





Kāpiti Flood Hazard Management

Paraparaumu Beach Model Build Report

2/12/2024



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Executive Summary

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

The model build has been undertaken utilising TUFLOW modelling software (Release 2020-10-AC) 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 Paraparaumu Beach model uses a rain-on-grid 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.
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 and additional stormwater network detail.

The report is structured as follows:

Section 1 - An overview of the study location.
Section 2 - A summary of model features and approaches applied.
Section 3 - A summary of the model build process.
Section 4 - A summary of the model results.
Section 5 - Calibration and validation discussion.
Section 6 - 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.

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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 Paraparaumu Beach catchment.

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

- The Paraparaumu Beach model was developed in 2012 to cover local drainage areas from just south of the Kāpiti Coast Airport to Paraparaumu. It includes the Tikotu Stream and the Kenakena Drain which are modelled as open channels. The model is a two-way MIKE FLOOD coupled model incorporating the stormwater network using the surcharging manhole hydrographs from MOUSE as inputs into MIKE21.
- No updated three-way coupled model has been built.

The legacy model is currently configured to simulate the 2090-climate-horizon for events from the 10 year-ARI through to the 100 year-ARI storm 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 2011.

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 Management Methodology Report.

1.2. Objectives

The Overarching objectives of the Paraparaumu Beach model build are covered in the initial contract terms.

> *To provide KCDC with a TUFLOW stormwater model of the Paraparaumu Beach 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 in a client workshop covered in the Kāpiti Flood Hazard Management Methodology Report.

Specific objectives of the Paraparaumu Beach model build were to develop a TUFLOW stormwater model of the Paraparaumu Beach catchment which can simulate a range of rainfall and tidal scenarios.

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

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- 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 Paraparaumu Beach Catchment updated by Jacobs in 2012.

Key features of the 2012 legacy model include:

PIPE NETWORK
- Simplified pipe network representation in MOUSE.
  - 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,
  - Connection to Waikanae River boundary.

2D DOMAIN
- Domain grid resolution of 5 m.

HYDROLOGY
- Sub-catchment-based hydrology.
  - 2090-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
- 2-way coupled M21, M11model.

1.4. Modelling Approach

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

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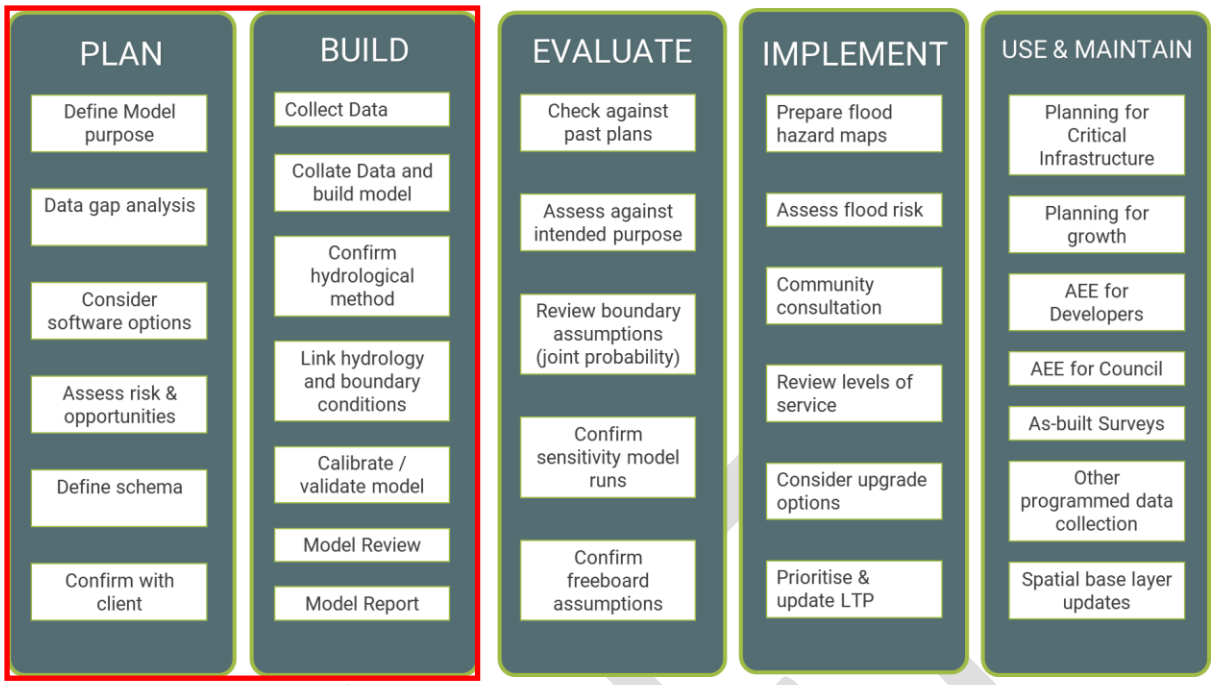


Figure 1. Modelling approach.[1]

1.5. Report Structure

The report is structured as follows:

Section 1 - An overview of the study location.
Section 2 - A summary of model features and approaches applied.
Section 3 - A summary of the model build process.
Section 4 - summary of the model results
Section 5 - Calibration and validation discussion
Section 6 - 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 expected to worsen with climate change, especially in coastal areas affected by Sea Level Rise (SLR).
2. The Paraparaumu Beach model uses a rain-on-grid 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.

[1] Adapted from the National Modelling Guidelines

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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 and additional stormwater network detail.

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2. Catchment Description

2.1. Location and topography

The Paraparaumu Beach catchment covers an area of approximately 4.8 km^2 and is located within the Kāpiti District. The catchment is largely confined to the coastal margin and is bounded by the Waikanae River to the north and the Mazengarb and Wharemauku catchments along its south-eastern extent, as shown in Figure 2.



Figure 2. Paraparaumu Beach catchment extent.

2.2. Geology

The geology of the catchment has been shaped by the interaction of aeolian and fluvial process 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] Kapiti Flood Hazard Management Methodology Report, 2024.

2.3. Existing Land Use

The Paraparaumu Beach catchment reflects the various growth phases which have occurred across the wider Kāpiti district. The catchment is predominantly residential in nature with traditional development along the coastal margin, broken by the commercial area adjacent the Tikotu Stream. To the north the Kotuku residential development represents an isolated location of more recent development. The two largest underdeveloped areas in the catchment are the links golf course and a section of the airport. While the airport may be developed in the future it is likely that intensification will be the main form of development in the catchment.

2.4. Stormwater system

The Paraparaumu Beach stormwater network consists of pipes, catchpits, manholes, detention ponds, pump-station and interconnected streams and drains. The Tikotu Stream, historic drainage course of the Mazengarb Stream, and the Kena Kena Stream are the main water courses in the catchment. Both streams are utilised for drainage from the surrounding stormwater network to the coast.

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3. Model Build

3.1. Model Overview

The purpose and use of the models is discussed in the Kāpiti Flood Hazard Management Methodology Report.

The following section defines the conceptual schema utilised to represent the real-world characteristics of the Paraparaumu Beach 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). • Tailwater conditions incorporating Sea Level Rise (SLR), Storm Surge and the Mean High-Water Springs (MHWS) tidal cycle for Paraparaumu Beach.

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
	Lynker - Kāpiti_Coast_Landcover_20210527.gdb	27th May 2021

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DATA	DETAILS	DATE SUPPLIED
Land cover	Koordinates - Landcare Research - Land Cover Database version 5 (LCDB v5)	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 - Gaps_North.xns11	6th March 2019
Culverts (survey)	Jacobs - Gaps North.nwk11	6th March 2019
Tide (validation)	Website - May 2015, December 2021 validation tide data from GWRC live monitoring and research website	N/A
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

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DATA	DETAILS	DATE SUPPLIED
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.

DATA	DETAILS
Pipe network	• Represented in 1D using TUFLOW's ESTRY module. • All stormwater drainage sumps, pipes 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. • The extent of open channels is shown in Figure 5.
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 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.

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

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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. Rain on Grid extent (blue).



Figure 7. Initial loss infiltration model.

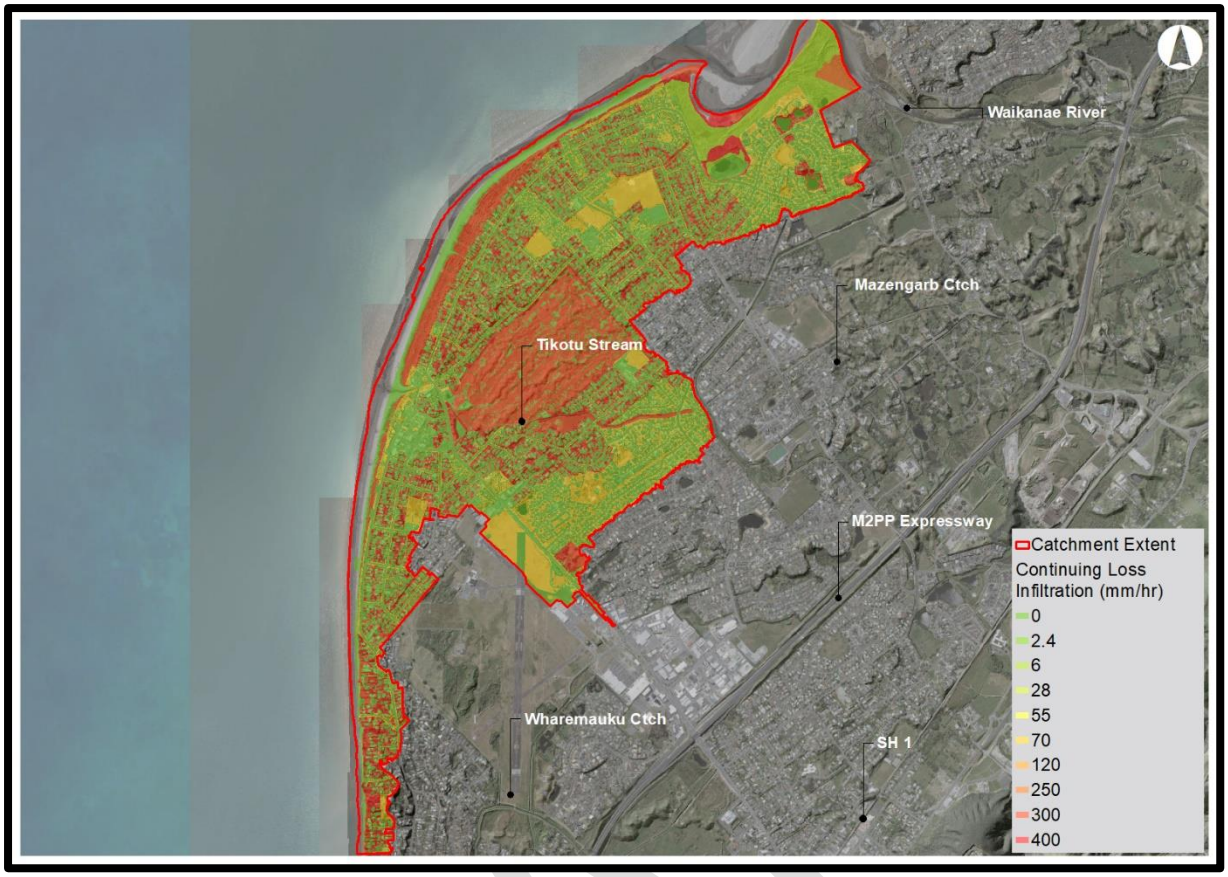


Figure 8. Continuing loss infiltration model.

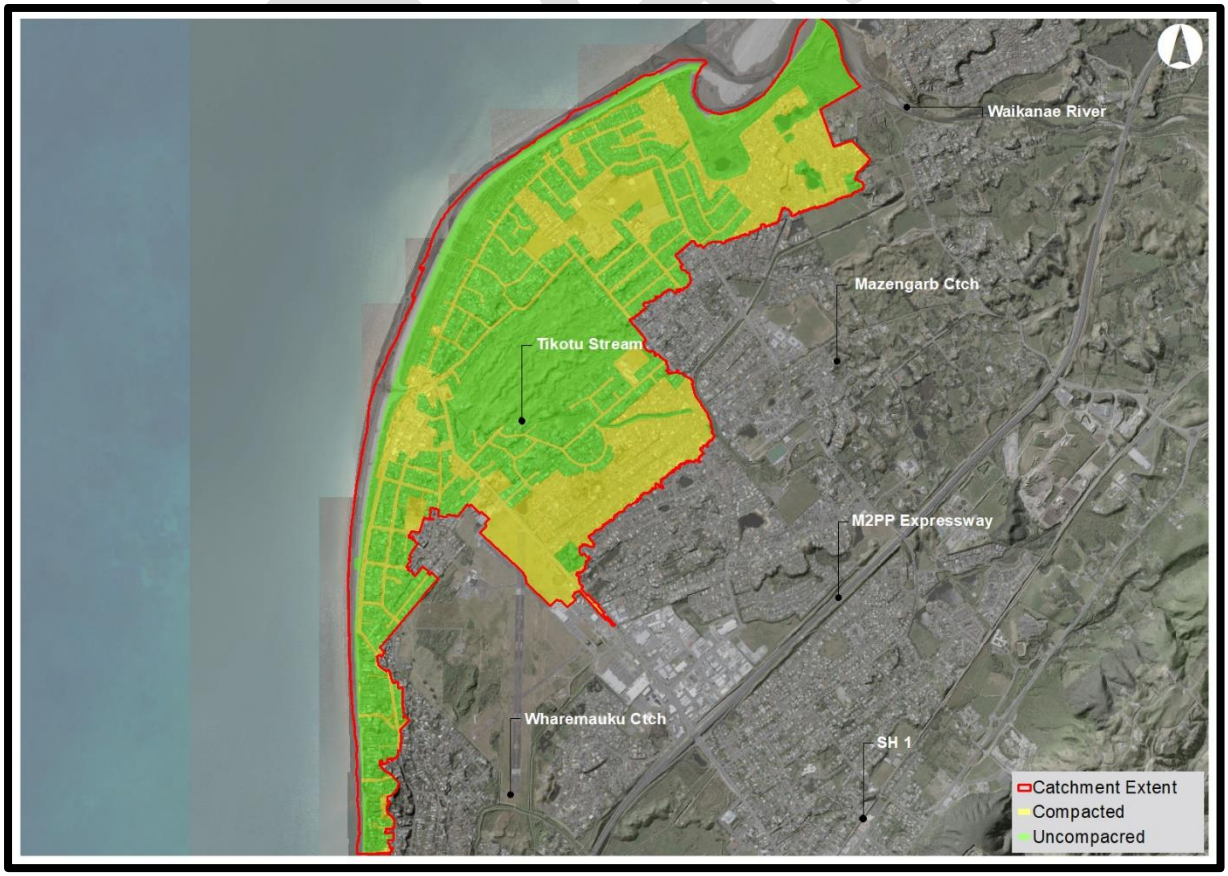


Figure 9. Extent of the soil compaction layer.

3.4. Pipe Network

The 1D network comprises gravity mains which drain to the Tikotu Stream or Kena Kena open channel with some isolated network draining directly to the coast or via pump-station.

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 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.

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DATA	DETAILS
	• 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.
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	• Percival Road pump-station

3.5. Key Structures and Assets

There are several key culverts within the Paraparaumu Beach catchment which represent constraints in the network. The location of these assets are shown in Figure 10 with the dimensions and configuration shown in Table 6.

There is one pump station within the catchment area. The location of this asset is shown in Figure 11 with the details shown in

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Table 7.



Figure 10. Locations of key open channel structures.

Table 6 Culvert descriptions

CULVERT ID	CULVERT NAME	DIMENSIONS/CONFIGURATION
1	Ocean Road	1 * arch culvert
2	The Sands	1 * 1.5 circular culvert
3	Kāpiti Road	1 * arch culvert
4	Marine Parade	1 * arch culvert
5	Mazengarb Road	1 * 0.9 circular culvert
6	Kena Kena	1 * 0.9 circular culvert
7	Manly Street	1 * 0.9 circular culvert

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Figure 11 Modelled pump stations

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Table 7. Pump station details.

MODEL ASPECT		DETAILS
Pump stations	(1) Percival Road	**Wet-well Details** • 3.1416 x 1.25m(2) x 3.5m. **Pump Details** • 2 x Homa M3448-E74, • 11 Kw, • 20 Amps, • Installation date 1990, • Flow rate (assumed). **Rising main details** • 254.24meters of 225mm PVC, • Static head 6.5m [contour lid level at PS (4.75m) – depth of well (3,5m) – contour at outfall (7.75m)], • Friction loss estimate (assumed), • Estimated flow rate based on above = assumed, • Pump start level 40%, • Pump stop level 10%, • Lid RL from GIS = 4.75m, • Highest point of rising main from GIS = 7.75m.

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.

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<table>
<tr><th>MODEL ASPECT</th><th></th><th>DETAILS</th></tr>
<tr><td></td><td>Model domain</td><td>

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.

</td></tr>
<tr><td rowspan="5">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.
The ground water table (used to limit soil capacity) is initialised to the Mean Sea Level (MSL) for the climate horizon being simulated: for 2130 (RCP8.5M) this corresponds to 1.32 m RL.

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

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<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 rowspan="2">2D configuration</td><td>Resistance</td><td>

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

The initial water level is set automatically to the level of the downstream water level boundary at the start of each simulation.

</td></tr>
<tr><td>Hydrology</td><td>Rain-on-grid</td><td>

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.

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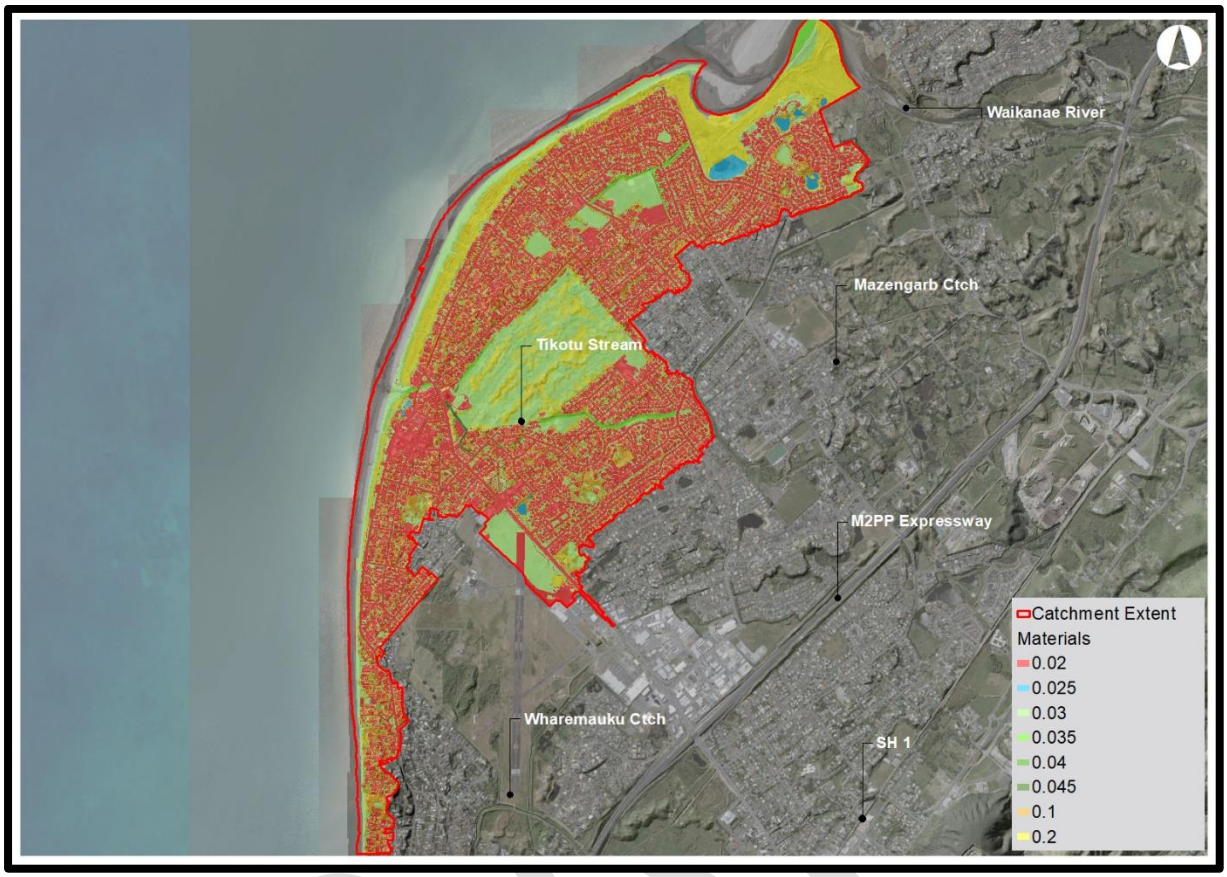


Figure 12. Manning's n overland flow resistance parameters applied to the model.

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

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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

Two different types of boundaries are applied to the TUFLOW model, as shown in Table 10.

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 and 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.
Tide	Applied at the downstream end of the Tikotu Stream and Kena Kena Stream branch at the coast.

3.8. Model Limitations

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

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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 and, in the absence of data, engineering judgement 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. Therefore, the invert level in the open channel in these locations may have changed over time depending on aggradation or scouring of the channel.
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 (2 m). 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 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.

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TYPE	ASSUMPTION
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.

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4. Model Summary

4.1. Results Comparison

While the legacy MIKE FLOOD Paraparaumu Beach Catchment model (2012) followed a different model build methodology to the recent TUFLOW modelling, it is worth undertaking a high-level comparison of the modelling results as 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 comparisons at various locations are shown in Figure 13 - Figure 16. 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 which 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 links golf-course and adjacent Kāpiti Road in the airport land.

In both these locations the TUFLOW model (rain-on-grid) captures the available storage within the catchments before flows enter the downstream open channels. In the MIKE FLOOD model, the catchment is loaded directly to the downstream open channel and pipe network, as shown in Figure 17.

Having reviewed the results our conclusion is 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 that has improved the quality of understanding of local flooding. The 100YR-ARI 2130 peak depth results are shown in Appendix A.

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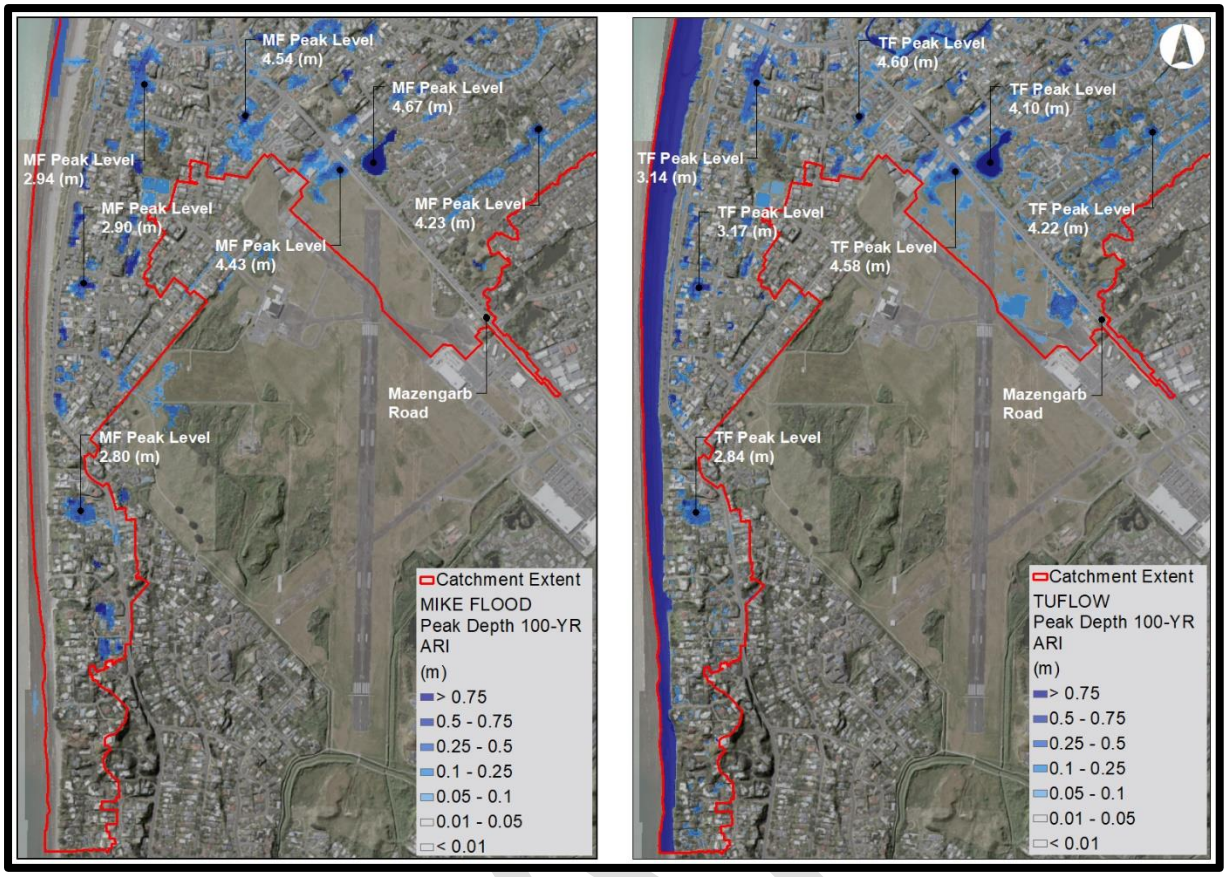


Figure 13. Paraparaumu Beach sheet 1 – peak water level results compare MIKE FLOOD verses TUFLOW.

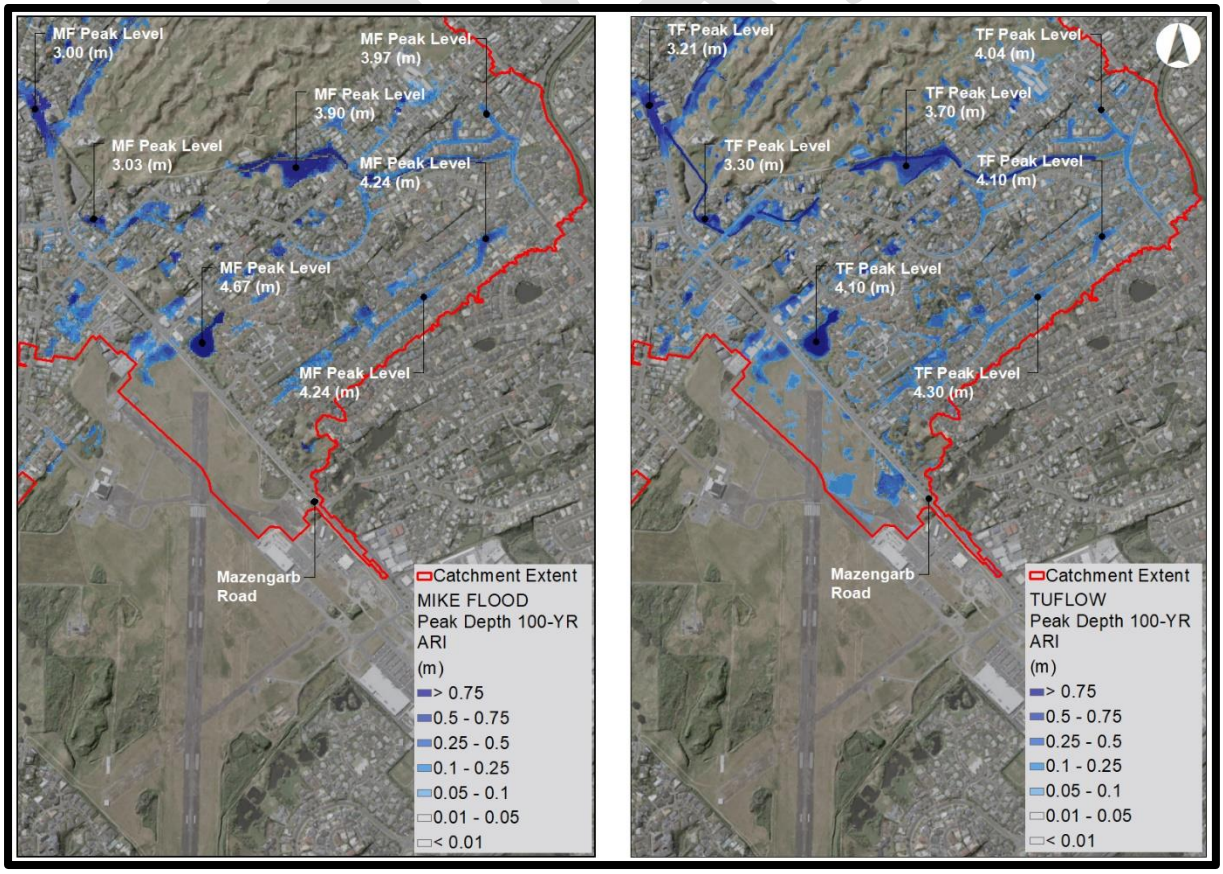


Figure 14. Paraparaumu Beach sheet 2 – peak water level results compare MIKE FLOOD verses TUFLOW.

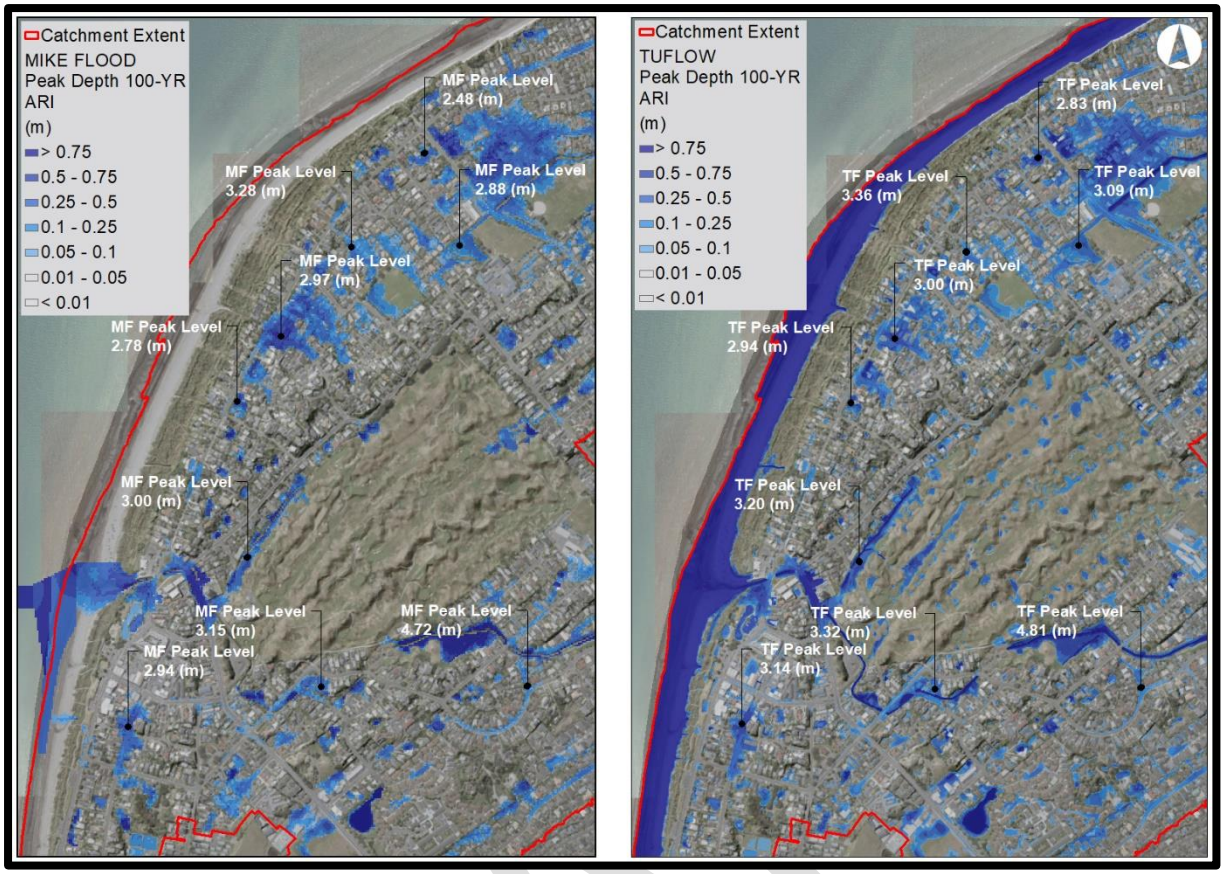


Figure 15. Paraparaumu Beach sheet 3 – peak water level results compare MIKE FLOOD verses TUFLOW.

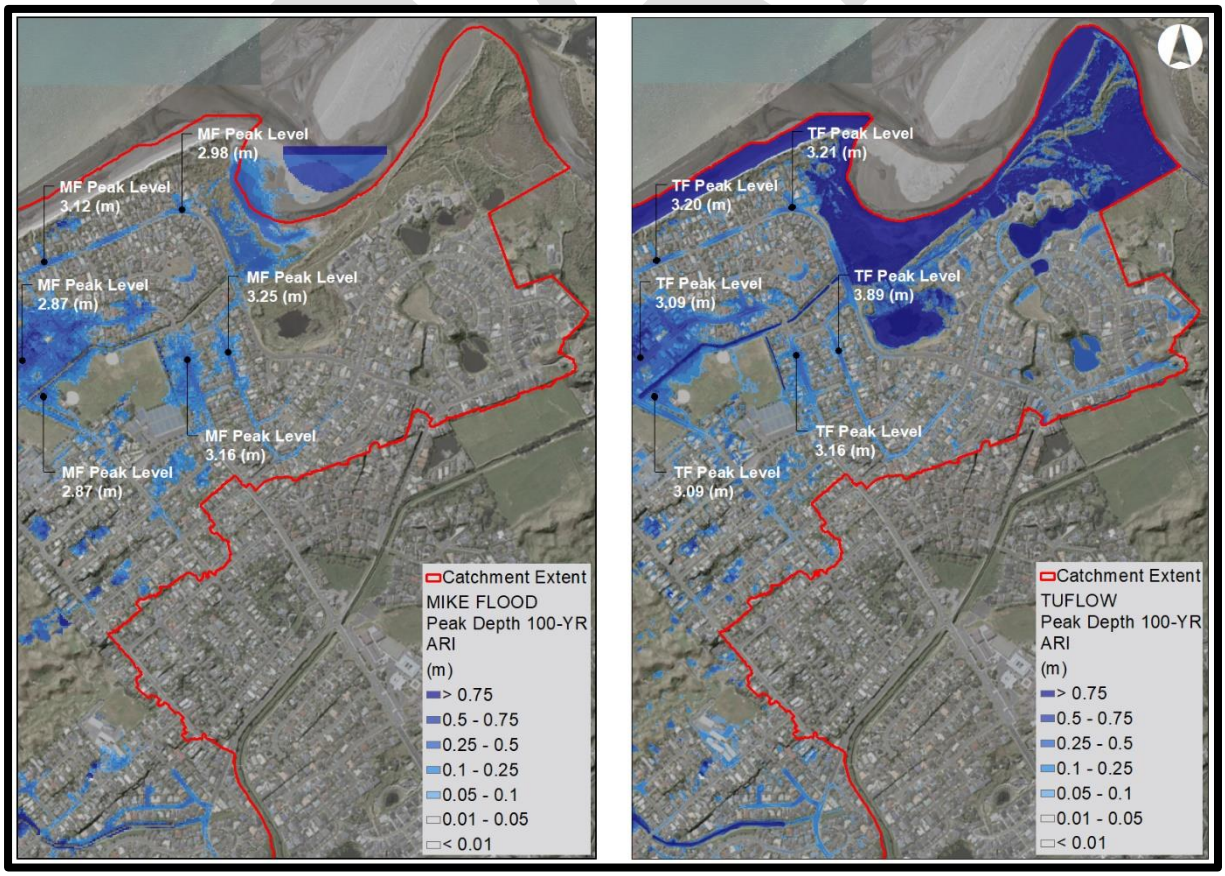


Figure 16. Paraparaumu Beach sheet 4 – peak water level results compare MIKE FLOOD verses TUFLOW.

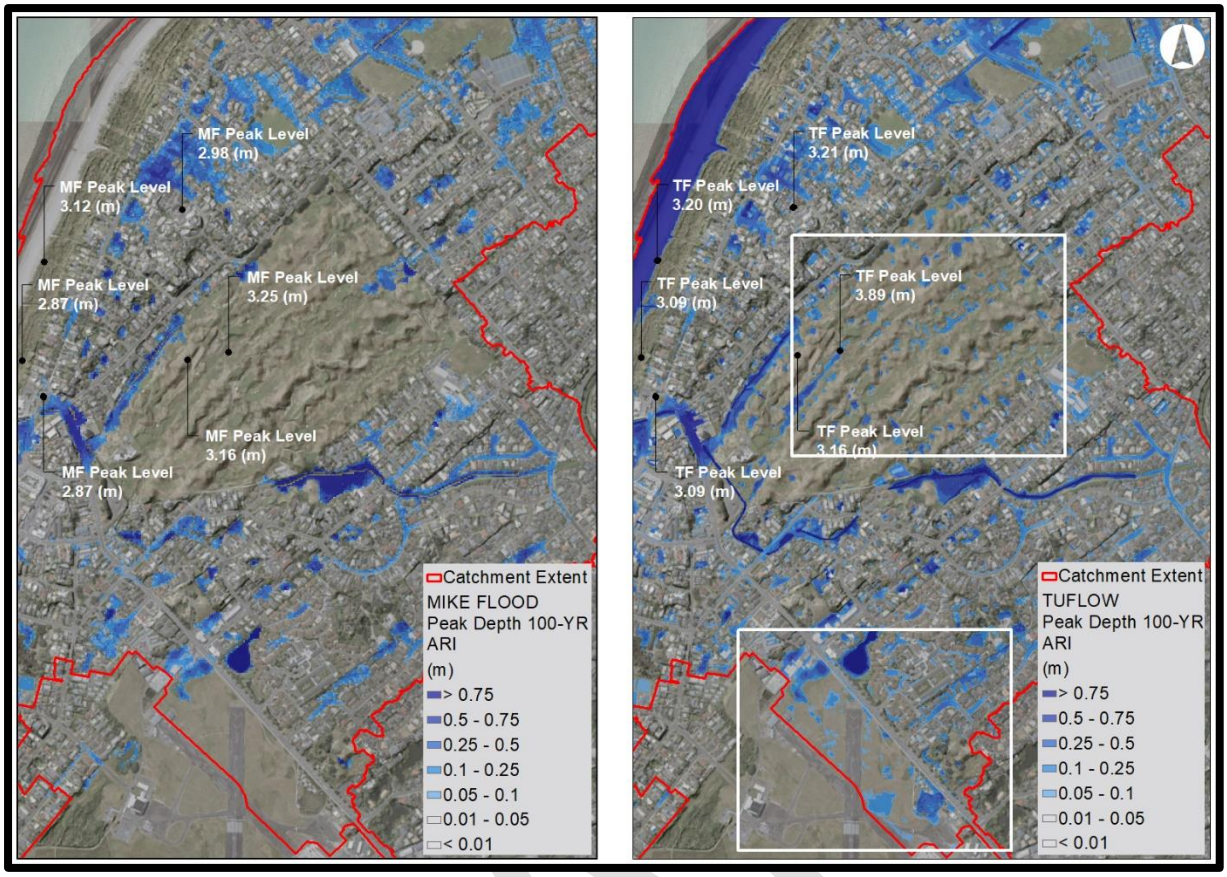


Figure 17. Difference in ponding as a result of modelling methodology (MIKE FLOOD verses TUFLOW).

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5. Model Validation

5.1. Introduction

To ensure confidence in the Paraparaumu Beach 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.

5.2. Flood Events

The Paraparaumu Beach 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 19). This rainfall gauge data was sourced from Cliflo and captured ~80 years of rainfall data, as shown in Table 13.

Table 13. 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

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5.2.1. May 2015

On the 14th-15th of 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 14.

Table 14. May 2015 peak rainfall, return period at Paraparaumu EWS (E04995).

TIME (HRS)	PEAK RAINFALL (MM)	RETURN PERIOD (ARI)[3]
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 18. 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 19.

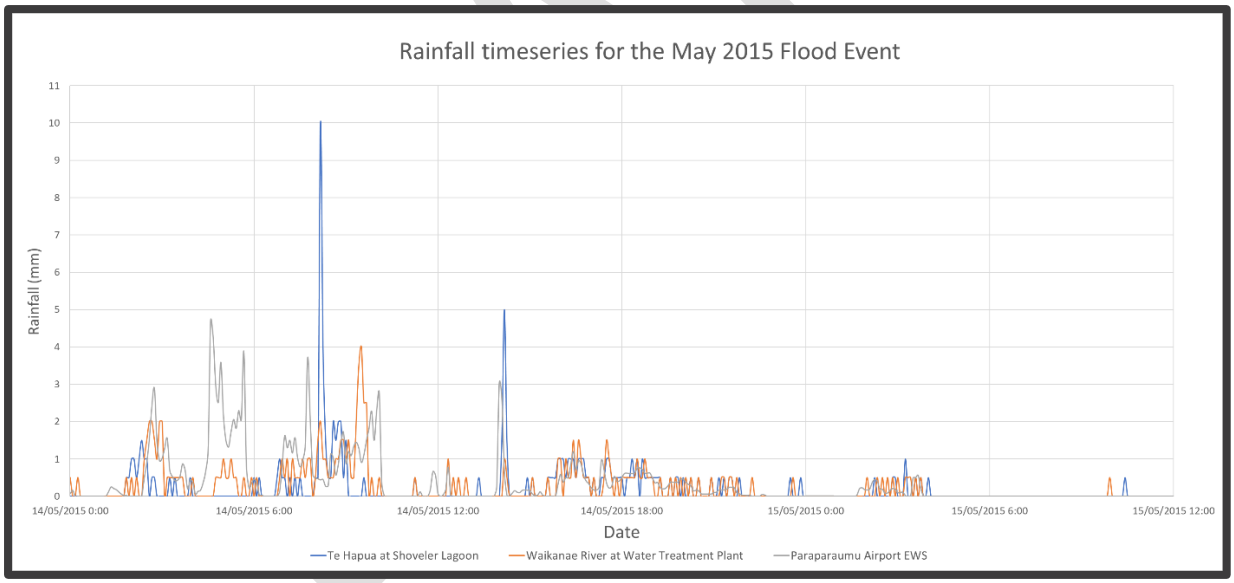


Figure 18. Rainfall depths at three gauging stations.

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

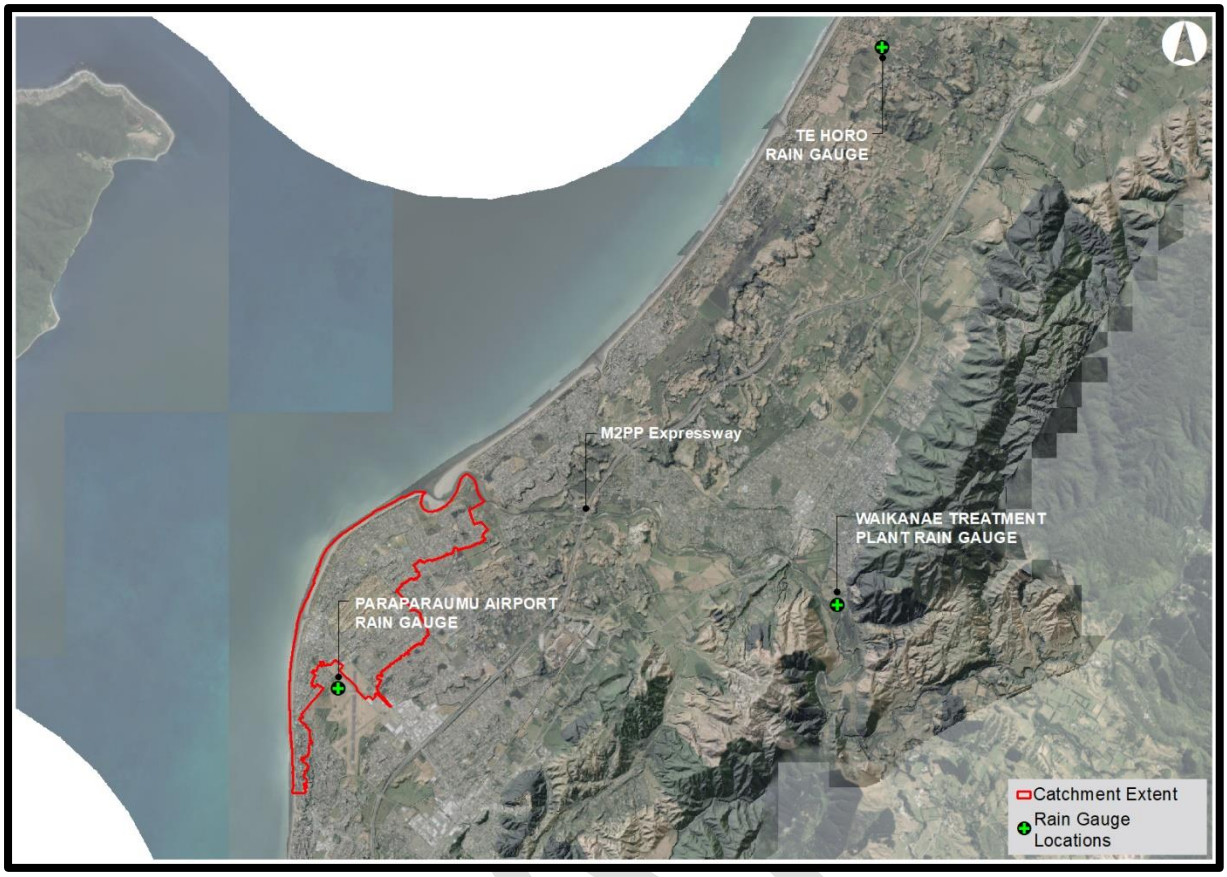


Figure 19. Rain gauge locations.

This rainfall event was significant enough to generate several flooding complaints to the Council which are spatially recorded in the incidence database as shown in Figure 20. 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.

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Figure 20. May 2015 Council complaints database locations.

5.2.2. 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 15. 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 15. 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

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The rainfall depths at the three key gauging sites are shown in Figure 21. 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.

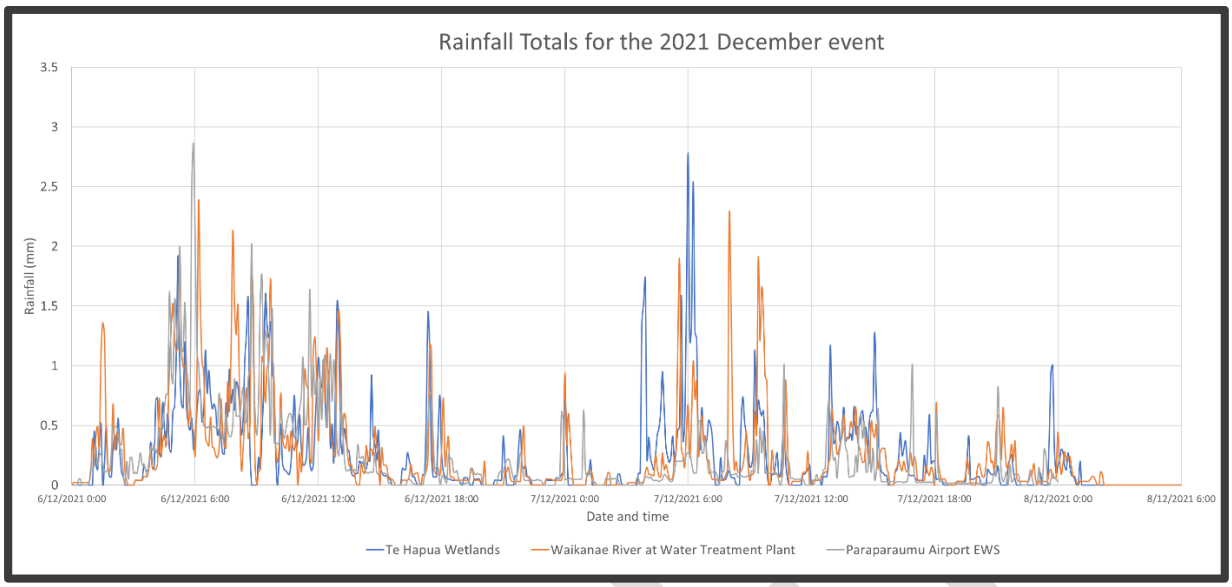


Figure 21. Rainfall depths at three gauging stations.

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 22.

There was also work undertaken by the Councils 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.

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Figure 22. December 2021 Council complaints database locations.

For each recorded complaint there is varying levels of information recorded in the incident database system. A selection of affected properties showing caller description and modelled peak flood depth for the 2015 rainfall event are shown in Figure 23 - Figure 28.

A selection of affected properties showing description, modelled peak flood depth and photographic evidence of flooding for the 2021 rainfall event are shown in Figure 29 – Figure 31.

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.

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REPORTED FLOOD INCIDENT (MAY 2015 EVENT)	
Affected properties	Vaucluse Avenue 11
Caller description	"Section is flooded, and water is up to her ankles in the garage - doorways are blocked with water. Can we deliver sandbags asap."
Description of modelled flooding	The model shows flooding, areas affected are situated in low lying areas.
MODEL RESULT	



Figure 23. Paraparaumu model results Vauluse Avenue

REPORTED FLOOD INCIDENT (MAY 2015 EVENT)	
Affected properties	Manly Street (142, 146)
Caller description	"2 houses at 142 & 146 Manly St, (low Line) PPB area concern due to flooding & there's no one home. Caller will keep an eye on this but still a good idea to investigate. Thanks."
Description of modelled flooding	The model shows flooding, areas affected are situated in low lying areas.
MODEL RESULT	



Figure 24. Paraparaumu model results Manly Street

REPORTED FLOOD INCIDENT (MAY 2015 EVENT)	
Affected properties	Te Kupe Road (34, 7a, 7b)
Caller description	Flooding from road going onto property requesting sandbags at entrance. House is flooding and needs attention. 34 Te Kupe Road, is concerned that at high tide, he is going to require sandbags. water has not reached drive yet. He said no one lives at property, can someone please call him
Description of modelled flooding	Catchpits are unable to keep up with the flooding in the road due to the water levels in the streams.
MODEL RESULT	



Figure 25. Paraparaumu model results Watson Drive/Te Kupe Road

REPORTED FLOOD INCIDENT (MAY 2015 EVENT)	
Affected properties	Ngapotiki Street 19
Caller description	Workshop at front has water right through attached to house is flooded and water is rising -requesting sandbags. Needs pumping out
Description of modelled flooding	There is a low-lying workshop that is getting flooded.

MODEL RESULT



Figure 26. Paraparaumu model results Ngapotiki Street

REPORTED FLOOD INCIDENT (MAY 2015 EVENT)	
Affected properties	Mahana Road 19a
Caller description	Re 19A Mahana Road which is being evacuated with help of a boat right now. Fire brigade has visited but couldn't pump out. Request review of situation - a visit to site, if possible, please. (Knee deep in water in house). Request for sandbags - section flooded and water is lapping up to conservatory windows
Description of modelled flooding	The front yard is a depression that has no way of draining quickly. Retaining the flooding.
MODEL RESULT	



Figure 27. Paraparaumu model results Mahana Road

REPORTED FLOOD INCIDENT (MAY 2015 EVENT)	
Affected properties	Mazengarb Road
Caller description	Water starting to run onto driveway - possible to get sandbags please - asap
Description of modelled flooding	Flooding in the road due to being unable to drain to the nearby stream.
MODEL RESULT	

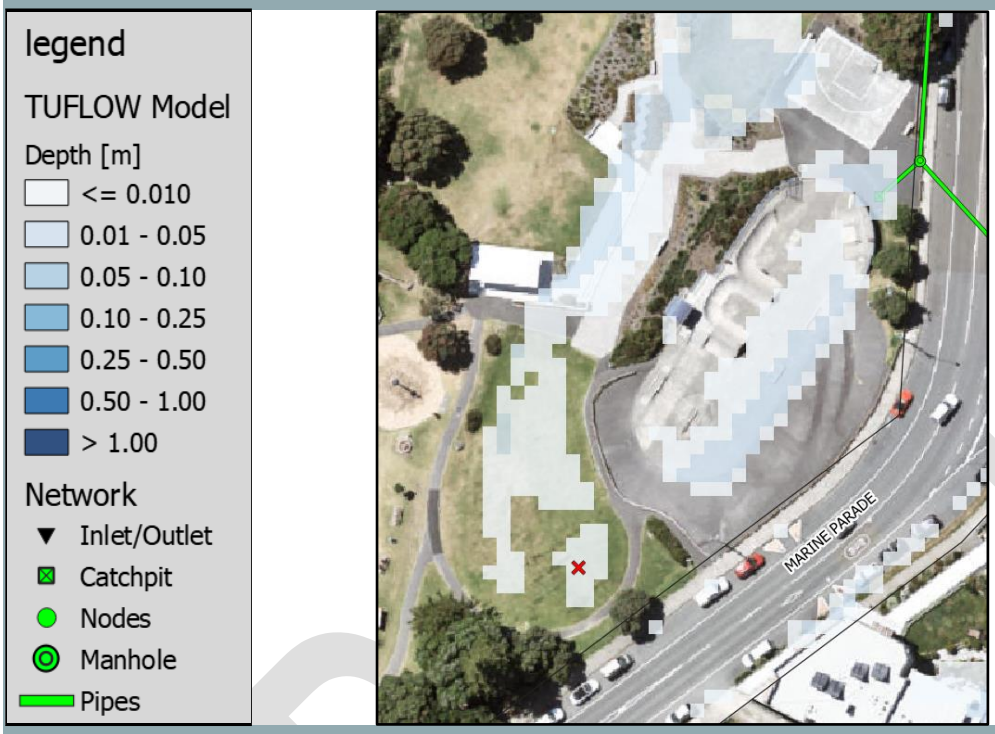


Figure 28. Paraparaumu Beach model resultsMazengarb road

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REPORTED FLOOD INCIDENT (DEC 2021 EVENT)	
Affected properties	Marine Parade
Description of modelled flooding	Shallow flooding on the field

MODEL RESULT



PHOTOGRAPHIC EVIDENCE (DEC 2021 EVENT)



Figure 29. Paraparaumu MacLean Park shallow flooding December Event

REPORTED FLOOD INCIDENT (DEC 2021 EVENT)	
Affected properties	Mazengarb Road (12,14,15,16,17,18,19,20,21,22,23,34,25,26)
Description of modelled flooding	The model shows flooding, areas affected are situated in low lying areas.

MODEL RESULT



PHOTOGRAPHIC EVIDENCE (DEC 2021 EVENT)



Figure 30. Paraparaumu Mazengarb Road flooding December Event

REPORTED FLOOD INCIDENT (DEC 2021 EVENT)	
Affected properties	Byron street
Description of modelled flooding	Flooding in low lying areas around the catchpits that drain into the nearby stream.

MODEL RESULT



PHOTOGRAPHIC EVIDENCE (DEC 2021 EVENT)



Figure 31. Paraparaumu Byron Street December Event.

5.3. Validation

Calibration, validation, and verification are detailed in the Kāpiti Flood Hazard Management Methodology Report.

Validation of the Paraparaumu Beach 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 to align model results with recorded flooding. The Mazengarb was our first validated catchment in the modelling programme and many learnings from this validation were carried through to other models. For the Paraparaumu Beach catchment the model went through two iterations.

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 the Kāpiti Flood Hazard Management 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 areas the modelled 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.

Three examples showing the comparison of the impact of model changes between the initial model iteration and the final model iteration, one utilising photographic evidence, from the December 2021 event are shown in Figure 32 - Figure 34.

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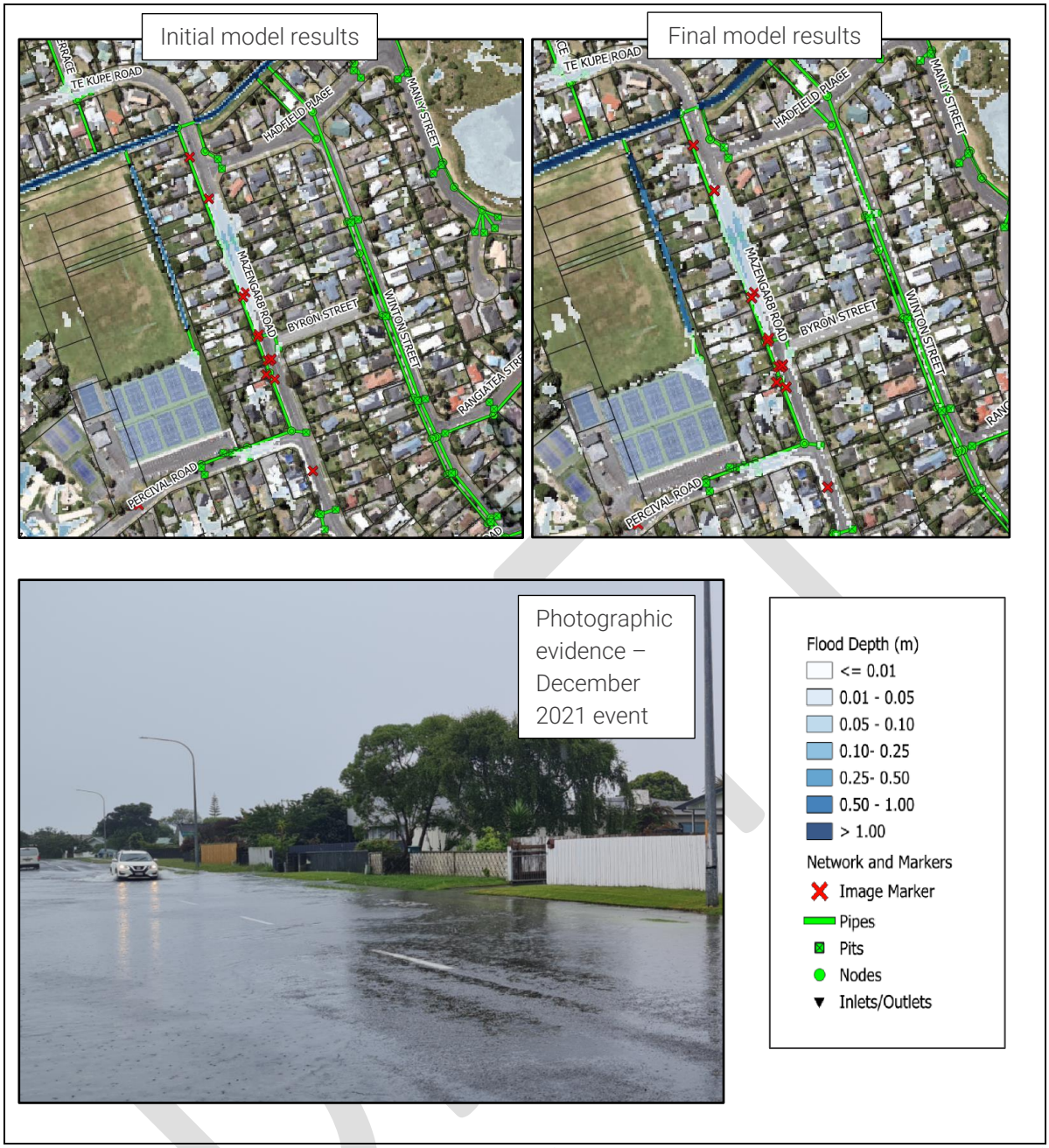


Figure 32. Mazengarb Road model results comparison (left- initial model results, right- final model results).

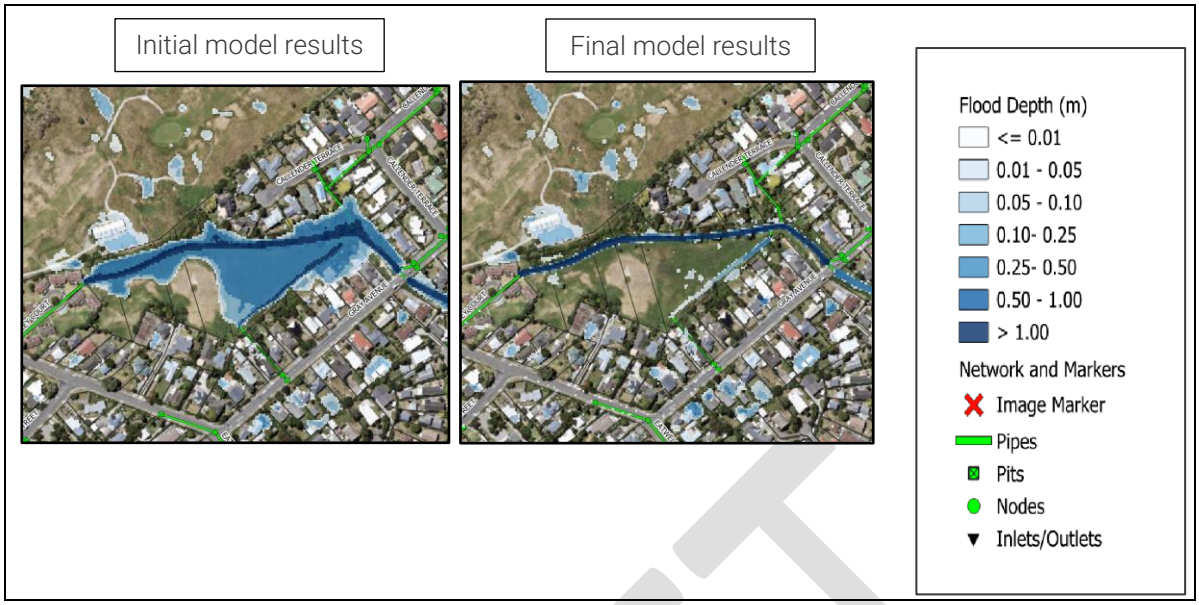


Figure 33. Paraparaumu Stream model results comparison. (left- initial model results, right- final model results).

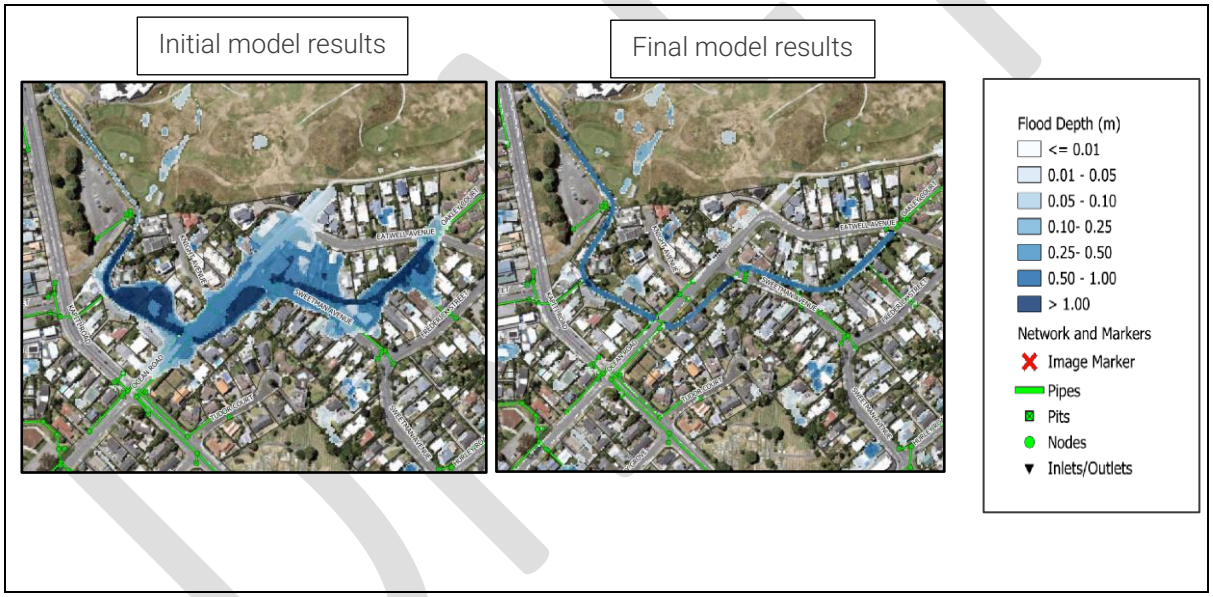


Figure 34. Paraparaumu Stream model results comparison. (left- initial model results, right- final model results).

In its final version the model achieved a good calibration with recorded flooding. It is important the Council continue to collect physical date stamped evidence of larger storm events to enable adequate verification of the validated model into the future.

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6. Recommendations

The model validation has provided confidence in the way the model performs for the Paraparaumu Beach 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.

6.1.1. 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.

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Appendix A – 100YR ARI 2130 Peak Flood Depths

DRAFT

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

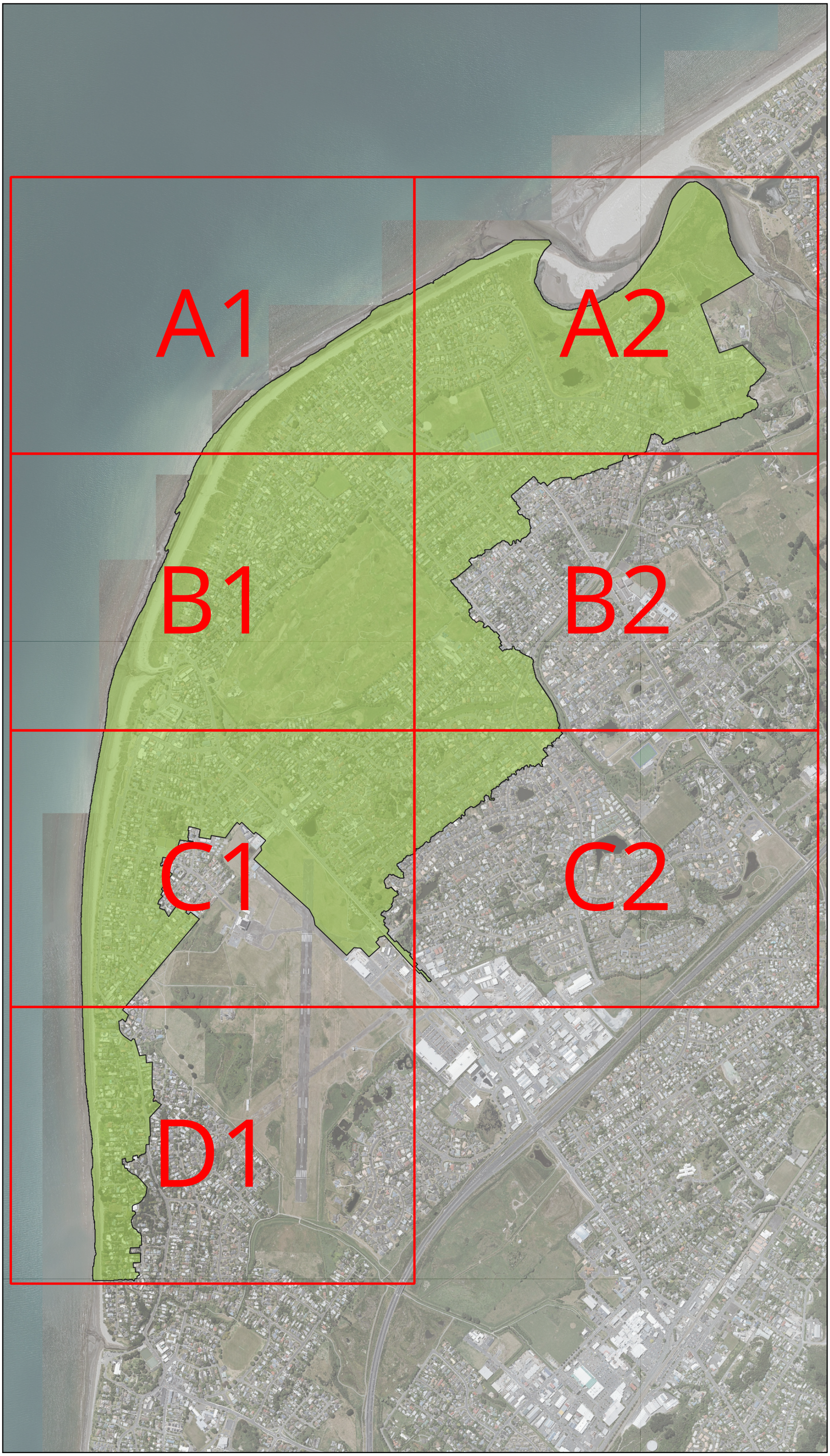
  Where a proposal occurs within Greater Wellington Regional Council's flood model extent, its written approval should be sort. Although the outputs from GWRC models are incorporated within the District Plan flood hazard maps, KCDC holds none of the supporting information. Both Councils have a duty under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

Paraparaumu Beach 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

0 500 m

Legend

- Page Reference
- Catchment Extent

Disclaimer:
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Paraparaumu Beach Flood Depth in a 100-Year Rainfall Event

2130 Projection - Page A1



Prepared by:
Awa Environmental Ltd
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Kapiti Coast District Council

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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:
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Paraparaumu Beach 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
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Paraparaumu Beach Flood Depth in a 100-Year Rainfall Event

2130 Projection - Page B1



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0 150 m

Legend

Catchment Boundary

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Paraparaumu Beach Flood Depth in a 100-Year Rainfall Event

2130 Projection - Page B2



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0 150 m

Legend

Catchment Boundary

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Paraparaumu Beach Flood Depth in a 100-Year Rainfall Event

2130 Projection - Page C1



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0 150 m

Legend

- Catchment Boundary

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Paraparaumu Beach Flood Depth in a 100-Year Rainfall Event

2130 Projection - Page C2



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Paraparaumu Beach Flood Depth in a 100-Year Rainfall Event

2130 Projection - Page D1



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0 150 m

Legend

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