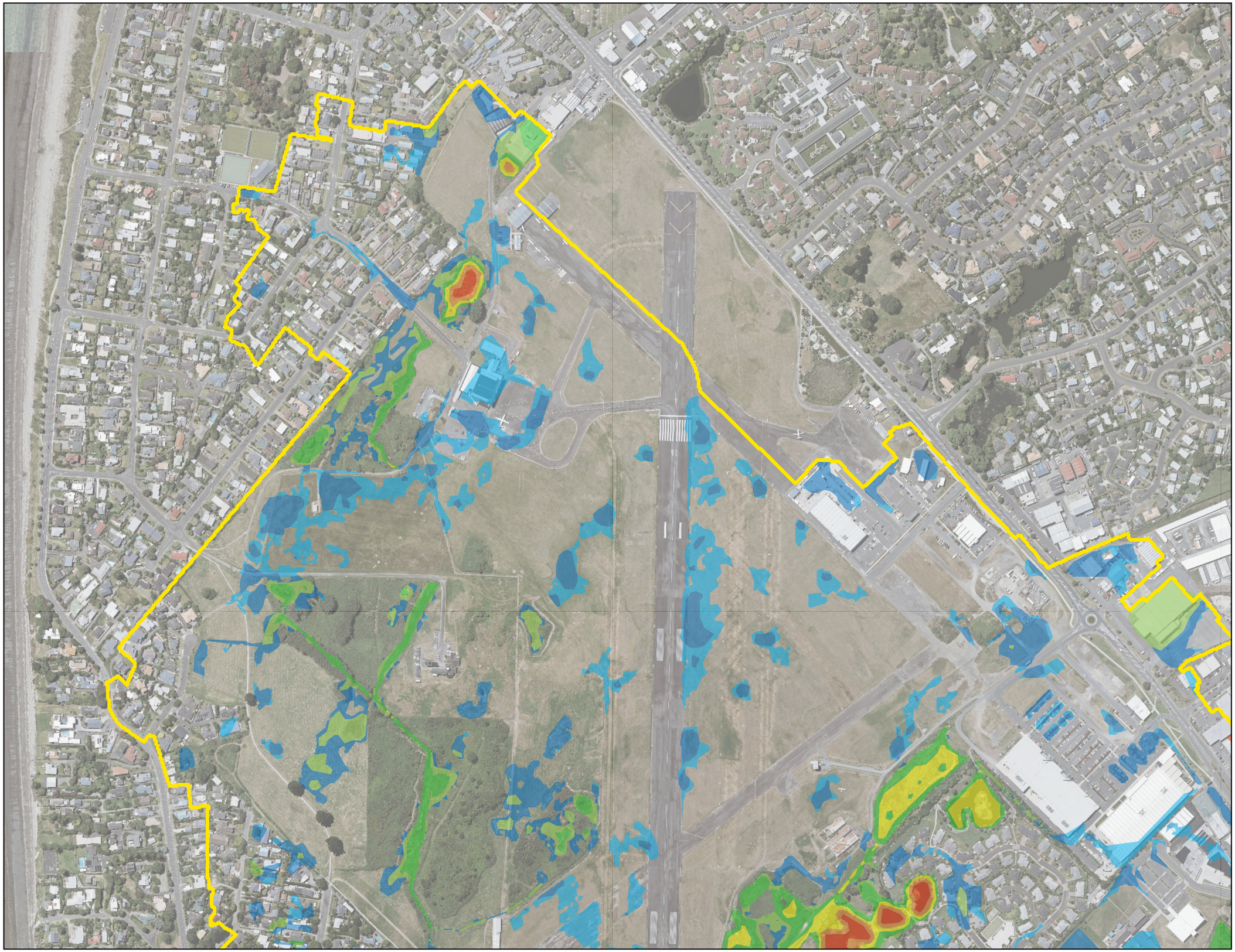
Legend

- Page Reference
- Catchment Extent

Disclaimer:
The flood information contained within these plans has been derived from information and techniques available at the time of the study. It is provided to assist in redusing the flood risk for development in the area.
However, the agencies and individuals involved in the assessment of the flood hazard assume no responsibility for any action by any agency or individual that is based on the information provided.

Wharemauku Flood Depth in a 100-Year Rainfall Event

2130 Projection - Page A1



Prepared by:
Awa Environmental Ltd
For:
Kapiti Coast District Council

1 Ghuznee St, Te Aro
Wellington 6011
www.awa.kiwi

0 150 m

Legend

Catchment Boundary

Depth

- 0.05 - 0.1 m
- 0.1 - 0.3 m
- 0.3 - 0.5 m
- 0.5 - 1.0 m
- 1.0 - 1.5 m
- 1.5 - 2.0 m
- 2.0+ m

Disclaimer:
The flood information contained within these plans has been derived from information and techniques available at the time of the study. It is provided to assist in redusing the flood risk for development in the area. However, the agencies and individuals involved in the assessment of the flood hazard assume no responsibility for any action by any agency or individual that is based on the information provided.

Wharemauku Flood Depth in a 100-Year Rainfall Event

2130 Projection - Page A2



Prepared by:
Awa Environmental Ltd
For:
Kapiti Coast District Council

1 Ghuznee St, Te Aro
Wellington 6011
www.awa.kiwi

0 150 m

Legend

- Catchment Boundary

Depth

- 0.05 - 0.1 m
- 0.1 - 0.3 m
- 0.3 - 0.5 m
- 0.5 - 1.0 m
- 1.0 - 1.5 m
- 2.0+ m

Disclaimer:
The flood information contained within these plans has been derived from information and techniques available at the time of the study. It is provided to assist in redusing the flood risk for development in the area. However, the agencies and individuals involved in the assessment of the flood hazard assume no responsibility for any action by any agency or individual that is based on the information provided.

Wharemauku Flood Depth in a 100-Year Rainfall Event

2130 Projection - Page B1



Prepared by:
Awa Environmental Ltd
For:
Kapiti Coast District Council

1 Ghuznee St, Te Aro
Wellington 6011
www.awa.kiwi

0 150 m

Legend

Catchment Boundary

Depth

- 0.05 - 0.1 m
- 0.1 - 0.3 m
- 0.3 - 0.5 m
- 0.5 - 1.0 m
- 1.0 - 1.5 m
- 1.5 - 2.0 m
- 2.0+ m

Disclaimer:
The flood information contained within these plans has been derived from information and techniques available at the time of the study. It is provided to assist in redusing the flood risk for development in the area. However, the agencies and individuals involved in the assessment of the flood hazard assume no responsibility for any action by any agency or individual that is based on the information provided.

Wharemauku Flood Depth in a 100-Year Rainfall Event

2130 Projection - Page B2



Prepared by:
Awa Environmental Ltd
For:
Kapiti Coast District Council

1 Ghuznee St, Te Aro
Wellington 6011
www.awa.kiwi

0 150 m

Legend

Catchment Boundary

Depth

- 0.05 - 0.1 m
- 0.1 - 0.3 m
- 0.3 - 0.5 m
- 0.5 - 1.0 m
- 1.0 - 1.5 m
- 1.5 - 2.0 m
- 2.0+ m

Disclaimer:
The flood information contained within these plans has been derived from information and techniques available at the time of the study. It is provided to assist in redusing the flood risk for development in the area. However, the agencies and individuals involved in the assessment of the flood hazard assume no responsibility for any action by any agency or individual that is based on the information provided.

Wharemauku Flood Depth in a 100-Year Rainfall Event

2130 Projection - Page C1



Prepared by:
Awa Environmental Ltd
For:
Kapiti Coast District Council

1 Ghuznee St, Te Aro
Wellington 6011
www.awa.kiwi

0 150 m

Legend

Catchment Boundary

Depth

- 0.05 - 0.1 m
- 0.1 - 0.3 m
- 0.3 - 0.5 m
- 0.5 - 1.0 m
- 1.0 - 1.5 m
- 1.5 - 2.0 m
- 2.0+ m

Disclaimer:
The flood information contained within these plans has been derived from information and techniques available at the time of the study. It is provided to assist in redusing the flood risk for development in the area. However, the agencies and individuals involved in the assessment of the flood hazard assume no responsibility for any action by any agency or individual that is based on the information provided.

Wharemauku Flood Depth in a 100-Year Rainfall Event

2130 Projection - Page C2



Prepared by:
Awa Environmental Ltd
For:
Kapiti Coast District Council

1 Ghuznee St, Te Aro
Wellington 6011
www.awa.kiwi

0 150 m

Legend

- Catchment Boundary

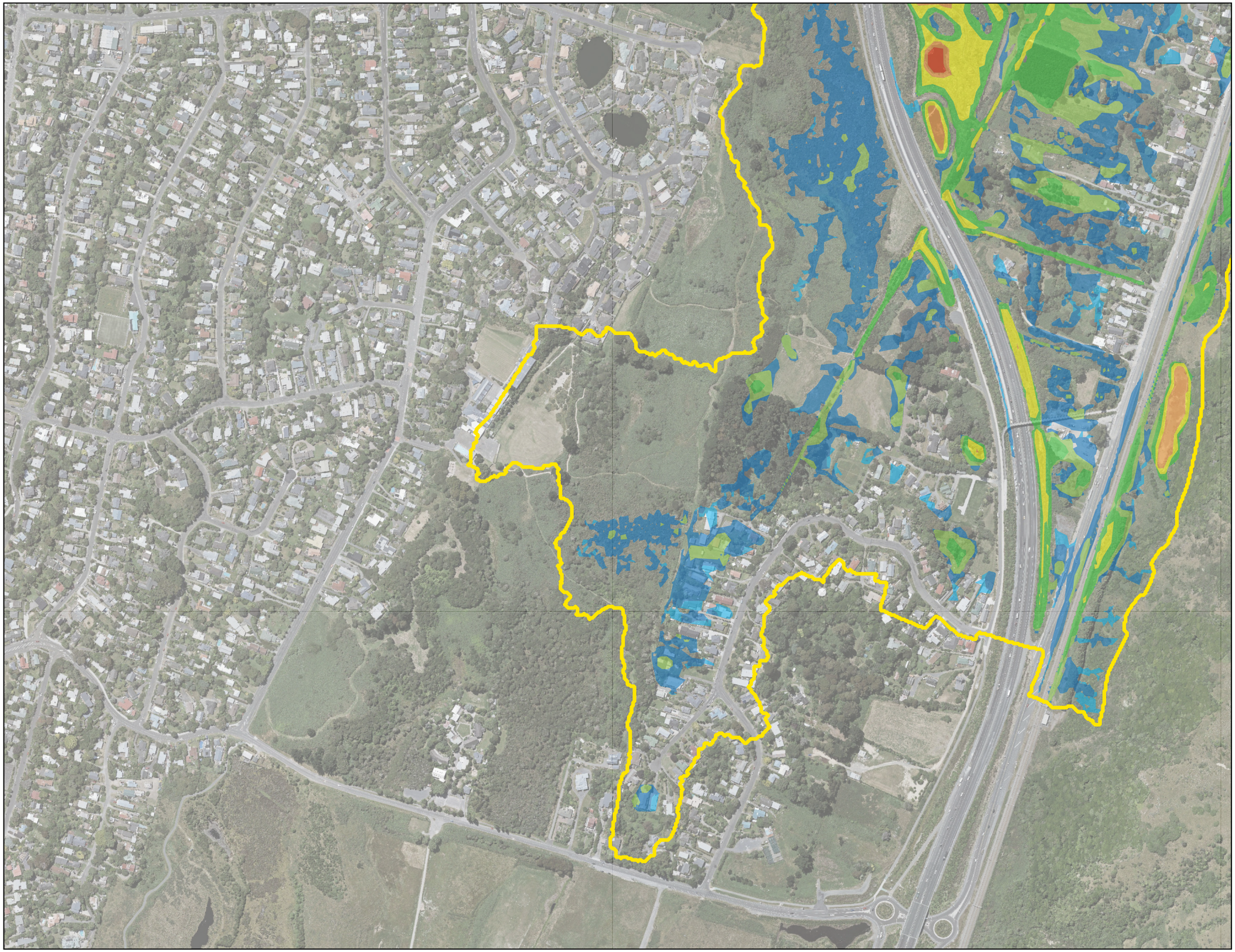
Depth

- 0.05 - 0.1 m
- 0.1 - 0.3 m
- 0.3 - 0.5 m
- 0.5 - 1.0 m
- 1.0 - 1.5 m
- 1.5 - 2.0 m
- 2.0+ m

Disclaimer:
The flood information contained within these plans has been derived from information and techniques available at the time of the study. It is provided to assist in redusing the flood risk for development in the area. However, the agencies and individuals involved in the assessment of the flood hazard assume no responsibility for any action by any agency or individual that is based on the information provided.

Wharemauku Flood Depth in a 100-Year Rainfall Event

2130 Projection - Page D1



Prepared by:
Awa Environmental Ltd
For:
Kapiti Coast District Council

1 Ghuznee St, Te Aro
Wellington 6011
www.awa.kiwi

0 150 m

Legend

- Catchment Boundary

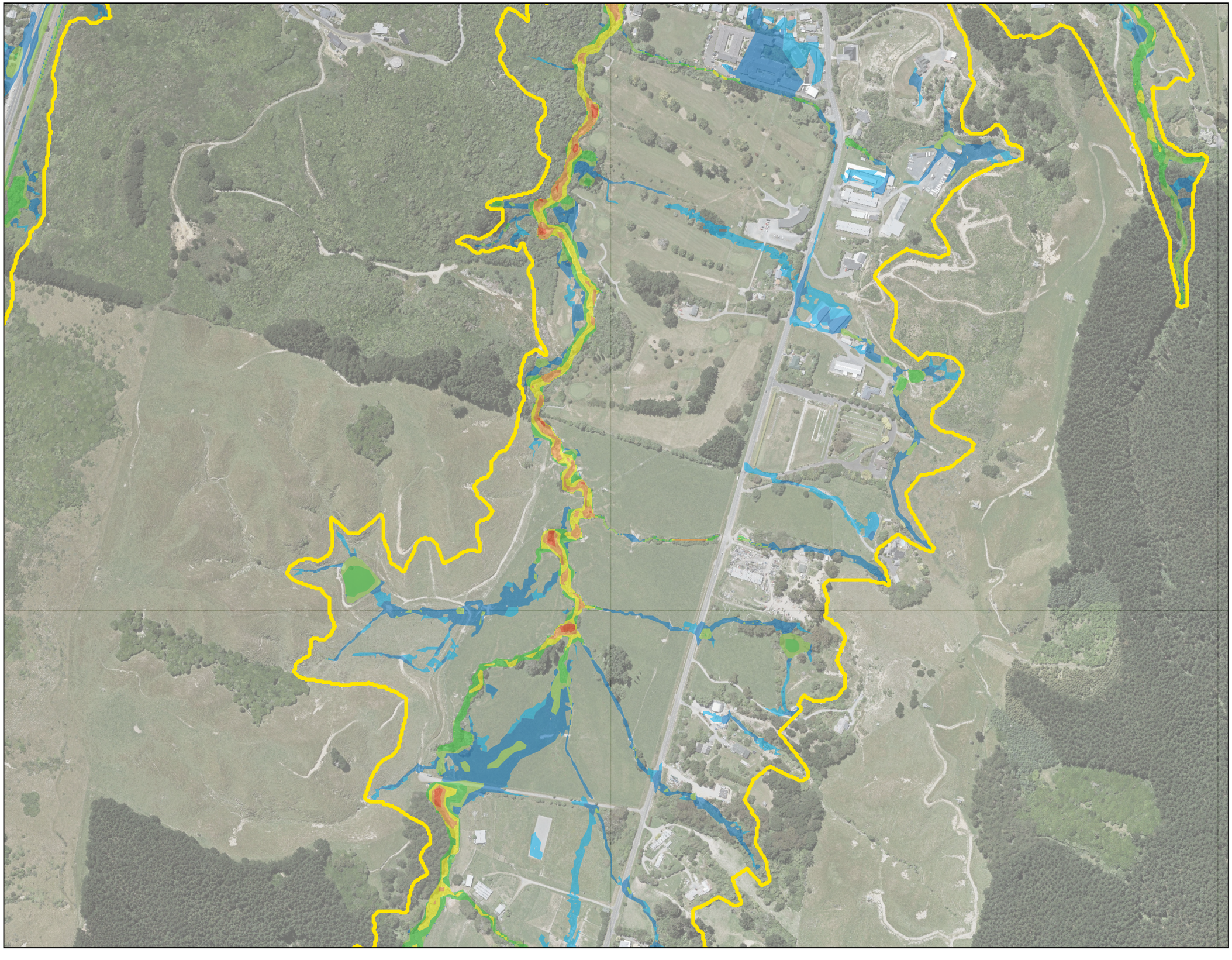
Depth

- 0.05 - 0.1 m
- 0.1 - 0.3 m
- 0.3 - 0.5 m
- 0.5 - 1.0 m
- 1.0 - 1.5 m
- 1.5 - 2.0 m
- 2.0+ m

Disclaimer:
The flood information contained within these plans has been derived from information and techniques available at the time of the study. It is provided to assist in redusing the flood risk for development in the area. However, the agencies and individuals involved in the assessment of the flood hazard assume no responsibility for any action by any agency or individual that is based on the information provided.

Wharemauku Flood Depth in a 100-Year Rainfall Event

2130 Projection - Page D2



Prepared by:
Awa Environmental Ltd
For:
Kapiti Coast District Council

1 Ghuznee St, Te Aro
Wellington 6011
www.awa.kiwi

0 150 m

Legend

Catchment Boundary

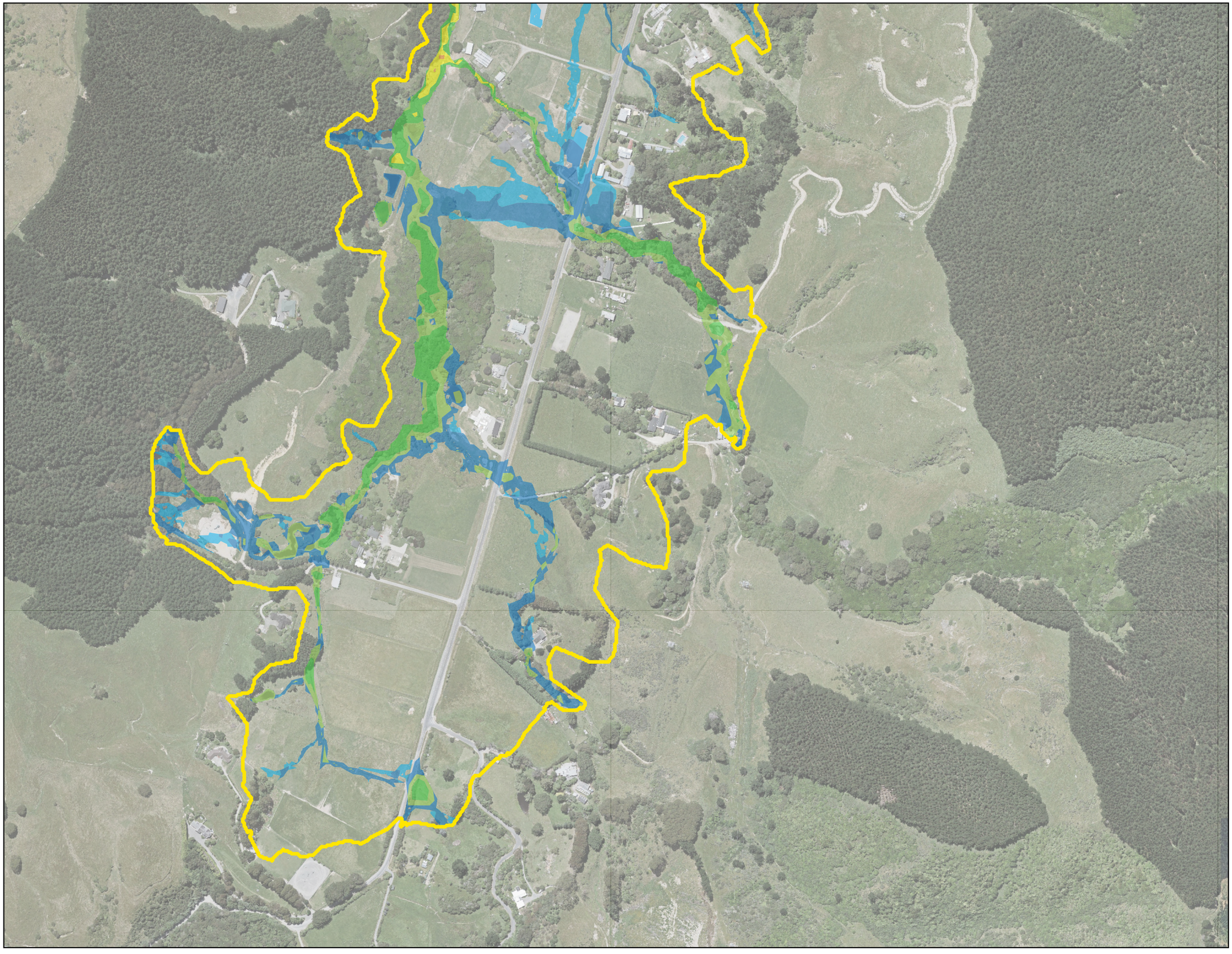
Depth

- 0.05 - 0.1 m
- 0.1 - 0.3 m
- 0.3 - 0.5 m
- 0.5 - 1.0 m
- 1.0 - 1.5 m
- 1.5 - 2.0 m
- 2.0+ m

Disclaimer:
The flood information contained within these plans has been derived from information and techniques available at the time of the study. It is provided to assist in redusing the flood risk for development in the area. However, the agencies and individuals involved in the assessment of the flood hazard assume no responsibility for any action by any agency or individual that is based on the information provided.

Wharemauku Flood Depth in a 100-Year Rainfall Event

2130 Projection - Page E2



Prepared by:
Awa Environmental Ltd
For:
Kapiti Coast District Council

1 Ghuznee St, Te Aro
Wellington 6011
www.awa.kiwi

0 150 m

Legend

- Catchment Boundary

Depth

- 0.05 - 0.1 m
- 0.1 - 0.3 m
- 0.3 - 0.5 m
- 0.5 - 1.0 m
- 1.0 - 1.5 m
- 1.5 - 2.0 m

Disclaimer:
The flood information contained within these plans has been derived from information and techniques available at the time of the study. It is provided to assist in redusing the flood risk for development in the area. However, the agencies and individuals involved in the assessment of the flood hazard assume no responsibility for any action by any agency or individual that is based on the information provided.



EMAIL: info@awa.kiwi

1 Ghuznee St, Te Aro, Wellington 6011