

Kāpiti Flood Hazard Management

Muaupoko Model Build Report

Date 27/06/2024

Excellence Heart Innovation

MUAUPOKO MODEL BUILD REPORT

Project number	J000865 Muaupoko Model Re-build
Version number	1.0
Date	27th June 2024
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VERSION	DATE	DESCRIPTION	AUTHOR	REVIEWED
1.0	27/06/24	Draft for client review	Avinash Chakravarthy	Tony Trueman

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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 Muaupoko catchment.

The model build has been undertaken utilising TUFLOW modelling software (Release 2023-03-AE) and includes all Council-owned manholes, 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 an update on the TUFLOW model developed in 2022. Key changes from the previous model include:

1. The Muaupoko 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.
2. 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.
3. 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 Muaupoko model has been validated using available historic data and achieved a good validation.

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 calibrated to the August 2022 and validated to the 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.

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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 Muaupoko catchment.

In 2022 a high-level sub-catchment based 2D TUFLOW model of the Muaupoko Stream catchment was built by AWA, which excluded the Nikau Valley residential catchment area.

The details of the standards used and the methodology for the model build are covered in section 01 of the Stormwater Modelling Methodology Report.

1.2. OBJECTIVES

The Overarching objectives of the Muaupoko model build is to update the Muaupoko Catchment Model to the same standard as the surrounding urban area models.

Specific objectives of the Muaupoko model build were to develop a TUFLOW stormwater model of the Muaupoko 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:

- 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. MODELLING APPROACH

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

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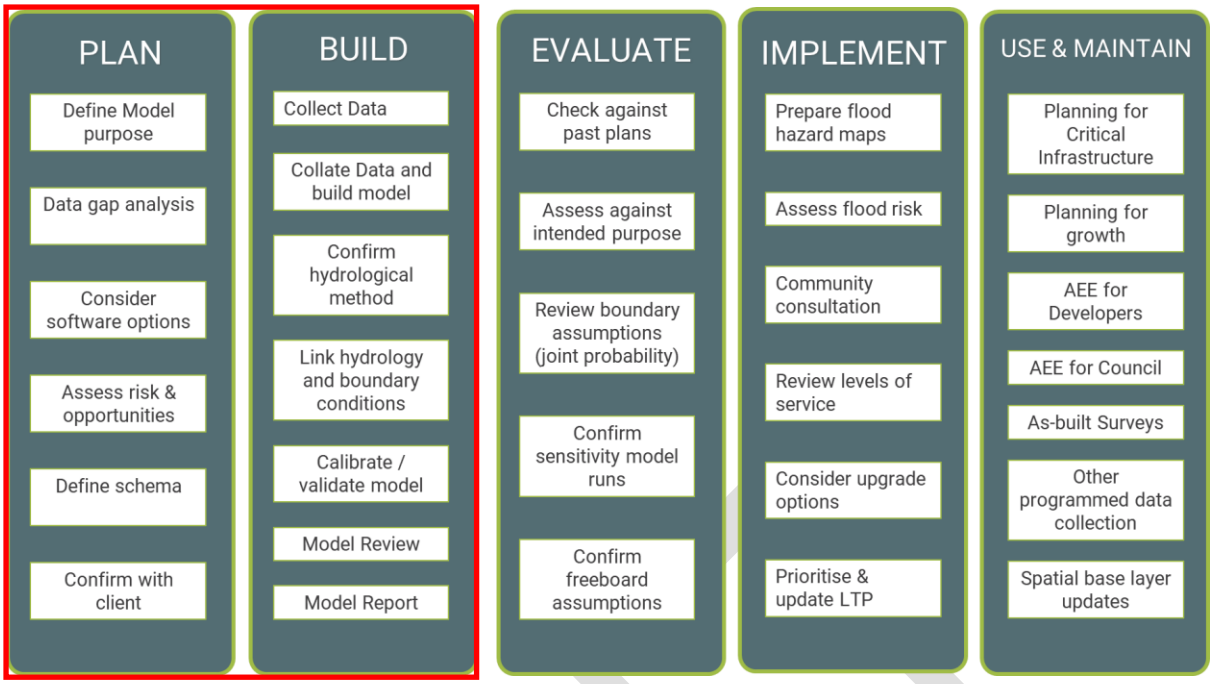


Figure 1. Modelling approach.

1.4. 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 - Calibration and validation discussion.
Section 5 - Conclusions and recommendations.

1.5. IMPORTANT MODEL UPDATES

The model is a substantial update on the historic model. 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 Muaupoko 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.

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2. CATCHMENT DESCRIPTION

2.1. LOCATION AND TOPOGRAPHY

The Muaupoko catchment covers an area of approximately 3.7 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 and the Waikanae River to the North, as shown in **Figure 2**.



Figure 2. Muaupoko 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.

2.3. EXISTING LAND USE

The Muaupoko catchment has largely been isolated from the various growth phases which have occurred across the wider Kāpiti district. South/east of the old SH 1, in the steeper ranges, the land use is predominantly native, exotic species and farmland. The Nikau Valley residential development is

located at the head of the catchment. This gives way to larger lifestyle blocks and farmland in the lower reaches of the catchment adjacent the Waikanae River.

2.4. STORMWATER SYSTEM

The Muaupoko stormwater network consists of pipes, catchpits, manholes, detention ponds and interconnected streams and drains with culverts under road and rail crossings. The Waikanae River is the main open channel at the downstream extent of the catchment.

There is limited stormwater network within the catchment, mostly concentrated within the Nikau Valley residential area and around the new SH1. The Muaupoko Stream is the main open channel in the catchment which intercepts run-off from the incised open channels in the ranges and routes it to the Waikanae River. The Muaupoko Stream is heavily modified along its length with a number of culvert crossings and piped sections.

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3. MODEL BUILD

3.1. MODEL OVERVIEW

The purpose and use of the models is discussed in the Methodology (**Section 1**) of the Kāpiti Flood Hazard Management report.

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

Table 1. Key details of the model build.

ITEM	DESCRIPTION
Software	TUFLOW version 2023-03-AE
Coordinate system	New Zealand Transverse Mercator 2000 (NZTM 2000)
Vertical datum	New Zealand Vertical Datum 2016 (NZVD2016)
Validation scenarios	December 2021 and August 2022 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, Storm Surge and the Mean High-Water Springs (MHWS) tidal cycle for Waikanae catchment, adjacent to Muaupoko. These tidal boundaries have been prepared in conjunction with the Takutai Kāpiti team.

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**.

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3.2.1. SPATIAL DATA

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

DATA	DETAILS	DATE SUPPLIED
Topography	KCDC_2021_1m_DEM_NZVD2016_NZTM_TeKowhai_clipped.asc	2021
	XR_SW_001_CombinedDesignContours_NZVD2016_Expressway.asc (Peka Peka to Otaki Expressway design contours converted to raster)	09/05/2019 (Drawing Version 3 Date)
Stormwater asset data	KCDC - KCDC_SW_Data_20240429-SW_Pipe.gdb	29th April 2024
Land cover	Lynker - Kāpiti_Coast_Landcover_20210527.gdb	27th May 2021
	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
	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 (Last updated 7th February 2024 and flown in January 2021)
	LINZ - nz-building-outlines-all-sources.shp	Last Updated 7th February 2024
	KCDC – 2021 Aerial Imagery	Flown in January 2021

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DATA	DETAILS	DATE SUPPLIED
Rainfall	HIRDS - HIRDS v4 gridded (2km 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
Rainfall (validation)	Website - December 2021, August 2022 validation rainfall data from GWRC live monitoring and research website	N/A
Tide (design)	Design tides generated by AWA	N/A
Discharge hydrograph	GWRC – Waikanae legacy model (Waikanae 2017 Design Q100CC) – DesignFlows2009-phaseshift	2023
Network (survey)	KCDC – Manhole Condition Survey	2021
River (survey)	GWRC – Waikanae legacy model (Waikanae 2017 Design Q100CC) - Waikanae 2017 design Q100CC	2023
Google Maps - Kāpiti	Street View October 2019, June 2021, November 2023.	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.

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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 2m 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 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** Error! Reference source not found.. The extent of the pipe network is shown in **Figure 4**.
Open channels	A 1D representation of the Waikanae River has been used as a downstream boundary condition providing a source of fluvial flood flows and a downstream water level boundary condition. The cross sections are based on the legacy GWRC Waikanae river model. 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**.
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** Error! Reference source not found..

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DATA	DETAILS
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** Error! Reference source not found..
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.

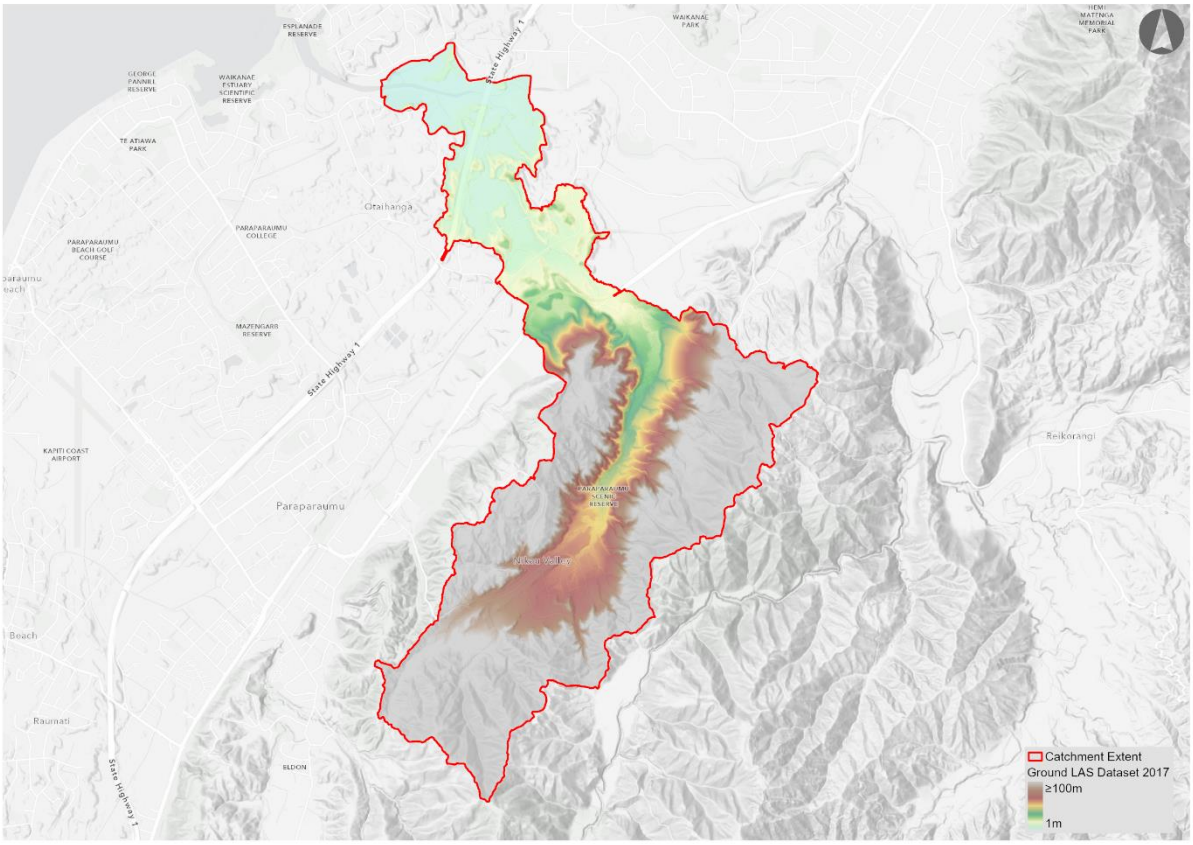


Figure 3: Surface elevation overlaid with model domain (shown in red).



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

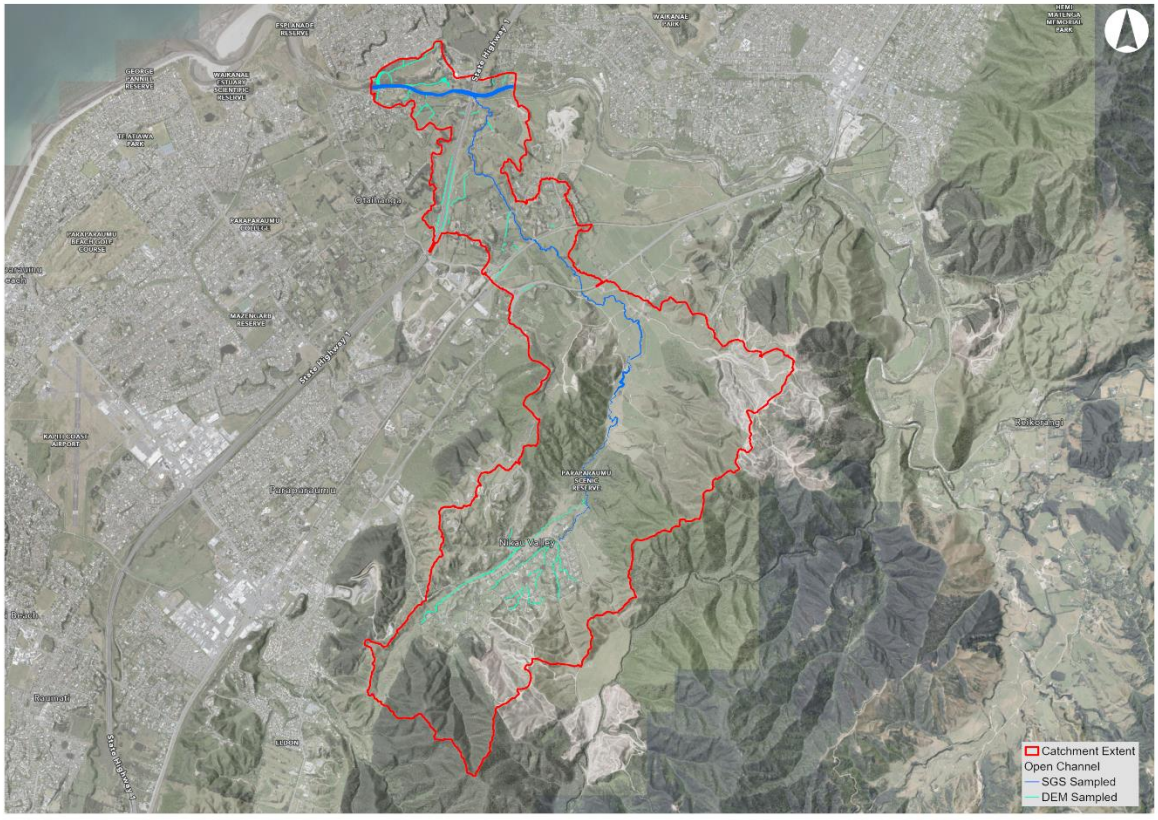


Figure 5: Open channel representation – sub-grid sampling (dark blue) and DEM (light blue).

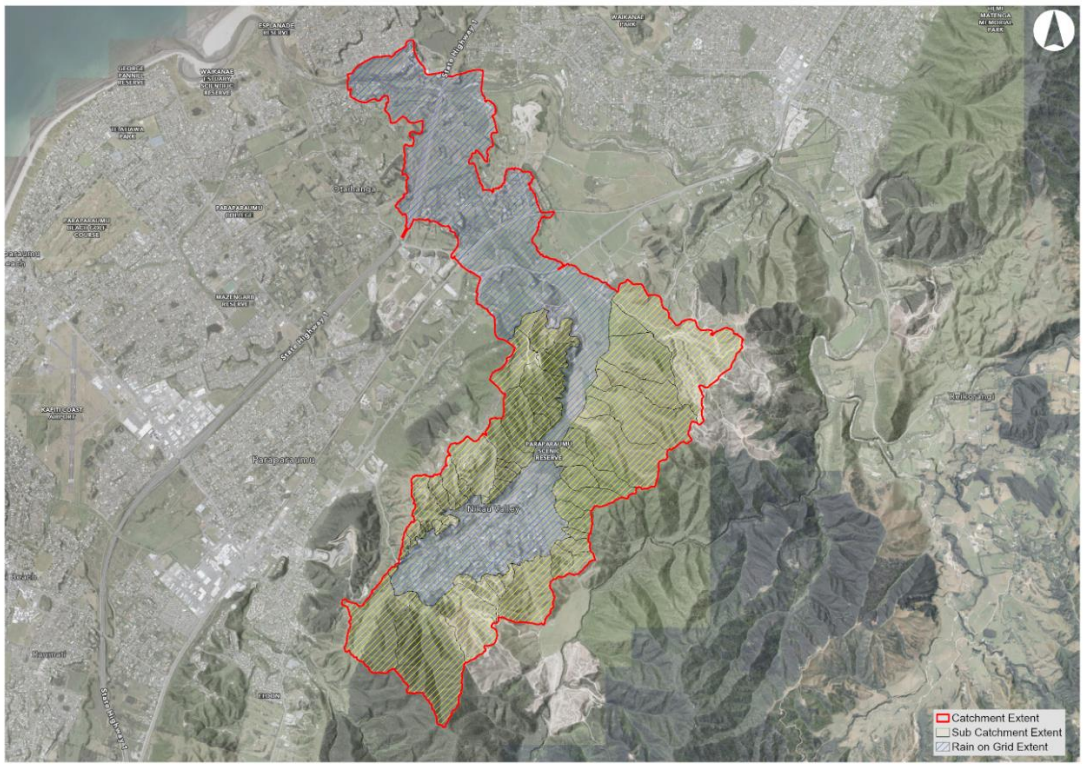


Figure 6: Sub-catchment runoff and rain on grid extents.

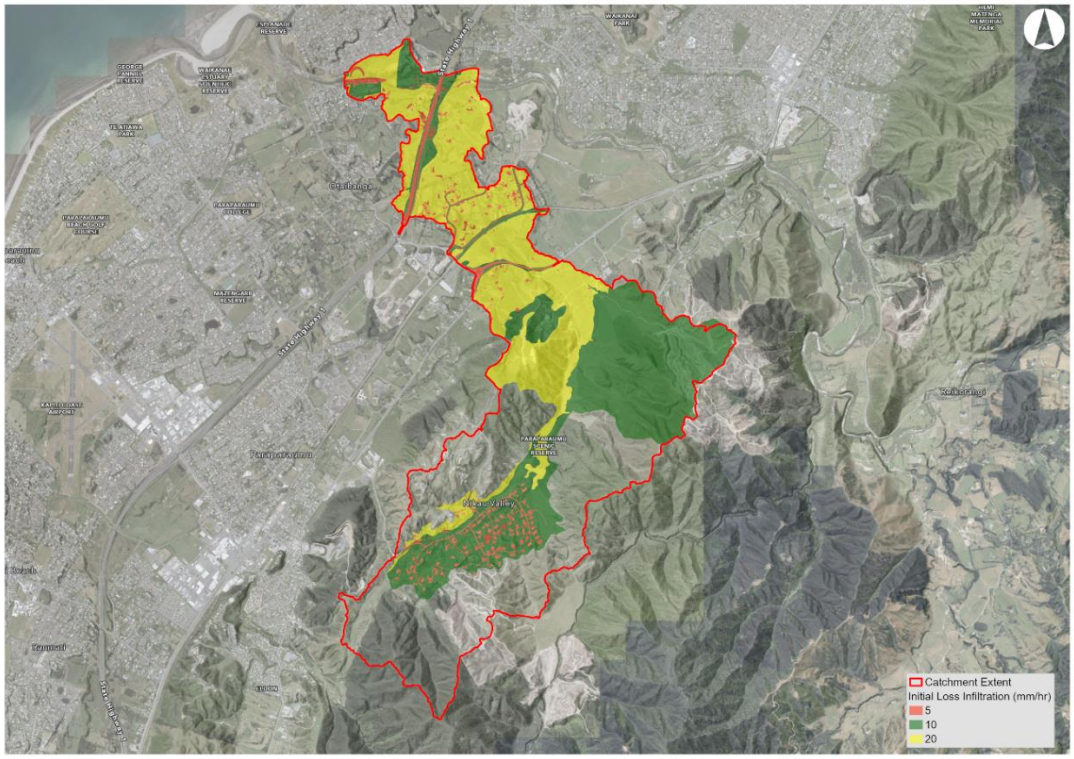


Figure 7: Initial loss infiltration model.

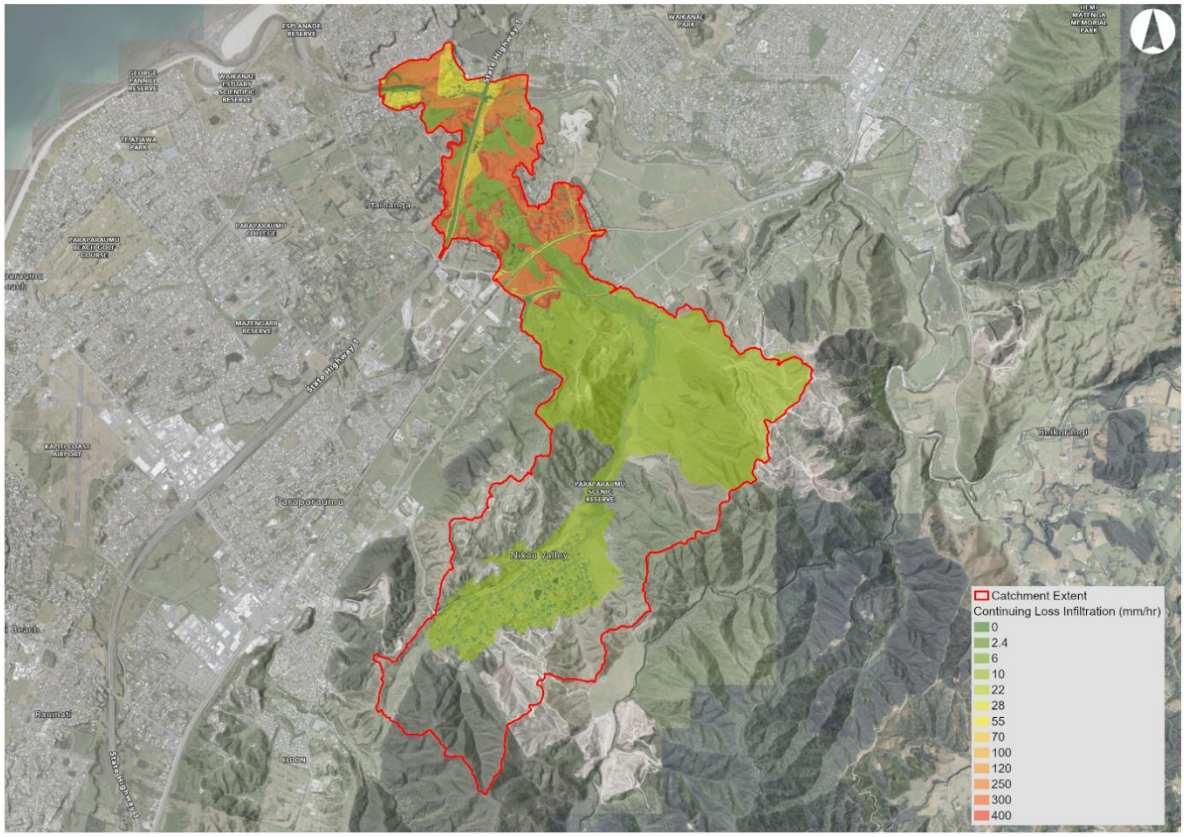


Figure 8: Continuing loss infiltration model.

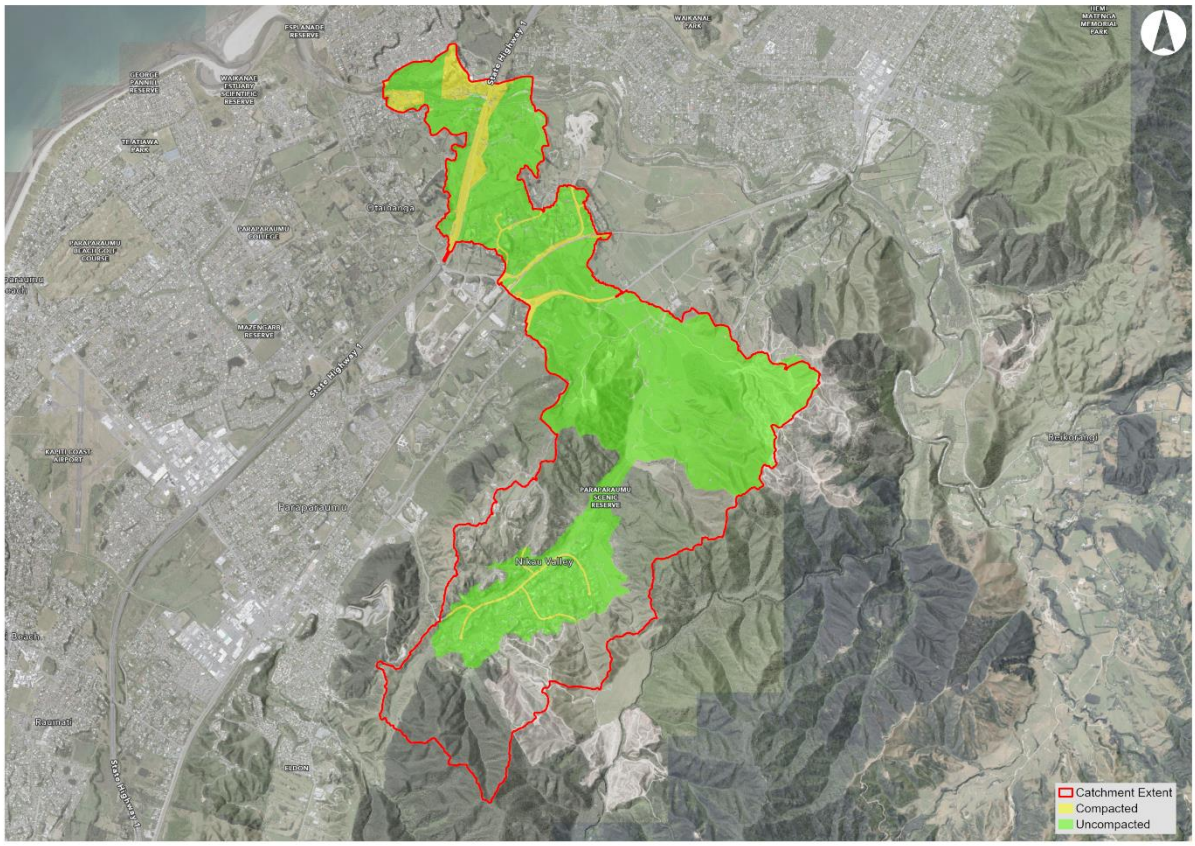


Figure 9: Extent of the soil compaction layer.

3.4. PIPE NETWORK

The 1D network comprises gravity mains which drain to several streams and ponds.

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

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DATA	*DETAILS*
Pipes	All pipes in the KCDC_SW_Data_20240429-SW_Pipe.gdb layer, excluding private drainage, are included in the model. Sump-lead connections in the KCDC_SW_Data_20240429-SW_Pipe.gdb layer is 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.

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DATA	*DETAILS*
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_SW_Data_20240429-SW_Pipe.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 8**. Lid levels are set from the LiDAR surface elevation. 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.

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DATA	*DETAILS*
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	None identified from the KCDC stormwater database.
Bridges	Represented in the 2D domain by TUFLOW layered flow constriction feature (2d_lfcsh layers). 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 piers or not). Second layer is the deck level that is 100% blocked. The levels were taken from old mike model and or DEM or survey. The third layer represents the railing that is generally 10%-20% blocked. Assuming a minimum height of 1m. During blockage scenarios the first layer can be adjusted to represent blockages.

3.5. KEY STRUCTURES AND ASSETS

There are several key culverts and bridges within the Muaupoko catchment which represent constraints in the network. The location of these assets is shown in **Figure 10**Figure 10: Locations of key open channel structures. with the dimensions and configuration shown in **Table 6**.

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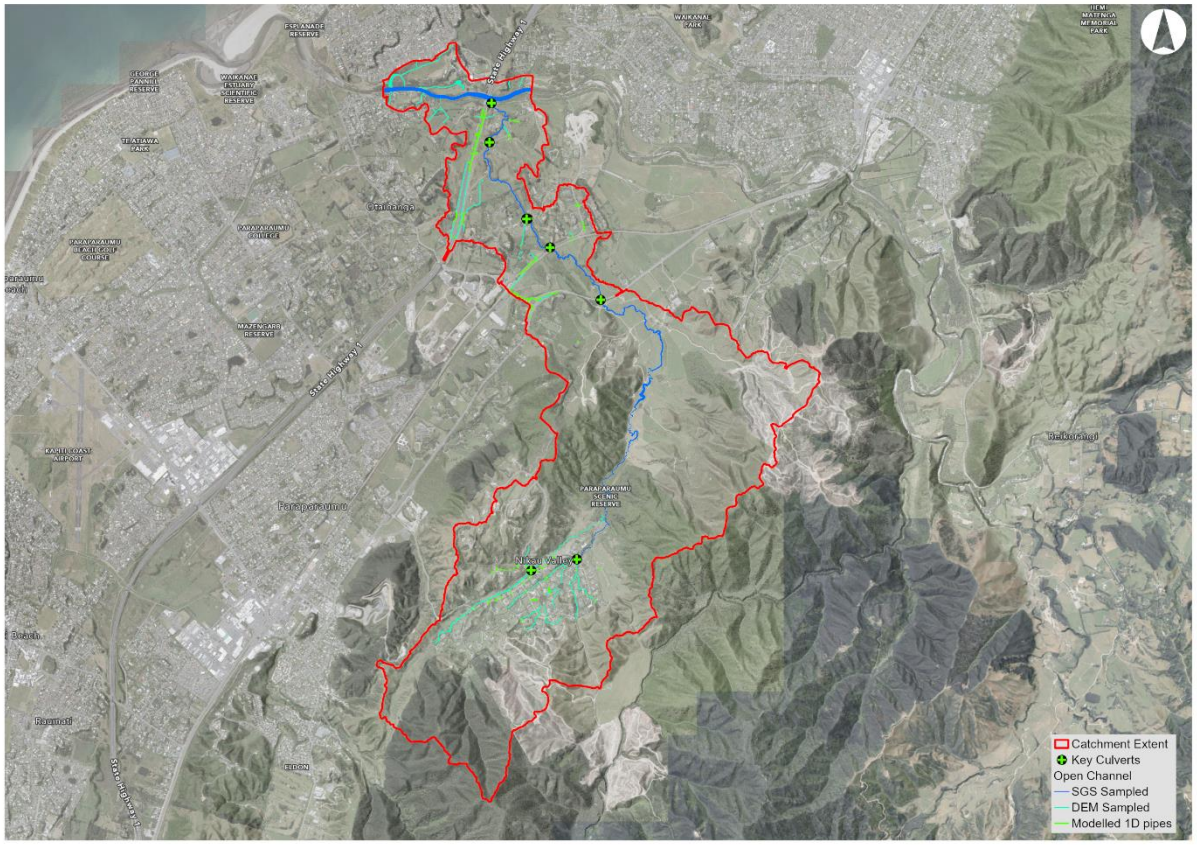


Figure 10: Locations of key open channel structures.

Table 6. Culvert description.

ID	CULVERT NAME	SHAPE	NUMBER OF CULVERTS	DIAMETER/ WIDTH (m)
1	KSWP008820	Circular	1	1.2
2	wai_new_pipe_032	Circular	1	1.2
3	KSWP000577	Irregular (Semi-circular)	1	4.16
4	KSWP008818	Irregular (Semi-circular)	1	3.97
5	KSWP008817	Irregular (Semi-circular)	1	5.4
6	KSWP008932	Circular	1	0.6
7	KSWP008819	Circular	1	1.17
8	wai_pipe_030	Circular	1	1.17
9	KSWP007455	Circular	1	1.95
10	KSWP011066	Circular	1	1.2

3.6. COMPUTATIONAL APPROACHES

The computational approaches for the various components are outlined in **Table 7**Table 7, including key hydraulic and hydrological parameters.

Table 7: 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 8**.
	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.
	River to overland flow	TUFLOW 2D HX link lines are used to connect the model surface and stream bed to a 1D representation of the Waikanae River reach running from State Highway 1 to the coast. This provides a downstream boundary for the catchment model, while allowing for water level variation along the river channel.
Boundary condition application	Waikanae River	The Waikanae River reach extends from State Highway 1 to the coast. The upstream inflow boundary is applied at the State Highway 1 bridge and is based on discharge extracted from GWRC legacy Waikanae model results. The downstream water level boundary is applied at the coast and is based on a recurring Mean High-Water Springs (MHWS) tidal signal with the addition of a sinusoidal storm surge profile and sea level rise offsets.
	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.
	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.

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<table>
<tr><th>MODEL ASPECT</th><th colspan="2">DETAILS</th></tr>
<tr><td></td><td colspan="2">Inflow from hill catchments is calculated outside the TUFLOW model.</td></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 on Landcare Research’s LCDB v5 land cover and Aerial Imagery elsewhere.

A map of the roughness grid used in the model is shown in <u>Figure 11</u>.

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</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>Stream/Channel</td><td>0.04-0.45</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>
<tr><td>Pond/Wetland</td><td>0.075</td></tr>
</table></td></tr>
<tr><td>Flood and dry parameters</td><td>TUFLOW default wetting and drying parameters are applied.

Wetting and Drying == ON METHOD B

Cell Wet/Dry Depth == 0.0002 [m]</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>
</table>

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<table>
<tr><th>MODEL ASPECT</th><th></th><th>DETAILS</th></tr>
<tr><td></td><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>
<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>2D configuration</td><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.</td></tr>
</table>

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MODEL ASPECT		DETAILS
		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.
	Initial conditions	The initial water level is set automatically to the level of the downstream water level boundary at the start of each simulation.
Hydrology	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.
	Sub-catchment-based	Applied to steep areas where determination of runoff is the principal concern. Sub-catchments are delineated using a GIS-based drainage analysis, which does not consider hydraulic effects. Hill sub-catchments are 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 Stormwater Modelling Methodology report. The routing model used is the Clark Unit Hydrograph method. The following parameters are required for each sub-catchment.

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MODEL ASPECT	DETAILS
	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).

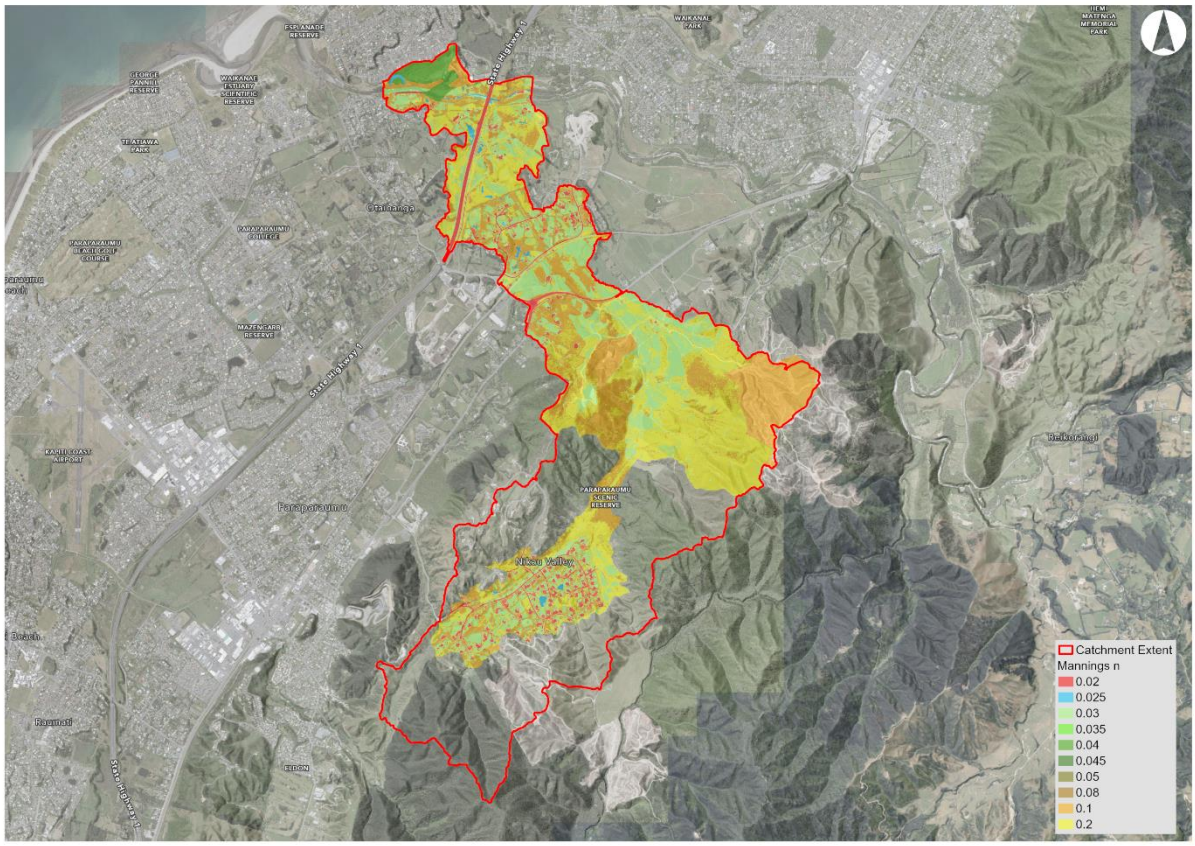


Figure 11: Manning's n overland flow resistance parameters applied to the model.

Table 8: 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

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INLET CONFIGURATION ID	CODE	CATCHPIT TYPE	INLET AREA (M2)	DISCHARGE COEFFICIENT (-)	QDH (M)
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 9**. 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 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 and the node is also connected to the boundary to allow for overtopping flows.

Table 9: 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 Waikanae River branch at the coast.
Flow	The Waikanae River inflow boundary is located at the SH1 bridge. Hill sub-catchment runoff is directed onto the 2D surface along the south-eastern edge of the 2D domain.

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3.8. MODEL LIMITATIONS

Model limitations which should be considered when using the model or interpreting outputs are discussed in **Table 10**.

Table 10. 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.
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 (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.

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3.9. ASSUMPTIONS

Assumptions made during the model build process are discussed in **Table 11**.

Table 11. 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 2020 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 2020 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 VALIDATION

4.1. INTRODUCTION

To ensure confidence in the Muaupoko 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.

4.2. FLOOD EVENTS

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

- August 2022
- 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. Two rainfall gauges were analysed, Paraparaumu Aero* and Waikanae Water Treatment Plant. This rainfall gauge data was sourced from Cliflo and captured ~55 years of rainfall data, as shown in **Table 12**.

Table 12: Gauging station period

GAUGE STATION	PERIOD OF DATA COLLECTED
Paraparaumu Aero EWS (E04995)	1996 - 2023
Waikanae Treatment Plant	1995 - 2023

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4.2.1. AUGUST 2022

In August 2022, the catchment experienced a small rainfall event. **Table 13** shows that this event was less than a 2-year event (compared to the flow and rainfall data on the Waikanae River at Waikanae Water Treatment Plant). Awa visited a site in the catchment close to the Waikanae River on the day to capture data on the flood extent. Details of the site visit are outlined below.

Awa visited the property on Friday, 19th August following a small rainfall event. Initially, AWA inspected the condition of the culvert under the driveway. The culvert was at full capacity with some overland flow on the driveway. Meanwhile, the downstream end of the culvert was also back-flowing onto the driveway and the paddock. The paddock and driveway heading to the house was heavily inundated with floodwaters.

It was observed that the flooding was getting stuck behind Muaupoko Stream and was not able to drain out. Awa headed up on the SH1 Waikanae River bridge to check the Muaupoko Stream mouth conditions. **Figure 12** shows the Waikanae River boundary with the Muaupoko Stream mouth containing eddies (yellow dashed circle), which shows the Muaupoko struggling to drain out to the Waikanae River. The walkway and the twin-culverts that the Muaupoko Stream flows through were also fully inundated. Additionally, the paddocks upstream were also extensively inundated with flood waters.



Figure 12: Photo from SH1 Waikanae River Bridge looking up the Muaupoko Stream (right) and Waikanae River (left).

Table 13: Rainfall and flow rates on 19th August 2022 event compared to 2-year return period rates.

Parameter	Observed rate at Waikanae Water Treatment Plant	2-Year return period
Rainfall	38.8mm over 12hours (20:00 18 Aug to 08:00 19 Aug)	58.7mm over 12 hours (HIRDS)
Flow	82.3 m^3/s (peak flow)	150 m^3/s (GWRC)

The rainfall and flow data for the hydraulic models were sourced from the GWRC website from the Waikanae Water Treatment Plant (see **Figure 13**)

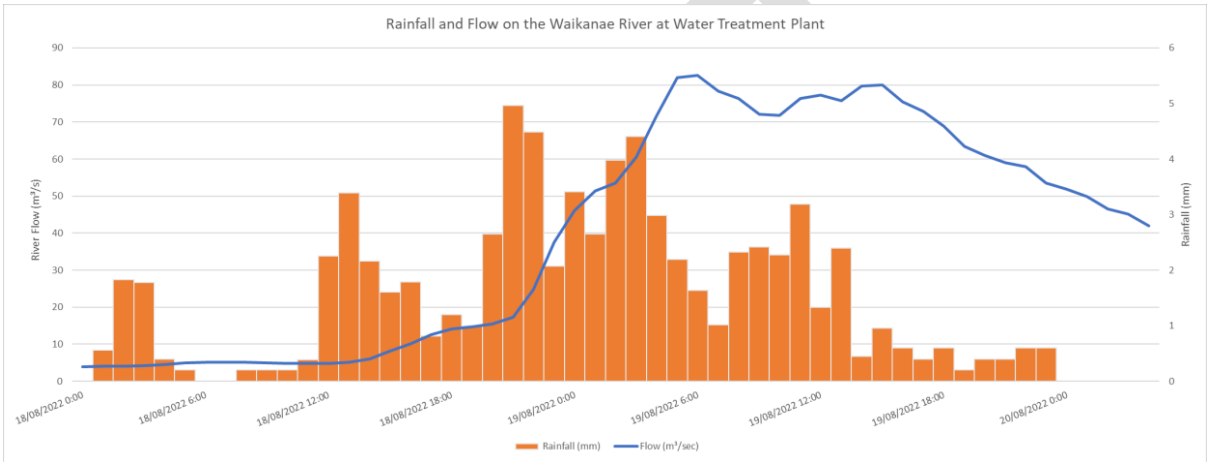


Figure 13: Rainfall and Flow rates from the Waikanae River at Waikanae Water Treatment Plant between 18 August 2022 0:00 to 20 August 2022 04:00.

The rain gauge is well-positioned to reflect the Muaupoko Stream catchment area. The August 2022 event is less than a 2-year flood event. Awa obtained photos on the day (see Site Visit) which were used to calibrate the model results.

Calibration of the Muaupoko Stream model was undertaken by matching the extents of flooding recorded on site from the August 2022 event to modelled flood extents. The following is a summary of key calibration parameters.

MUAUPOKO STREAM ROUGHNESS

Blockage scenarios were implemented on the models in response to flood depths observed within the riparian margin of the Muaupoko Stream.

Initial implementation of constrained flow on the Muaupoko Stream was applied on the model runs using increased bed roughness. The roughness was increased up to 0.55 at certain locations to mimic the constrained flows in the Muaupoko Stream.

GRAVEL AGGRADATION

In addition to increased Muaupoko Stream roughness, Awa addressed the increased gravel aggradation in the modelling process. Awa commissioned cross section surveys on the Waikanae River on June 2022 to better understand the levels of aggradation at the time. The cross sections showed higher levels of aggradation compared to previous surveys. After several model runs, the June 2022 cross sections (2-dimensional) were not able to accurately represent the aggradation in the models. In recognition of this, Awa commissioned a 'Point Cloud survey' using a drone (3-dimensional) to better represent the aggradation and its effects on the model.

Awa provided a Point Cloud survey (drone) to measure the elevation around the Waikanae River between cross section 140 and 155. The Point Cloud survey represented the degree of aggradation by more accurately capturing the height of the aggradation, as well as its extent (i.e., width and length) down the Waikanae River. This survey showed higher level of gravel build up across cross section 150 (in comparison to the June 2022 surveys) and was used to represent the bar in the calibration for post-M2PP conditions.

HYDROLOGY AND RAINFALL

In combination with increased roughness and an updated representation of the gravel aggradation, the hydrology and rainfall were also updated. The rainfall was sourced from the rainfall gauge at the Waikanae Water Treatment Plant.

Awa suspected that the flow on the Waikanae River was less than what was recorded at the Water Treatment Plant (around 5 kilometres upstream) due to attenuation. Awa remodelled the Waikanae River input by running the Water Treatment Plant data through an existing Waikanae River model to better estimate a time of concentration as the river approaches the Muaupoko Stream confluence. The model showed that there was a reduction of flow (approximately 20m^3/s) from the Treatment Plant data, which was applied to the TUFLOW model. The results showed that although there were some decreased flood depths near the mouth of the Muaupoko Stream which aligned with the photos from the site visit, the calibration was not representative of the paddocks further upstream, which were heavily inundated during the August 2022 event.

Awa then focused on the rainfall depths and intensities. Awa investigated whether the rainfall rates were similar to rates in the upper Muaupoko Stream catchment due to the difference in elevation and locations of both sites. Kāpiti Coast District Council's guidance on rainfall distribution was used to understand possible differences. The rainfall was adjusted and increased by 15%. After running the model, the results showed that flood extents and depths were similar in the lower catchment of the Muaupoko Stream, but the upper catchment were still underestimating the flooding experienced in August 2022.

BLOCKAGE SCENARIOS

After applying increased roughness, updated aggradation levels, adjusted hydrology, and increased rainfall, the upstream catchment of the Muaupoko Stream was still underestimating in comparison to the site visit photos in August 2022. Awa suspected that the increased roughness might not have been sufficient to represent the constrained flows on the Muaupoko Stream.

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Figure 14: Fallen trees and vegetation in the Muaupoko Stream.

To get a better understanding of the degree of flow constraints on the Muaupoko Stream, Awa visited the site on April 27, 2023. After the visit, Awa determined that increased roughness parameters had to be applied as blockage scenarios to represent the vegetation debris on the Muaupoko Stream more accurately (see **Figure 14**).

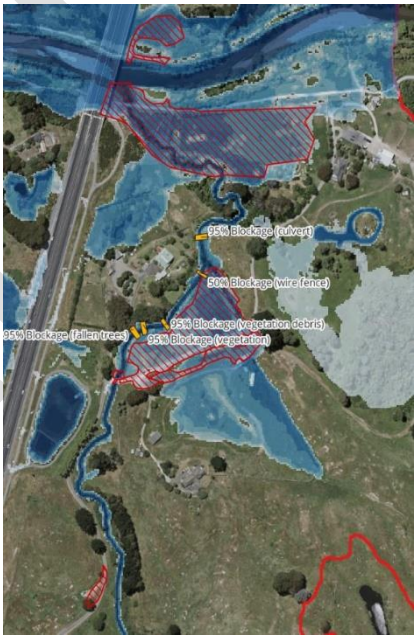


Figure 15: Location of blockages

Using the photos taken on the visit, blockage scenarios were applied to the model at 5 different locations on the Muaupoko Stream (**Figure 15**). After these were applied, the flood extents matched the site visit photos more accurately, particularly in the upper catchment of the Muaupoko Stream.

SUMMARY

The calibration for the August 2022 event utilised adjustments of the following parameters:

- Drone footage to represent the gravel bar on Waikanae River more accurately.
- Adjustment of Waikanae River flows which reduced overall flow as it enters the Muaupoko Stream confluence but provided a more accurate time of concentration.
- Increased rainfall rates to match the higher elevation of the upper Muaupoko Stream catchment.
- Application of increased surface roughness and subsequent blockages caused by vegetation debris on the Muaupoko Stream.

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This resulted in a more accurate representation of the flooding from our site visit on the 19th August 2022.

4.2.2. 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 14**. 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 14: 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 16**. 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.

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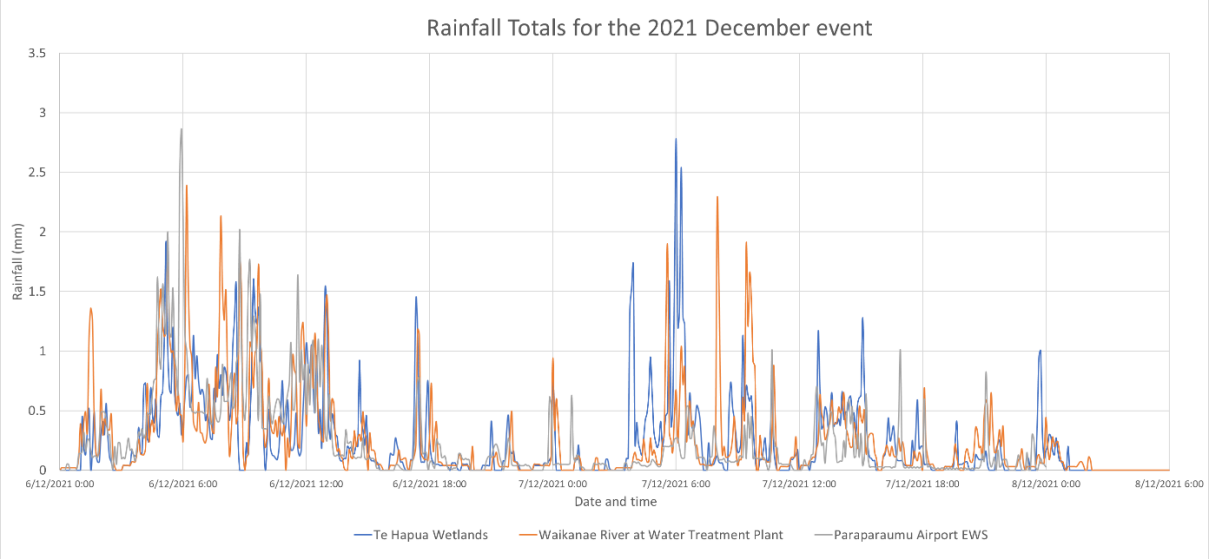


Figure 16. Rainfall depths at three gauging stations.

The 2021 event generated several flooding complaints to the Council which are spatially recorded in the incidence database as shown in **Figure 17**.

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 reasonably sound basis for validation of the model.



Figure 17: December 2021 Council complaints database locations.

For each recorded compliant there is varying levels of information recorded in the incident database system.

Examples of affected properties showing description, modelled peak flood depth and photographic evidence of flooding for the December 2021 rainfall event is shown in **Figure 18**.

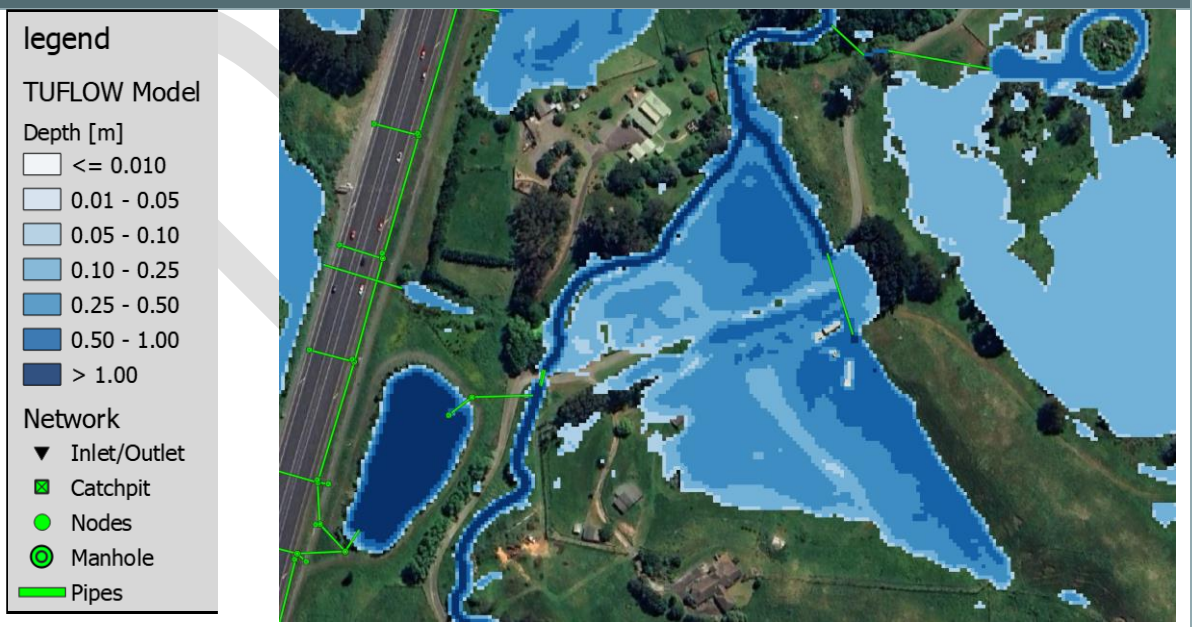
Examples of affected properties showing description, modelled peak flood depth and photographic evidence of flooding for the August 2022 rainfall event is shown in **Figure 19**.Figure 18

Reported Flood Incident (Dec 2021 Event)	
Affected properties	Greendale Drive
Description of modelled flooding	There is very shallow flooding that is below the 50mm cut off depth. Having been to the site, we can confirm that there is a high chance of the culverts getting blocked and thereby causing flooding along the road.
MODEL RESULT	
	
Photographic Evidence (Dec 2021 Event)	



Figure 18: Muaupoko model results

Reported flood Incident (Aug 2022 Event)	
Affected properties	Otaihanga Road
Description of modelled flooding	The model shows the flooded driveway shown in the picture below
MODEL RESULT	



Photographic Evidence (Aug 2022 event)



Figure 19: Muaupoko model results

4.3. VALIDATION

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

There is some historic low flow gauging data from the Waikanae River at the water treatment plant that was considered for use in model calibration, however this gauging data was for a short period of time, was unrated, and did not include peak flows required for calibration of the catchment model.

Validation of the Muaupoko catchment is based on recorded historic flood complaints. 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.

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 Management report. Some adjustments were also made to the hill catchment runoff parameters after the calibration of the Wharemauku Stream which informed the Waikanae validation previously and now applied to Muaupoko validation as well.

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 (2021) was secured by the Council. Where these were identified, the DEM was updated to include these anomalies.

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5. RECOMMENDATIONS

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

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 becomes available.
- 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 - FLOOD MAPS

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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

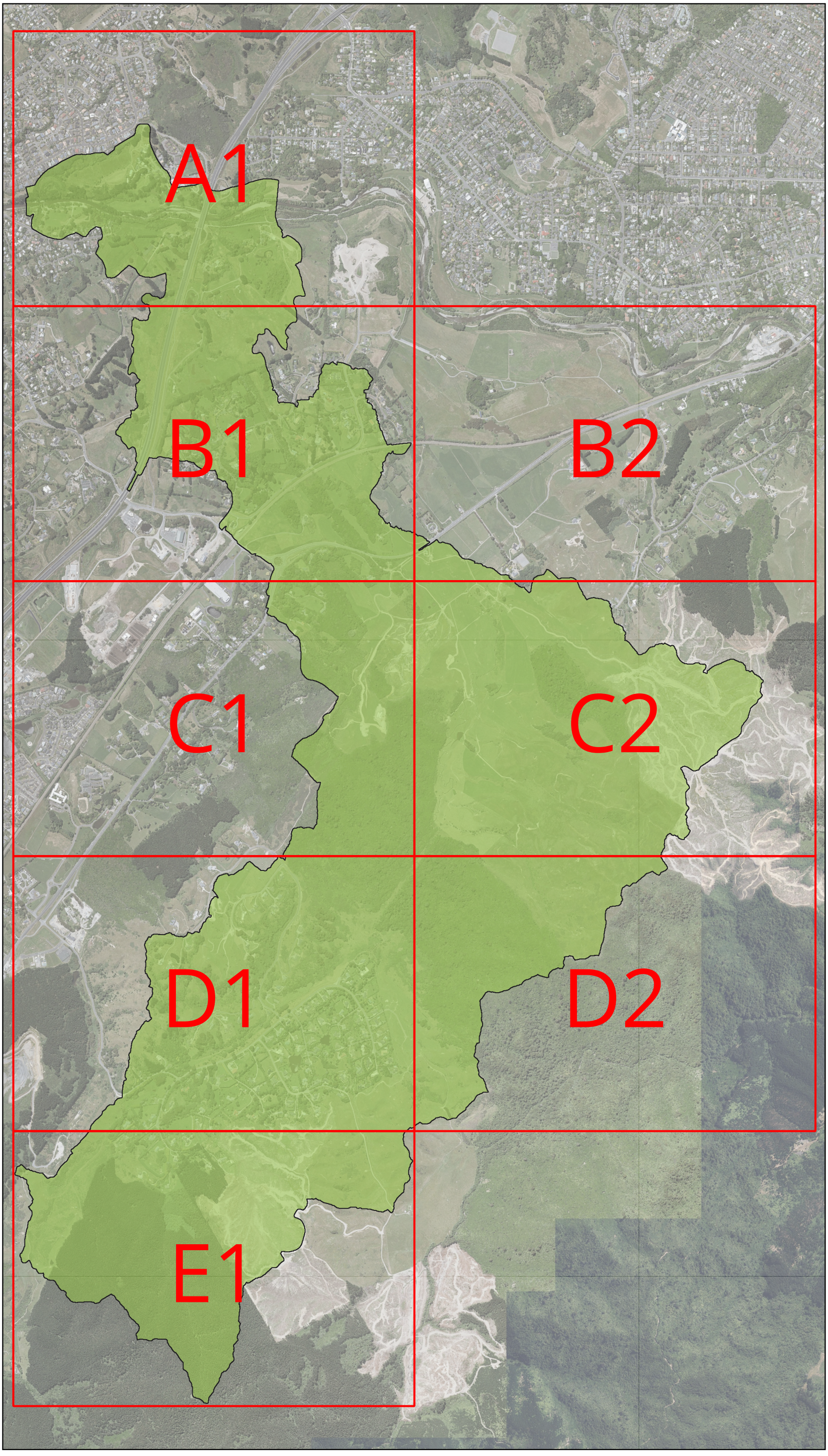
  Where a proposal occurs within Greater Wellington Regional Council's flood model extent, its written approval should be sort. Although the outputs from GWRC models are incorporated within the District Plan flood hazard maps, KCDC holds none of the supporting information. Both Councils have a duty under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

Muaupoko 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

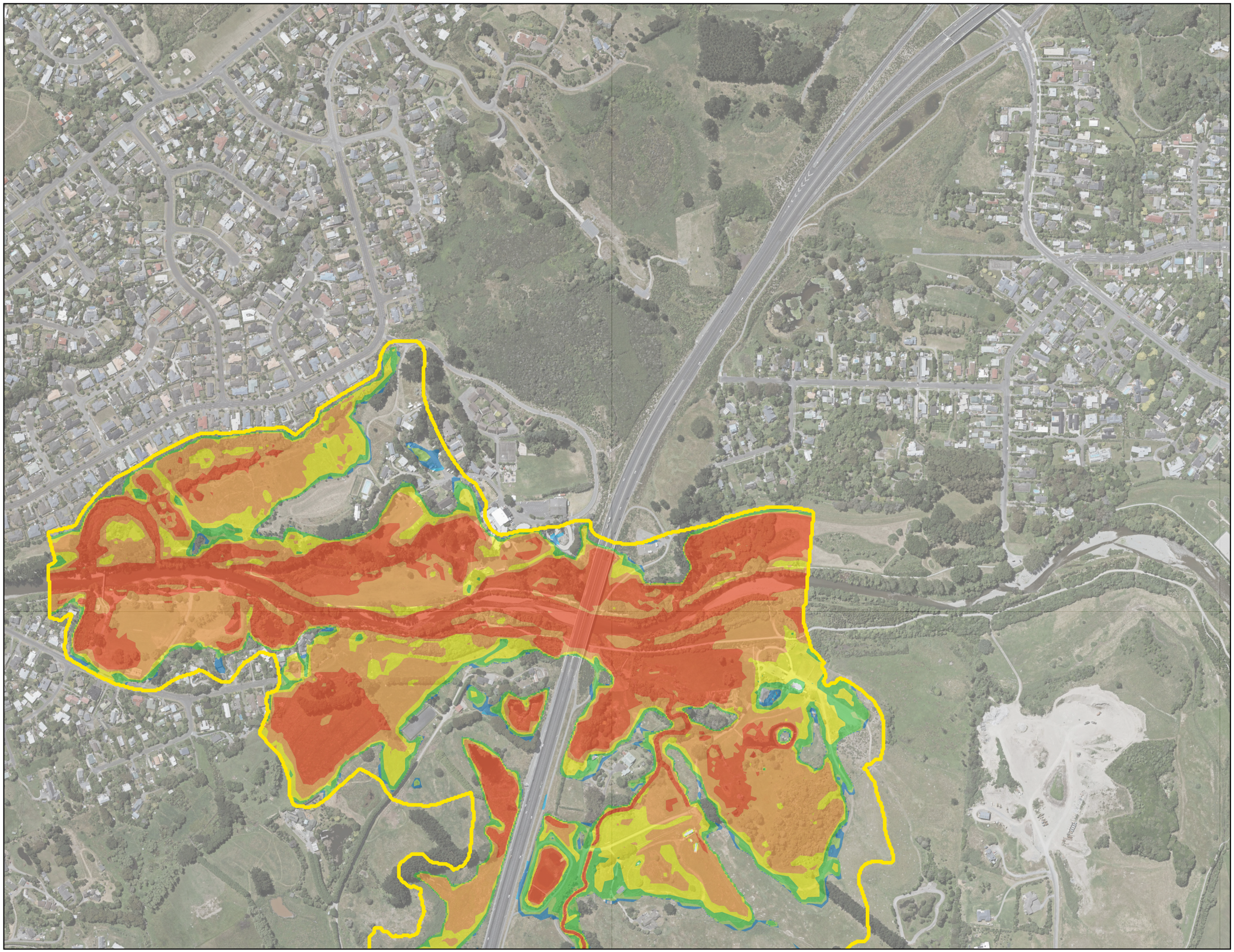
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- Page Reference
- Catchment Extent

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Muaupoko 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
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0 150 m

Legend

Catchment Boundary

Muaupoko Catchment

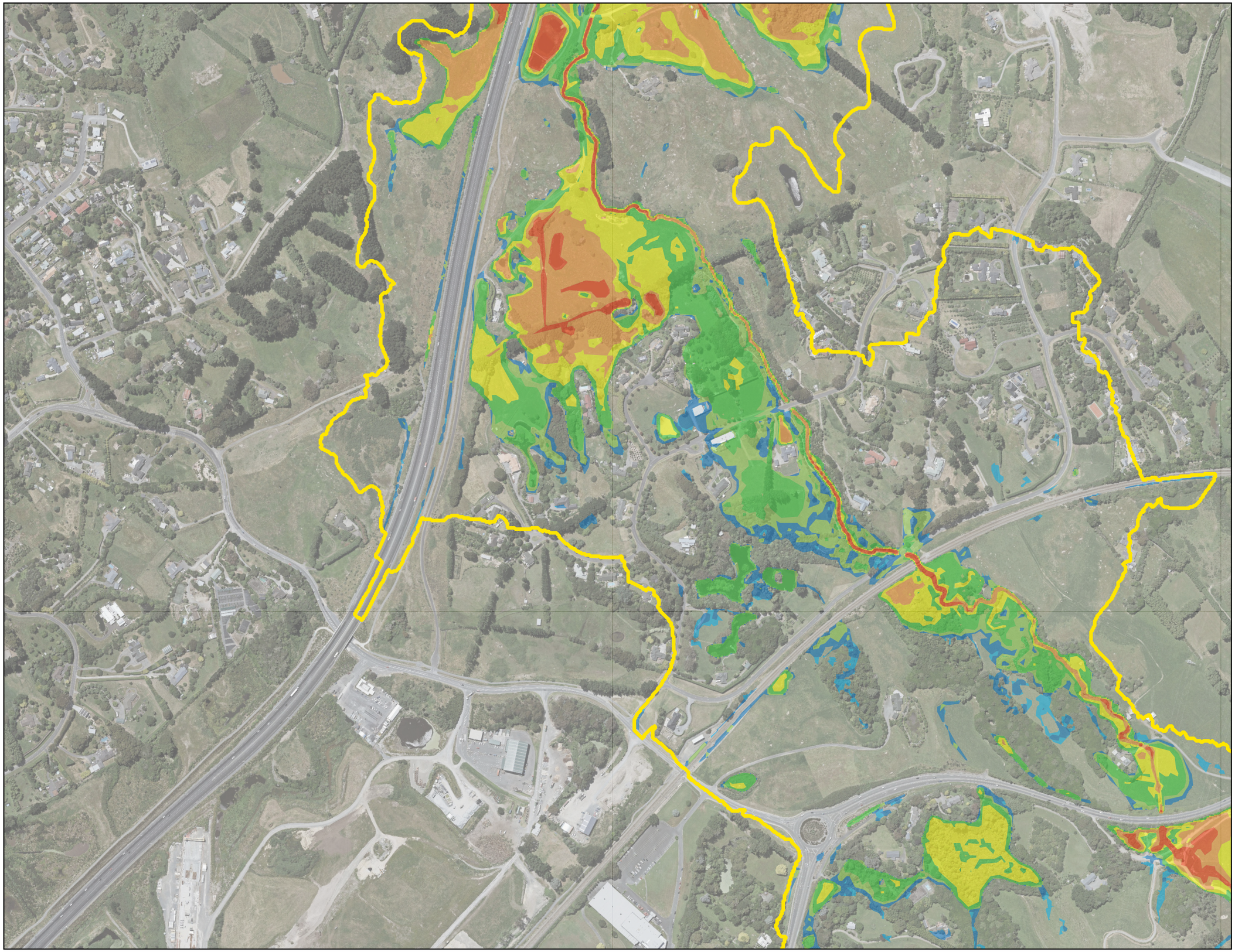
Depth

- 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

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Muaupoko 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
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0 150 m

Legend

Catchment Boundary

Muaupoko Catchment

Depth

- 0.05 - 0.1 m
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- 0.3 - 0.5 m
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Muaupoko Flood Depth in a 100-Year Rainfall Event

2130 Projection - Page B2



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Kapiti Coast District Council

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

0 150 m

Legend

Catchment Boundary

Muaupoko Catchment

Depth

- 0.05 - 0.1 m
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Muaupoko Flood Depth in a 100-Year Rainfall Event

2130 Projection - Page C1



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0 150 m

Legend

Catchment Boundary

Muaupoko Catchment

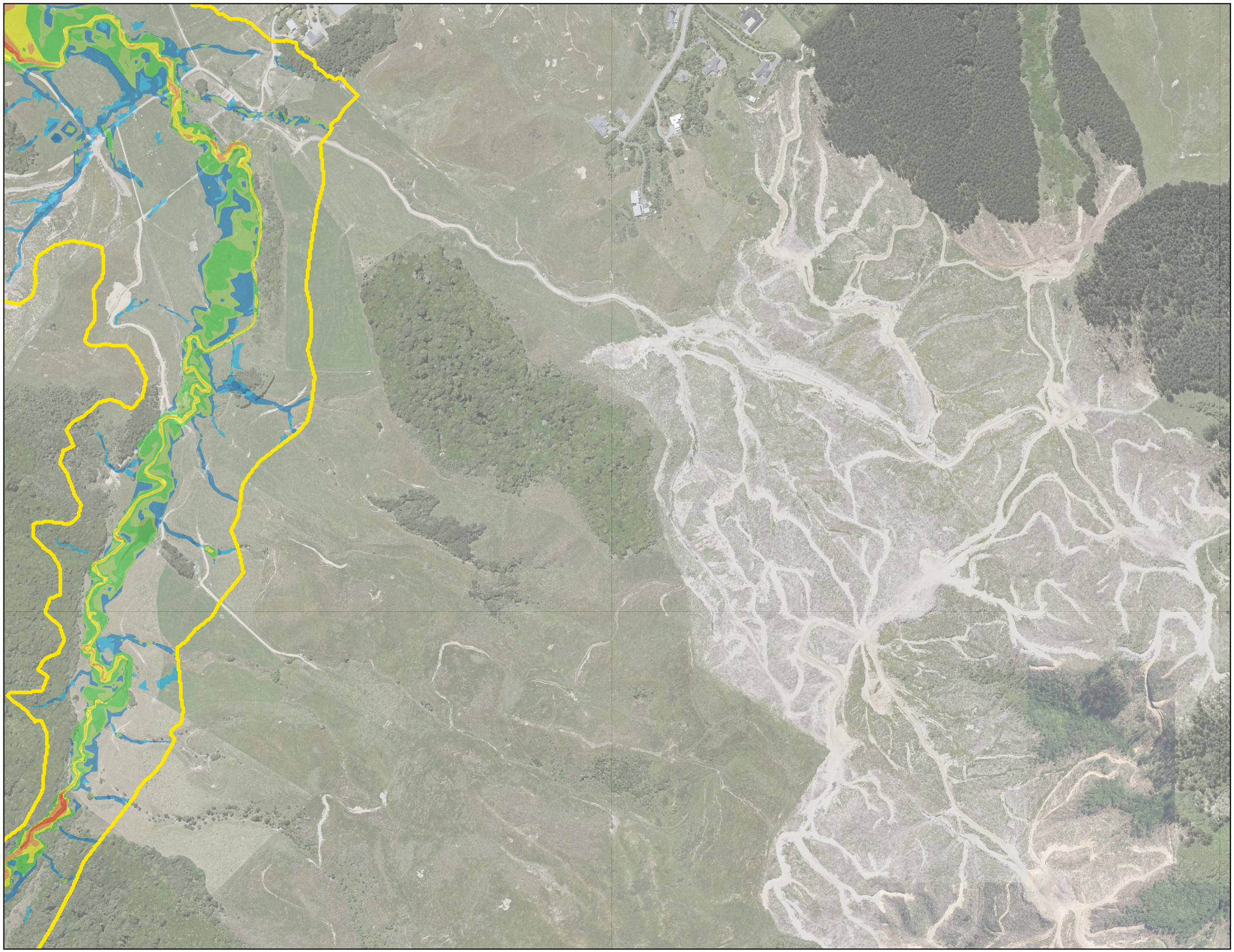
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Muaupoko Flood Depth in a 100-Year Rainfall Event

2130 Projection - Page C2



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0 150 m

Legend

Catchment Boundary

Muaupoko Catchment

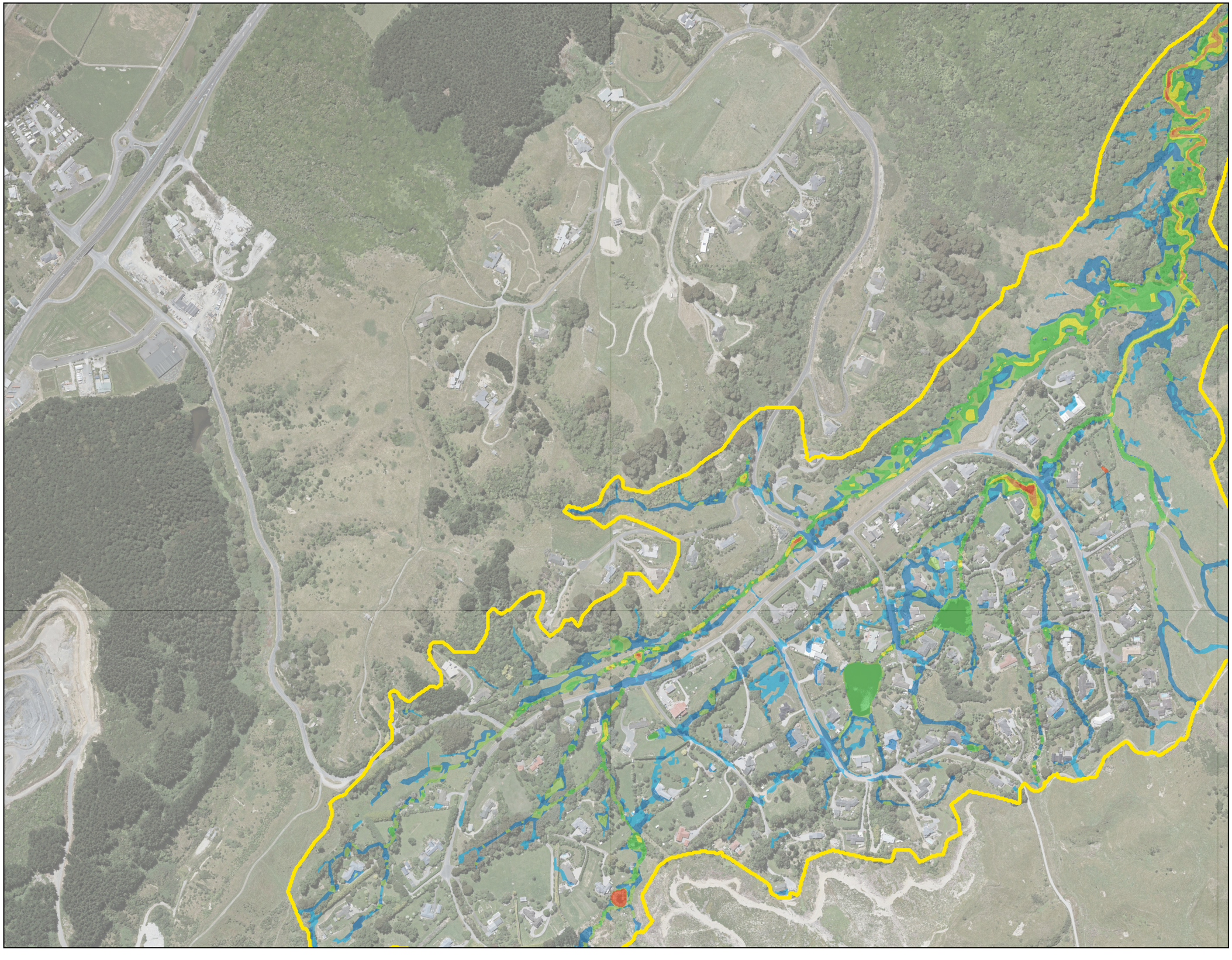
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Muaupoko Flood Depth in a 100-Year Rainfall Event

2130 Projection - Page D1



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Muaupoko Flood Depth in a 100-Year Rainfall Event

2130 Projection - Page D2



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Legend

Catchment Boundary

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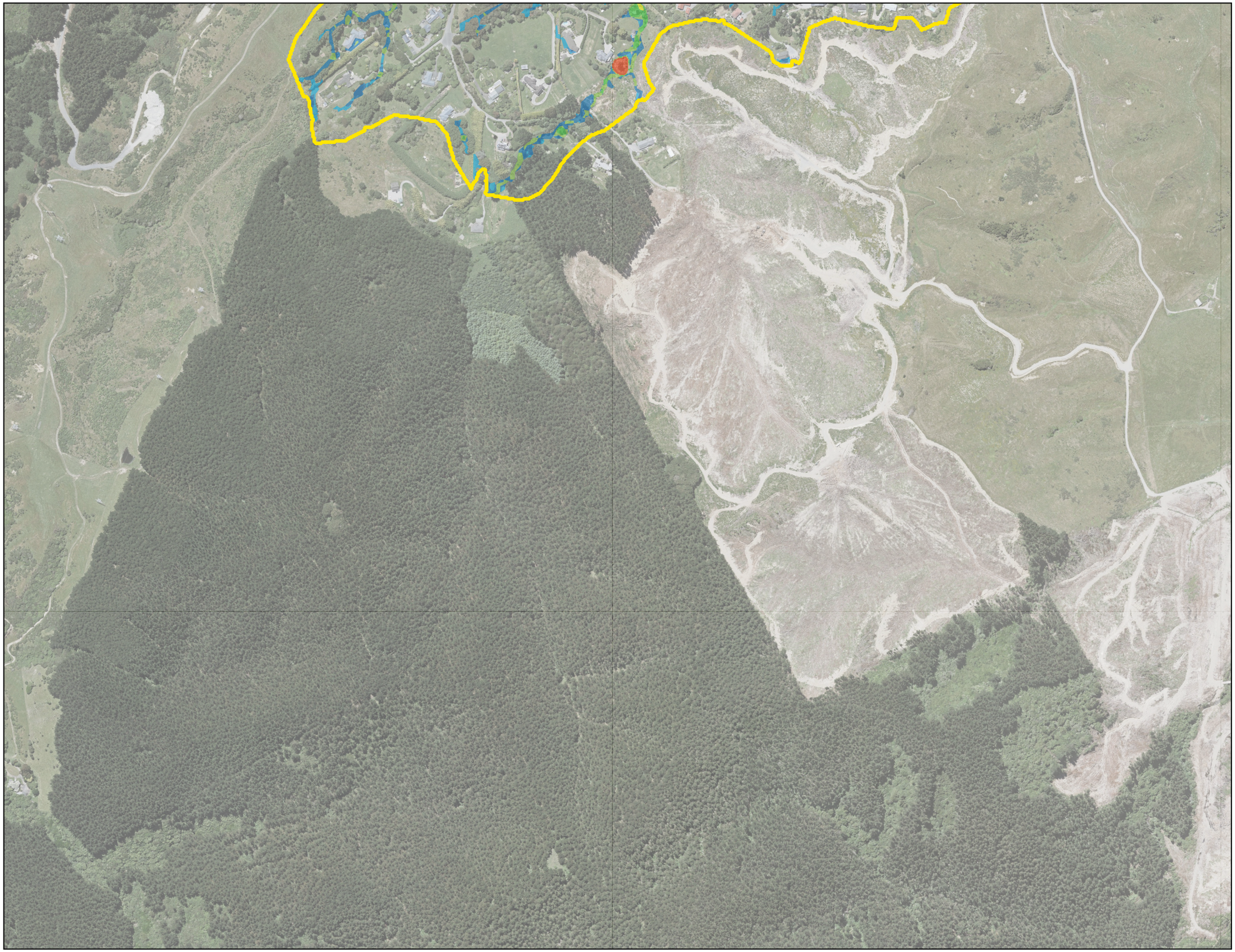
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