Lower Manawatū Model Report (Task 5, FVA)

February 2026

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REGIONAL COUNCIL

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Horizons Regional Council
Flood Vulnerability Assessment

Lower Manawatū Model

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Flood Vulnerability Assessment

Lower Manawatū Model

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EXECUTIVE SUMMARY

WSP was engaged by Horizons Regional Council (HRC) to build an updated 'Level B' hydraulic model covering the full Lower Manawatū catchment. The aim of this work was to develop an updated catchment-scale hydraulic model of the Lower Manawatū catchment to support HRC's future operational and design-use purposes. To achieve this aim, a methodology was developed to represent identified key channels and tributaries, to include key assets such as stopbanks, roads and floodgates, and produce flood maps showing the extents and depths across key catchment locations of five selected design flood events.

An overview of the modelling is given below:

- TUFLOW HPC model developed to represent catchment-scale flood risk mechanisms
- Model terrain defined mostly by LiDAR, with 2023 watercourse survey used to create an interpolated channel surface on the Manawatū River
- Main watercourses and flowpaths included in areas of refined, small cell sizes
- Stopbanks and Roads modelled as breaklines along their crests to represent key spilling mechanisms
- Key structures modelled including Moutoa Gates, Flygers Line Spillway, Mangaone Bridges
- 29 inflows, including 8 intervening inflows, along key watercourses
- Mean High Water Spring (MHWS) downstream boundary at Foxton
- Five events simulated: 50 year present day, 100 year present day, 100 year 3°C climate change, 200 year present day, 200 year 3°C climate change.
- Nine key flood risk areas were established: Feilding, Palmerston North, Oroua South Floodplain, Oroua North Floodplain, Mangaone Floodplain, Linton Drain Floodplain, Southern Moutoa Floodplain, Eastern Moutoa Floodplain, Aratangata Drain Floodplain
- Flood Mapping for extents, depths and velocities across five simulated events.

Following the model build, 14 recommendations were made including the following key items:

- Establish Long-term Model Scope – this report has focussed on the catchment-scale fluvial flood risk in the Lower Manawatū catchment. A key component of future work will be to agree and establish the long-term scope and scale of this updated Lower Manawatū catchment model with respect to its wider goals and aims. This will dictate the identification of key areas and prioritisation of data collection.
  - Source of Flood Risk – is the focus primarily on fluvial flood risk, or does surface water risk (pluvial) to and from urban areas need to be considered in more detail, and to what extent?
  - Joint Probability – in areas of multiple flood risk sources such as Eastern Palmerston North (fluvial and pluvial flood risk), should this model be the go-to asset to consider the joint probability of flooding from surface water (pluvial) and rivers (fluvial)? How would the hydrology of joint pluvial-fluvial events be considered?
  - Urban Flooding – to what extent should this model address flood risk to urban areas with no fluvial flood risk? What advantage is sought from including detailed urban drainage features with the associated slow-down in model simulation times, compared to individual smaller models of these areas?
- Data Collection – data gaps should be identified by undertaking a prioritisation exercise to focus on key areas of the catchment. This should highlight the greatest uncertainties across the catchment where gaps exist in terrain definition, channel surfaces, structure dimensions and asset information. Data collection should include new and existing topographic survey, bathymetry and watercourse surveys. Initial high-level findings from this updated model indicate the following priorities:

- Stopbanks – updated stopbank survey covering key areas of stopbank overtopping, in particular along the Manawatū River near Moutoa Gates and Palmerston North, and the Oroua left-bank.
- Flood gates and channel – updated channel and structure surveys for key floodgate channels in the lower extent of the catchment. Modelling accurate floodgate structure levels and associated channel levels is crucial for simulating the outflow and attenuation on these minor drain catchments (for example Sluggish Drain and Koputaroa Drain).
- Oroua River – updated watercourse survey or bathymetry to better represent channel capacity and shape.

— Calibration and Validation – the Lower Manawatū model has not been explicitly validated or calibrated. Future work should identify key flood events to calibrate the model, ideally more recent events that are more closely representative of the up-to-date dataset used to define model geometry (for example February 2023 Cyclone Gabrielle). The calibration should focus on gauged levels and travel time between upstream and downstream catchment locations (e.g. Teacher's College and Moutoa Gates).

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WSP and NIWA. (2025a). *Horizons Flood Modelling and Mapping Guideline.*

WSP and NIWA. (2025b). *Horizons Flood Vulnerability Assessment - Current State Analysis.*

As part of the Flood Vulnerability Assessment (FVA) project undertaken for the Horizons region, the following reports have been delivered:

WSP & NIWA. (2025a). Horizons Flood Modelling & Mapping Guideline [Prepared for Horizons Regional Council]. WSP New Zealand Ltd & National Institute of Weather and Atmospheric Research Ltd.

WSP & NIWA. (2025b). Current State Analysis [Prepared for Horizons Regional Council]. WSP New Zealand Ltd & National Institute of Weather & Atmospheric Research Ltd.

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WSP. (2025b). Moutoa Gates - Model Build Report to Support 2025 Operational Upgrades [Prepared for Horizons Regional Council]. WSP New Zealand Ltd.

1 PROJECT BACKGROUND

1.1 INTRODUCTION

WSP was engaged by Horizons Regional Council (HRC) to build an updated hydraulic model covering the full Lower Manawatū catchment. This work was funded as part of the wider Flood Vulnerability Assessment (FVA) project undertaken for the Horizons region completed by WSP in July 2025.

Historically HRC have developed and used a series of predominantly one-dimensional (1D) DHI MIKE flood model(s) of the catchment, which is summarised in the 2015 Lower Manawatū Scheme (LMS) Comprehensive Design Report (Doull, 2015):

> *A library of Mike11 models has been built up over the years, each model covering the reaches that were of interest at the time. There is no comprehensive model of the entire Lower Manawatū main stem plus tributaries, although some of the larger models cover most of it.*

The updated model is required for HRC's future operational and design-use purposes to provide flood risk protection to the region, notably through key infrastructure assets such as the Moutoa Gates and Moutoa Floodway, region-wide stopbanks, floodgates and pumping stations.

As a precursor to this updated Lower Manawatū model, WSP prepared the '*Moutoa Gates – Model Build Report to Support 2025 Operational Upgrades*' in June 2025 (WSP, 2025b). This Moutoa Gates report detailed the initial model build for the southern extent of the Lower Manawatū catchment, from Oroua River at Kopane Bridge and Manawatū River at Teacher's College down to the outlet at Foxton Beach with a focus on the operation of the Moutoa Gates under different scenarios. This updated Lower Manawatū model report focuses on the model build for the full Lower Manawatū catchment. Whilst this report makes every effort to distinguish from and include details of the initial model build where appropriate, this report should be read in conjunction with the Moutoa Gates report (WSP, 2025b) to provide full context.

1.2 PURPOSE AND DRIVERS

Flooding is the most frequent and significant natural hazard in the Horizons region, in particular the Lower Manawatū catchment which has historically experienced widespread damage and disruption as a result of large floods. In February 2004 a 1 in 100 year rainfall event hit the Lower Manawatū catchment, resulting in significant flooding across the region that was in part attenuated by the use of the Moutoa floodgates (Fuller, 2005).

The increasing impacts of climate change makes managing flood risk and achieving long-term resilience a top priority for HRC, which is identified HRC's 2024-34 Mahere Roa (Long-term Plan) and their 2024-2054 Infrastructure Strategy. This underpins the requirement for an updated Lower Manawatū catchment model, which is driven specifically by the following factors:

- **Known Deficiencies of Existing MIKE Model(s) –** Doull (2015) summarises the known issues with the existing MIKE model(s). This includes, but is not limited to, inadequate February 2004 calibration compared to surveyed flood levels, simplification of roughness to approximate energy losses in large meandering 1D channels, and significant uncertainties associated with the flow through the Moutoa Gates. For the Moutoa Gates, which is the most important flood asset in the Lower Manawatū catchment, significant underestimation of modelled gate flow (particularly at higher flows such as those experienced in February 2004) has reduced HRC's confidence in understanding the gate hydraulics and associated system response. Without implementing a fundamental re-working of the MIKE11 algorithm, HRC addressed this by artificially increasing gate dimensions (22 m modelled width vs.15.24 m actual width) to achieve expected gate flow as well as by modelling only 3 gates (vs. 9 actual gates) with 3x the

flow capacity to improve stability.
Overall, HRC had limited confidence in the use of the MIKE model(s) for purposes of future design use and operational management.

- **Updated Data** – over the years, new and updated information has become available including LiDAR, channel survey, stopbank survey and data from recent high-flow events (such as February 2023). An updated model should reflect the availability of this recent data.
- **Computing Power** – recent advancements in computational power and efficiencies of hydraulic modelling engines have highlighted the superior benefits of predominantly two-dimensional (2D) schematisations for large catchments like the Lower Manawatū, compared to the predominantly 1D-only models developed in the past. New 2D TUFLOW modelling features such as Quadtree Flexible Mesh and Sub-Grid-Sampling have significantly reduced the prior comparative advantage of using 1D model for time and cost-savings.
- **Asset Infrastructure Management Plans** – key assets such as Moutoa Gates, stopbanks and pumping stations need accurate, representative flood risk modelling to inform their future operational use requirements to address long-term risk quantification and achieve asset resilience. An improved hydraulic model will inform residual risk profiling via scenario testing, support future asset design needs, and align with planning and development requirements.
- **Emergency Flood Risk Management Procedures** – the Manawatū-Whanganui Civil Defence and Emergency Management Group requires calibrated, accurate flood risk information to prepare for emergency flooding situations through Civil Defence measures. This includes operational use of key assets like Moutoa Gates, which requires comprehensive modelling to mimic the complex, interconnected hydrological-hydraulic dynamics of the Lower Manawatū system. This works also supports wider flood forecasting efforts.
- **Property and Infrastructure Risk** – flood modelling is an important asset required for understanding property and infrastructure damages. Increasingly detailed two-dimensional (2D) representation of floodplains and out-of-bank flowpaths will improve estimations of risk profiles associated with property damages.
- **Planning and Development** – in the short-term, sustainable infrastructure development for the Horizons region will in part involve reducing their commitment to development of projects in pursuit of building resilience to climate change. In the long-term, identifying and prioritisation of key areas which balance climate resilience and affordability will require comprehensive understanding of flood risk across the catchment.
- **Single-Source of Flood Risk Information** – as part of the Long-term Plan to develop this updated model, it will be beneficial to have a single point of reference for catchment flood risk. This will become a tool that can be continually improved and refined to achieve HRC strategic goals. The model can become a well-understood tool with known applicability, advantages and limitations.

1.3 HRC REGIONAL FLOOD MODELLING FRAMEWORK

WHAT IS THE FRAMEWORK?

As part of the FVA project the Current State Analysis report (WSP and NIWA., 2025b) provided a thorough review of international and domestic best practice for flood modelling and mapping practices, which culminated in a regional flood modelling framework. The framework adopts a staged approach based on the required detail of output and available data, allowing for assessments at different scales. The hydraulic model methodology framework assesses modelling on a four-level scale from A to D (Level D being the highest). The framework was used to highlight existing flood risk use cases identified by HRC and relevant Territorial Authorities.

Figure 1-1 shows the regional flood modelling framework.

Level of Detail	Key Features	Output Features	Uses
Level A – Basic Desktop Assessment	Regional model Validated against extents Structures/assets identified from LiDAR Calibration/sensitivity includes check of selected locations against historic records	Low resolution may include flood depth. Approximate map scale down to 1:5,000 or greater. Could be greater than 1:25,000 Unlikely to have velocity Suitable to understand the extent of flooding for further detailed investigation Exposure assessments and prioritising areas for further investigation	Emergency management readiness and recovery planning Regional policy and development plan High level community engagement High level asset management and long-term planning for flood infrastructure
Level B – Basic Validated Desktop Assessment	Regional model Validated against extents Structures/assets identified from lidar Calibration/sensitivity includes check of selected locations against historic records	Low resolution may include flood depth. Approximate map scale down to 1:5,000 or greater Unlikely to have velocity (aspire to have velocity) Suitable to understand the extent of flooding for further detailed investigation Exposure assessments and prioritising areas for further investigation	Asset management for flood infrastructure Local Government (Regional and District) policy setting Readiness, recovery and high-level response planning Contingency and evacuation planning District scale planning or policy adjustments Zoning as a function of spatial planning Long-term infrastructure planning
Level C – Localised Catchment Model	Detailed catchment model Includes some assets and streams Sensitivity testing. Validation of model parameters to extents and some levels. Starting to look at gauge calibration.	Refined model Approximate scale down to 1:1,250-1:500 May have velocity and depth Shows exposure (spatial extent) Flows at gauges Water levels, depths and velocities at critical infrastructure/areas Flood hazard classification	Strategic catchment and infrastructure planning Regional and district policy setting Urban growth and land use planning Decision support for Integrated Catchment management (ICM) Climate adaptation planning Resource Management Act Consents (including land-use, subdivision and resource) Zoning as a function of spatial planning Readiness and recovery planning Community response planning
Level D – Specific Detailed Assessment	Site specific model Includes all assets/structures Often a property/parcel level Sensitivity testing. Calibration at gauges for multiple events and comparison with historic records.	High resolution Approximate map scale down to 1:500 (or less) Includes depth, velocity along with spatial extent Flood hazard classification	LIMS – public use case for property-specific decision making Detailed design of flood protection assets Emergency management response and recovery during a flood Urban growth and land use planning decisions Detailed site planning and development controls Resource Management Act Consents (including land-use, subdivision and resource) Building Consents and site considerations

Figure 1-1 Regional Flood Modelling Framework for Horizons Regional Council. *Source: Table 3, Horizons Flood Modelling and Mapping Guideline* (WSP and NIWA., 2025a).

To support the Regional Modelling Framework, Table 4 of the report developed a Model Methodology Framework which determined the Level A-D criteria for the following key modelling components:

> Data Methodology, Asset Surveying, Channel Surveying, Hydrological Methodology, Flood Events and Climate Change, Terrain, Land Cover, Cell Size / Resolution, Structures, Stormwater Network, Sensitivity Testing, Validation and Calibration, Outputs.

As part of the wider effort to standardise and consolidate HRC's database of modelling, the updated Lower Manawatū model is the first new-build which fits within the modelling framework, which is described below.

LOWER MANAWATŪ MODEL – LEVEL B MODEL

This report presents the work undertaken on the first stage of model development for the 2024/25 period to June 2025. Table 1-1 gives an overview of the component levels assigned to the Lower Manawatu model, with full details of the Phase 1 model build methodology contained in Section 2.

Overall Lower Manawatū Model has been assigned Level B. The hydrological methodology and validation / calibration, both assigned Level B, are key model inputs which should be addressed in future work (see Section 5.4 Recommendations). The fundamental components of the model (data, assets, structures, terrain, channel, cell size) are strongly Level C and in some cases pushing towards Level D (such as cell size, outputs and structures). The flood risk mechanisms are well represented at a catchment-scale and have been validated in the main areas of interest by a Level D assessment from the Moutoa Gates model (WSP, 2025b).

Table 1-1 Lower Manawatū Model Level Criteria (Criteria sourced from Current State Analysis Report (WSP and NIWA., 2025b)

Criteria	Level	Description
Data Methodology	C	Report describes data and sources, includes review of vertical datums for consistency. Data from reputable primary sources including survey and LINZ. Checked quality of surveys and asset information such as Flygers Line Spillway, Moutoa Gates and stopbank validation to LiDAR DEM.
Asset Surveying	C	Model includes all key structures with detailed survey and drawing dimensions including stopbank survey, Moutoa Gates, Mangaone watercourse bridges and culverts.
Channel Surveying	C	Manawatū River defined by 2023 channel survey using interpolated surface from evenly-spaced cross-sections. Approximations calculated from channel survey used to define capacity of Oroua River. Smaller watercourses rely on LiDAR DEM.
Hydrological Methodology	B	Based on NIWA TopNet hydrological model to define inflow hydrographs at the upstream model boundaries. Flows derived from spatially and temporally varying design rainfalls. No explicit representation of storage or floodplain dynamics for the sub-catchments upstream of the inflow points. Antecedent conditions included to give physically realistic starting states.
Flood Events and Climate Change	B	Focus on larger events (1 in 50-, 100-, 200-year events). Climate change included to represent 3-degrees of warming. One duration considered (60-hour). Main model domain validated to two smaller (1 in 2-year return period) events as part of the Moutoa Gates Model build (WSP, 2025b).
Terrain	C	Terrain defined by high-resolution 1 m DEM from LINZ, which picks up all key features at fine resolution. No gaps in data. Main Manawatū channel

		corridor defined by recent LiDAR survey (2022-23). DEM validated to HRC survey data.
Land Cover	C	Materials defined by Land Cover Database v5.0 (latest at time of model build). Specific roughness values assigned to each land cover. Manawatū river roughness and turbulence parameters validated from the Moutoa Gates modelling assessment (WSP, 2025b).
Cell Size / Resolution	C	Spatially-varying cell size methodology developed to address specific topographical and watercourse features. Includes justification and cell size convergence, determining small sizes (2 m) where required for key flowpaths and larger cell size (32-64 m) on flatter, volume-accumulating floodplains. Uses sub-grid-sampling (SGS) to define cells at high resolution for all cell sizes.
Structures	C	All key structures included (Moutoa Gates, Flygers Line Spillway, Mangaone culverts and bridges) based on surveyed dimensions. Moutoa Gates modelled with full open logic operations and validated with TUFLOW expert team, by showing 60% of Manawatū flows diverted when opened in large events. Mangaone Bridges included. Key floodgates included based on surveyed dimensions, including Rangiotu, Burkes, Koputaroa, Okuku Gates.
Stormwater Network	N/A	Stormwater network not modelled as this is a fluvial model.
Sensitivity Testing	C	Identifies key uncertainties associated with flooding mechanisms, including roughness, turbulence, hydrological methodology, gate operations, channel definition. Sensitivity tested roughness and turbulence as part of Moutoa Gates model (WSP, 2025b) and validated parameters by comparing to two observed events.
Validation and Calibration	B	Model extent only validated to lower catchment extent south of Palmerston North as a result of work from the Moutoa Gates Model (WSP, 2025b). Validation focussed on smaller 2-year magnitude events (June 2021, February 2022).
Outputs	D	Mapping of flood extents, depths, velocities, time series plots. Comprehensive analysis of results across multiple return periods and locations. Specific overtopping locations analysed.

LOWER MANAWATŪ PHASES – FROM LEVEL B TO LEVEL D

As a significant and operationally complex catchment, this is part of HRC's planned long-term modelling programme that aims to continually refine and improve their database of models to deliver long-term flood-risk resilience, support asset management and inform regional development plans. At Phase 1, the outputs of the model are intended to represent Level B catchment-scale fluvial flood risk from key watercourses such as the Manawatū River, Oroua River and Mangaone Stream. Although the model architecture is built to a Level C, the outputs are limited by the hydrological assessment and validation / calibration undertaken which are crucial to provide a higher level of reliability and confidence for assessments.

Future model refinement will be supported by data collection and survey to deliver high-resolution asset representation (for example stopbanks, pumping stations, floodgates, channel topography), detailed representation of flood risk to urban centres (such as Palmerston North and Feilding) and improved drainage scheme operations. This will support more detailed local-scale assessments and analyses such as designing stopbanks, designing asset upgrades, urban flood risk and fluvial-pluvial flood risk interaction.

With the known limitations for the hydrological inputs and validation / ciliation, this Level B model's outputs are limited to informing policy and planning initiatives at a strategic level. Level of service for flood protection assets could be informed at catchment-scale or flood scheme level when it becomes a Level C model, although an extent of uncertainty will remain without detailed calibration. The detailed design of assets and their areas of influence should rely on further refinements to model inputs with finer scale modelling more aligned with Level D modelling. The below example demonstrates how Level of Service for a stopbank upgrade might look from different model levels:

- Level B Model Outputs – not appropriate to inform design but outputs can inform policy adjustments or strategic planning or prioritisation exercises relating to the stopbanks.
- Level C Model Outputs (Validated) – identify flood-prone areas, develop strategic upgrade options (raising crest levels, extending lengths, re-alignment), evaluate options based on performance criteria, generate short-list from long-list. Sensitivity testing of the short-listed options to account for uncertainty in modelling without detailed calibration undertaken.
- Level D Model Outputs (Calibrated) – fine-scale model refinements for specific areas of interest with survey, minimise all uncertainties with detailed calibration (hydrological and hydraulic parameters), simulate preferred option, finalise detailed design for construction.

Table 1-2 gives an overview of the planned phases of model development and how this aligns with the Modelling Framework and indications of modelling use cases.

Table 1-2 Lower Manawatū Model Development Phases.

Phase	Examples of Modelling Use Cases

Phase 1: July 2024 – June 2025
 	
This Report
 	
Level B
	Catchment non-validated flood model – suitable for regional scale assessment and analyses such as:
	— **Regional District Advice** – current outputs are not appropriate for district advice. Maps should not be viewed at site-specific scales but can provide sub-catchment or catchment-scale indications of flood risk.
	— **Emergency Management** – map outputs can inform catchment-scale assessments for readiness, contingency planning and response evaluation and operational planning.
	    — Level B models can inform contingency and evacuation planning but shouldn't be used to inform the development of community response plans until Level C.
	— **Asset Management** – modelling can be used to determine impacts on flood extents from specific assets such Moutoa Gates, but they can't inform Levels of Service.
	— **Regional Planning** – model output can inform district-scale planning or inform policy adjustments. The model might be used for community and suburb scale planning to identify priority locations or those requiring further investigation.
	— **Development Planning Stages** – Level B modelling can be used in the pre-feasibility stages of planning.
	— **Investigations and Design** – interpretation and review of flood hazard maps to advise and support other personas such as spatial and land use planning.
	— **Damages Assessments** – Level B modelling can inform an overview of property and infrastructure damages at the regional and catchment scale to identify suburbs, villages and towns at greater risk
	    — Level C modelling should be used if specific sub-catchment or suburb damages are required

	— **Sub-Catchment Drainage Schemes** – Level B modelling is unlikely to captures the scheme operations and does not represent channel capacity fully. The model will miss some structures or assets and accompanying operational procedures. — Level of modelling is not appropriate for informing nor designing local drainage scheme upgrades.

Phase 2a: Future Work
 	
Level C
	Catchment validated flood model – suitable for regional scale assessment and analyses such as:
	— **Regional District Advice** – map outputs can be used by TAs for the provision of hazard and property information to support subdivision consenting
	— **Emergency Management** – map outputs can inform catchment-scale assessments for readiness, contingency planning and response evaluation and operational planning.
	    — Level C models are particularly useful to inform the development of community response plans.
	— **Asset Management** – modelling can be used to inform levels of service for larger assets such as regional stopbanks, Moutoa Gates and Flygers Line Spillway.
	    — Identifying assets / locations for infrastructure upgrades and investment can be undertaken – for example stopbank upgrades
	    — Long-list to short-list optioneering
	    — Detailed design is not considered appropriate for Level C modelling.
	— **Regional Planning** – model output can inform plan changes, regional policy amendments, urban growth planning and land use planning.
	    — Level C models can also inform community adaptation planning through options assessments such as cost-benefit.
	— **Development Planning Stages** – Level C modelling can be used in the feasibility and consenting stages of planning.
	    — Level C is not appropriate Consenting and Detailed Design.
	— **Investigations and Design** – modelling can inform catchment-level levels of service and planning for infrastructure upgrades for flood protection schemes.
	    — Detailed design of assets is not considered appropriate for Level C modelling.
	— **Damages Assessments** – Level C modelling can inform property and infrastructure damages at the regional and catchment scale to identify suburbs, villages and towns at greater risk
	    — Level C modelling is not appropriate for detailed damages assessment at the site-scale or plot-scale
	— **Sub-Catchment Drainage Schemes** – Level C modelling captures a high-level understanding of the scheme operations, likely missing some structures or assets and accompanying operational procedures.
	    — Level of modelling is only appropriate for informing but not designing local drainage scheme upgrades.

Phase 2b: Future Work **Level D**	Detailed calibrated flood model using detailed hydrological inputs with site- and plot-scale outputs for water depths, velocities and flows. Suitable for local-scale assessments and analyses such as: — **Regional District Advice** – map outputs can be used to inform site-specific building consents — **Emergency Management** – map outputs can inform detailed response and recovery functions — **Asset Management** – modelling can be used to inform detailed design of flood protection infrastructure to provide a strong understanding of levels of service for major and minor assets.

	— For example – stopbank upgrades can be designed to specific levels of service, ready for construction — **Local Planning** – site-specific flood modelling and mapping can be used for detailed site planning and development control, urban growth planning, and land use planning. — **Development Planning Stages** – Level D modelling can be used in the consenting and detailed design stages of planning. — Examples could include flood mitigation options analysis for stopbanks or pumping station upgrades, and detailed design of mitigation structures for catchment/community planning. — Floor Levels can be confidently established at Level D — **Investigations and Design** – Level D modelling is appropriate to design most assets with engineering solutions for specific flood protection assets. — Level D modelling will include the best and most detailed survey and data available. — Level D modelling will include sensitivity testing to quantify residual risk and uncertainty to inform design. — **Damages Assessments** – Level D modelling can inform property and infrastructure damages at the local plot- and site-scale. — Modelling outputs could be used to inform detailed risk-based assessments such as insurance. — **Sub-Catchment Drainage Schemes** – Level D modelling captures a full understanding of the scheme operations, incorporating all key structures or assets and accompanying operational procedures. — Level of modelling is appropriate for designing and implementing local drainage scheme upgrades, such as Sluggish Drain

1.4 AIM AND SCOPE

The overall aim of this report is to:

> *develop an updated catchment-scale hydraulic model of the Lower Manawatū catchment to support HRC's future operational and design-use purposes*

The following scope was developed to achieve this aim:

- Develop and build upon the initial Moutoa Gates model build (WSP, 2025b) to incorporate the full Lower Manawatū Catchment.
- Represent inflow hydrology as routed hydrographs (not rainfall) from the NIWA Regional Flood Modelling Report.
- Model all key channels and tributaries as 2D flowpaths using available terrain data, including LiDAR and topographic survey.
- Model key identified assets which control catchment-scale flood risk mechanisms, specifically stopbanks, roads, floodgates (including Moutoa Gates), spillways (natural and built), bridges and culverts.
- Simulate five key events:
  - 1 in 50-year event (2% AEP)
  - 1 in 100-year event (1% AEP)
  - 1 in 100-year event plus climate change (1% AEP with climate change)

    - 1 in 200-year event (0.5% AEP)
    - 1 in 200-year event plus climate change (0.5% AEP with climate change)
- Produce flood maps showing extents and depths across the catchment.
- Identify all key assumptions, limitations and recommendations to inform the next stages of the forward work programme.

2 MODEL BUILD METHODOLOGY

2.1 BACKGROUND

Doull (2015) details the Lower Manawatū Catchment history and scheme operations, which provides comprehensive context to the data and information included in this model build. This Model Build Methodology should be read in conjunction with Section 3 of the Moutoa Gates report (WSP, 2025b). For the avoidance of doubt any repetition, replication or amendment of methodology contained in this report supersedes that which was contained in the Moutoa Gates report.

The following sub-sections describe the methodology of this model build.

2.2 DATA SOURCES

This section details the information sources for the data used in the model build. Table 2-1 provides more detail on each data source and indicates when the data was accessed. More detail on how each data source was used in the model is provided in Section 2.4 and Section 2.5.

Table 2-1 Data Sources.

Data	Details	Source / Reference	Date Accessed
Model Base Terrain	— Raster datasets ranged from 2016 to 2024, with more recent data prioritised in areas of overlap — LINZ datasets prioritised over NIWA datasets	LINZ NIWA	September 2024
Vertical Datum Conversion	— Moturiki 1953 to NZVD2016 conversion raster — Wellington 1953 to NZVD2016 conversion raster	LINZ	May 2025
Land Cover	— Defines material / land cover type based on 2018 coverage — Roughness value assigned to material type	Land Cover Database V5.0	September 2024
Structure Dimensions	— Dimensions sourced from HRC Drawings where available, else information sourced from LiDAR, otherwise dimensions estimated from HRC site photography — Drawings clearly identified throughout report using syntax 'HRC Drawing XXX-X'.	HRC LiDAR (LINZ)	April 2025
Stopbank locations	— Layer defining the centreline of stopbanks — Some adjustments required to align to centreline indicated by LiDAR data	HRC	September 2024

Data	Details	Source / Reference	Date Accessed
Watercourse and Topographic Surveys	— 2023 Manawatū watercourse survey used to define channel terrain — 2021 topographic survey used to define stopbanks between Mile 17 and Mile 28	HRC	April 2025
Road Centrelines	— 1:50k road centrelines	LINZ	May 2025
Inflow Hydrology	— Modelled inflow boundaries and tidal boundaries from the NIWA Regional Flood Modelling	NIWA	May 2025
Aerial Imagery	— 'Aerial Basemap Imagery' – used to inform model refinement. Sourced from LINZ: — Manawatū-Whanganui 0.3m Rural Aerial Photos (2021-2022) – covering approximately 90% of the catchment — Manawatū 0.1m Urban Aerial Photos (2022-2023) –covering Feilding — Manawatū-Whanganui 0.2m Rural Aerial Photos (2023-2024) – covering Pohangina	LINZ	May 2025

2.3 MODEL EXTENT AND OVERVIEW

The upstream boundaries reflect the key watercourses which contribute to catchment-scale flooding in the Lower Manawatū catchment (Figure 2-1). Minor drains and watercourses that have not been included are expected to be considered and potentially included in later stages of model development that will consider more local-scale flood risk mechanisms, in particular local drainage schemes. In total the modelled catchment extent of the Lower Manawatū is 788 km^2, with approximately 102 km of the Manawatū River and 52 km of the Oroua River included.

Figure 2-1 shows the key topographic features within the model boundary extent. These are key hydraulic controls and topographic features in the catchment:

- Roads – these often act as de facto spillways and stopbanks that form barriers to flow.
- Stopbanks – these act to contain flood waters within the river channel.
- Moutoa Gates – these act to divert water down the Moutoa Floodway during large events.
- All upstream inflow boundaries are also marked in Figure 2-1 as 'Inflow Watercourses'.

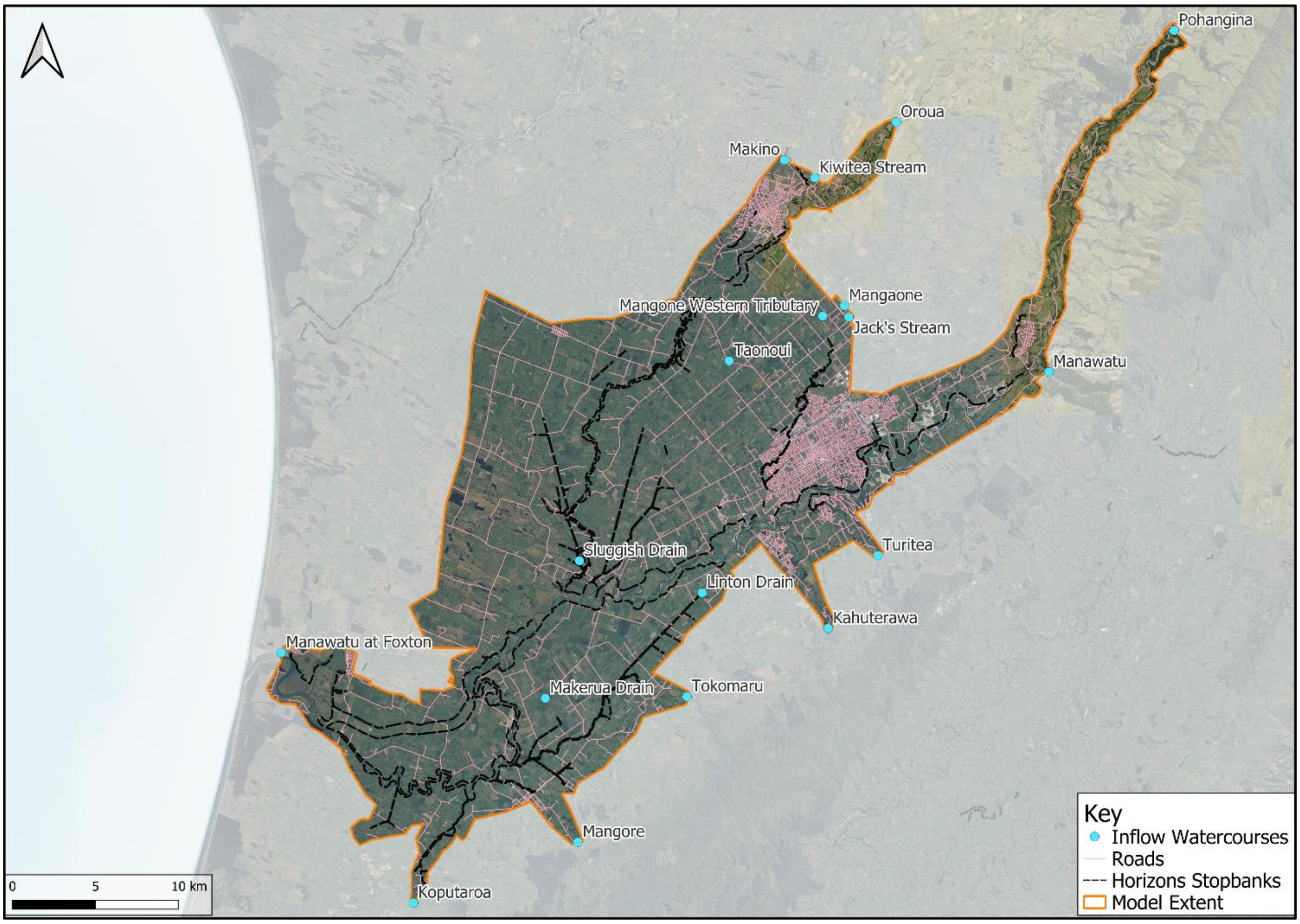

Figure 2-1 Model Extent, Inflow Watercourses and Key Features.

2.4 TUFLOW MODEL FILES AND PARAMETERS

The model was built in TUFLOW HPC using GPU hardware. Table 2-2 introduces each TUFLOW file and how they define key model inputs and components.

Table 2-2 Model Components and Methodology.

Component	Details

TUFLOW Model Files	• **TUFLOW Control File (TCF) – parent file**
	— This parent file defines key model parameters, the output settings and the location of supporting files.
	— The model uses BMT's TUFLOW version 2025.0.1, the HPC Solution Scheme and GPU hardware.
	— The 2D grid solver is used for all overland flowpaths through rivers and floodplains. The 1D solver (ESTRY Control File) is defined separately to represent floodgate structures and the Moutoa Gates.
	— Turbulence Formulation set to 'Wu', 3D parameter of 3 and 2D parameter of 0.25 (see Section 2.6 Moutoa Gates 2025 Model Validation for more information)
	— Output settings include:
	    — 15-minute output interval
	    — High-resolution (HR) outputs for depths and water levels

Component	Details
	— Plot Output (PO) objects defined to extract time series of flow and water levels from 2D grid at key locations, such as Moutoa Gates. • **ESTRY Control File (ECF) – 1D Domain** — 1D solver used for floodgate structures and Moutoa Gates via 1d_nwk objects. — Contains TUFLOW Operation Control file (TOC) which determines how operational structures open and close. • **TUFLOW Geometry Control File (TGC) – geometry definition** — Includes model extent, materials, gridded initial conditions and terrain definition. — Terrain modifications modelled using 2d_zsh objects, such as stopbanks and roads. — Bridges modelled using 2d_bg lines and points. These represent energy losses in the 2D domain through form loss coefficients (FLC) at varying elevations of structure dimensions (piers, soffits, decks). • **TUFLOW Boundary Control File (TBC) – boundary definition** — All inflows modelled as 2d_sa objects on the 2D grid. — The downstream boundary modelled as 2d_bc object to represent Head-Time tidal conditions. — 1D-2D connections were modelled using 2d_bc objects, specifically the 'SX' type. • **Quadtree Control File (QCF) – cell definition** — Determines variable mesh cell sizing for the model grid.
Cell Size and Definition	• **Quadtree and Sub-grid-sampling (SGS)** – The QCF file determines variable cell sizing. It defines smaller cell sizes in areas of greater topographic variability near key features such as watercourses, roads and at stopbanks. Larger cells are used on flatter floodplains that operate like 'buckets' where flooding extents are controlled by volume accumulation (for example the 'Southern Floodplain' south of the Moutoa Floodway). The cell sizes that were used in the model are: – Watercourses – 8 m cells on Manawatū and Oroua, 4 m cells in all other minor watercourses – Stopbanks – 4 m cells – Roads – 8 m cells – Floodplains – 8-64 m cells — **Sub-Grid Sampling (SGS)** – SGS allows cells to have greater resolution of detail at the sub-single cell level. For example, 4 m cells are sampled at the 1 m resolution, 64 m cells are sampled at 4 m resolution. This generates an elevation-volume relationship for the cell's volume and an elevation-surface area relationship for the cell sides. — As part of the initial model build phase, cell size convergence testing was undertaken to balance sufficient topographic detail with computational run time considerations.
Datums	— **Vertical Datum** – The model was built in New Zealand Vertical Datum 2016 (NZVD2016). All values used throughout the report are NZVD2016 unless stated otherwise. — LINZ vertical datum conversion rasters were used to convert WLG53 and MVD53 levels to NZVD2016. — **Projection** – New Zealand Transverse Mercator 2000 (NZTM2000).

2.5 MODEL METHODOLOGY

This section is split into two main model components:

1. Terrains and Model Geometry – the base surface representation, land cover definition and terrain definition for key features such as stopbanks and roads
2. Structures – Moutoa Sluice gates, bridges, floodgates and spillways

2.5.1 TERRAINS AND MODEL GEOMETRY

The Lower Manawatū catchment has multiple significant topographic features that require defining in the model including watercourse channels, floodplains, roads and flood protection assets such as stopbanks. Table 2-3 details the key features.

Table 2-3 Terrains and Model Geometry.

Feature	Detail
Base Terrains, Topography, Land Assets	— **Model terrain** – LINZ LiDAR DEM was used to define the bare ground terrain (filtered to exclude buildings and vegetation) using the latest dataset available in all locations. The DEM represents fully filtered Datasets ranged from 2016 to 2024, with prioritisation given to terrains retrieved from the LINZ data service. Figure 2-2 shows the data sources used for the model terrain. — The 2020 'NIWA DEM Surface' was converted from Wellington 1953 (WLG53) to NZVD2016, following checks of against the 2022-23 LiDAR surface. A histogram of the level difference between both surfaces converged to 0.45 m (in areas where they overlapped in spatial coverage). This was considered reasonably close to the 0.39-0.43 m vertical datum difference between WLG53 and NZVD2016. The difference also didn't account for differences in LiDAR capture dates or other processing discrepancies. Despite these data quality checks reducing uncertainty associated with the NIWA LiDAR surface, the LINZ surfaces were prioritised based on the quality assurance required for LINZ datasets.

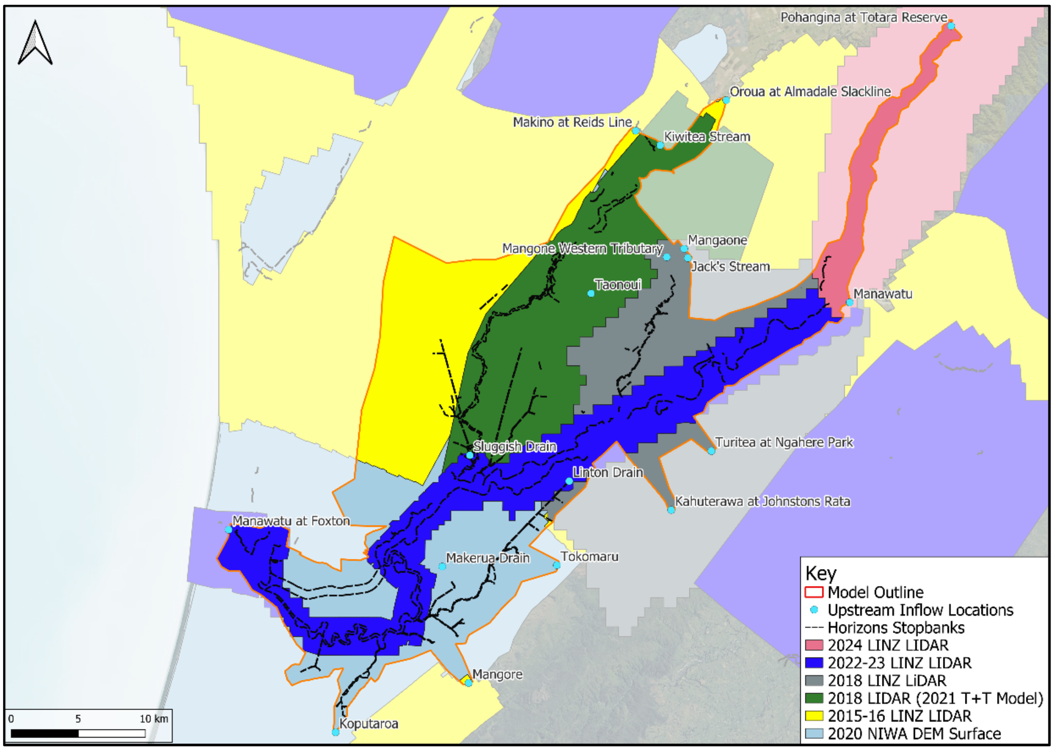

Figure 2-2 Terrain layer coverage, listed in order of preference.

- **Stopbanks** – all stopbanks were modelled as 'zero width' breaklines along their crest, which modifies the levels at the cell sides using a 2d_zsh object.
  - Levels were mostly defined by LiDAR, searching for the maximum elevation within a 15 m radius of each vertex along the bank. The frequency of bank points was determined by the vertex spacing along the line, ranging from 5 m or less near bends to 100 m along straight alignments.
  - The 2021 stopbank survey was included between 'Mile 17' (Springs Road / Foxton – Shannon Road intersection) and 'Mile 24' (Moutoa Gates) on the Manawatū River Right Bank. Surveyed levels were taken at 20 m spacing along the stopbank. Level checks were made against the LiDAR surface, which generally showed close agreement (within +/-50 mm). Levels between Barber Road (Mile 19) and Foxton-Shannon Road bridge (Mile 18) were the exception, where the stopbank survey levels were approximately 250-300 mm lower than the LiDAR levels. This discrepancy should be investigated further in future stages of model development.
- **Roads** – all stopbanks were modelled as 'zero width' breaklines along their crest, which modifies the levels at the cell sides using a 2d_zsh object.
  - Levels were enforced by searching for the maximum elevation within a 15 m radius along the road centreline. The frequency of bank points was determined by vertex spacing, ranging from 5 m or less around bends to 100 m along straight alignments.
- **Structure Parapets** – where a 1D structure has been modelled, for example Rangiotu Gates or Burkes Gates, a 2d_zsh region is used to block the 2D flowpath up to the height of the structure parapet, which represents the spilling mechanism.
- **Channel Connectivity** – LiDAR data typically filters out bridges or roads over watercourses, meaning there is a continuous channel connection for flow either side of the structure or road.
  - For minor watercourses, where the LiDAR surface blocked watercourse connectivity, a basic connection was made by interpolating levels upstream and downstream of the structure or road (Figure 2-3). This was the case for 60 structures, covering mostly the Taonui Stream and Mangaone Stream.

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— Where a 1D structure is modelled, for example Moutoa Gates or Rangiotu Gates, the 2D channel remains blocked to avoid double-counting flowpaths.

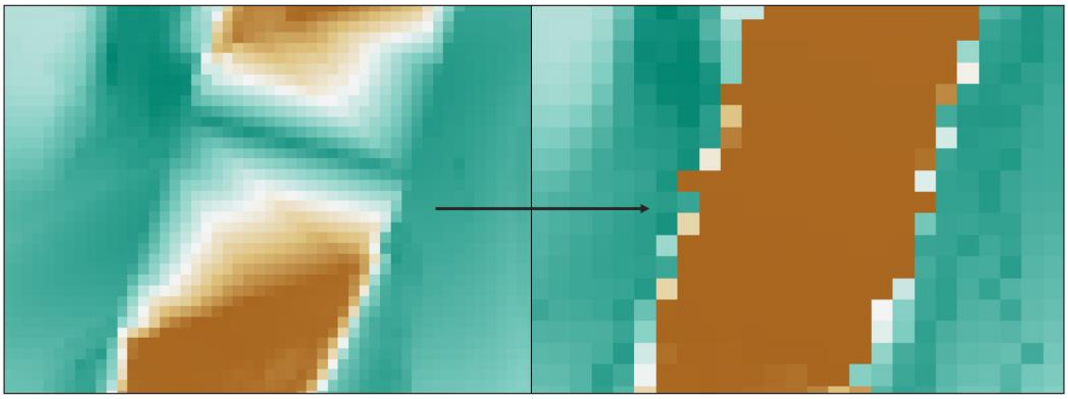

Figure 2-3 Terrain Modifications on the Mangaone Stream under Tremain Avenue road bridge.

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<td>Channel Terrain</td>
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— **Manawatū River** – the river channel surface is not well-defined below the water level (the wetted channel perimeter) because LiDAR does not penetrate the water surface. This means that LiDAR levels within the wetted perimeter of the channel are often flat (Figure 2-4). To overcome this, the 2023 Manawatū River survey cross-sections were used to create an interpolated channel surface from Foxton to the confluence with the Pohangina River (the full survey extent). Figure 2-4 shows that this interpolated Manawatū River channel surface gives a closer approximation of channel shape and capacity than LiDAR, although it does not account for natural variation in channel shape between the cross-sections.

  — This interpolated surface supersedes the rectangular-equivalent depth surface used for the Manawatū River in the Moutoa Gates model (WSP, 2025b).

  — In total 223 of 228 available Manawatū River cross-sections were used to create the channel surface, with distances between cross-sections varying from approximately 400 m to 600 m. The following cross-sections were excluded due to issues with poor horizontal alignment, preventing representative interpolation: 81064, 79383, 63969, 43797, 29856.

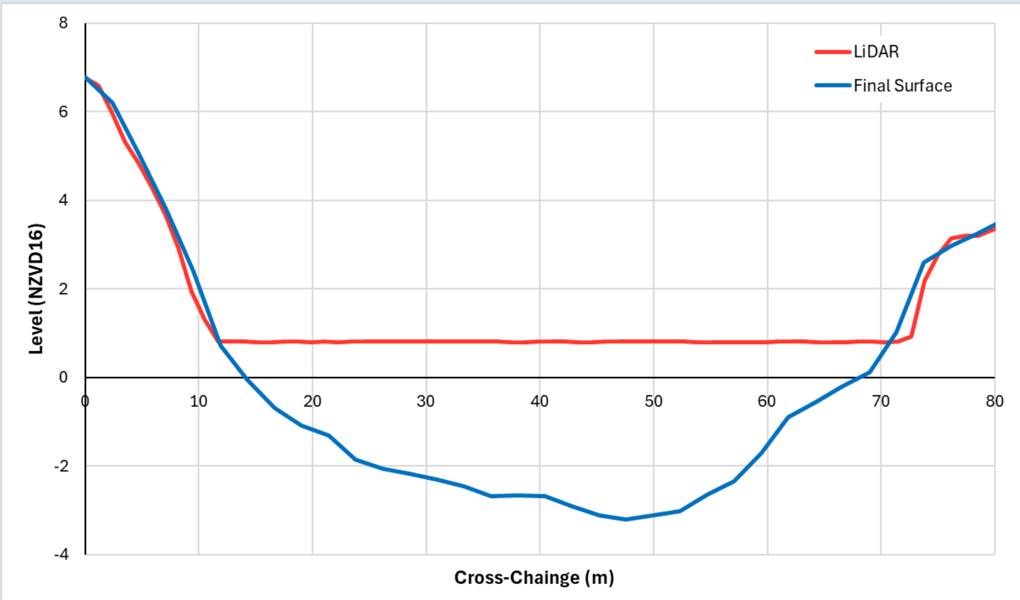

Figure 2-4 Cross-section of the model surface using the interpolated channel compared to the LIDAR surface, at the location of the Moutoa Gates channel gauge).

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- **Pohangina River** – the 2023 Pohangina watercourse survey was not used to create an interpolated surface. As a braided river often with 3 or more meandering flowpaths across the watercourse, it was not possible to create a surface that was representative of channel levels between cross-sections.
  - LiDAR data was preferred primarily because it could be relied upon to define inter-channel areas better than an interpolated surface.
  - As a relatively narrow corridor of active floodplain, the exclusion of channel survey should impact only localised flood depths and extents without impacting downstream flooding mechanisms.
- **Oroua River** – at this stage of model development, no cross-section survey was available for the Oroua River. This means that LiDAR data defined the channel terrain as flat. Given the size of the Oroua River channel and the importance of representing its capacity, the wetted channel perimeter was lowered by 1.5 m using a 2d_zsh to create a simplified rectangular channel. This 1.5 m modification was justified at this stage of assessment because the same value was calculated for the Manawatū River in the vicinity of the Oroua confluence in the Moutoa Gates model (WSP, 2025b) when using the 2023 watercourse survey. This approximation is listed as a limitation and should be addressed in future model updates to get a more realistic understanding of the Oroua River channel shape and capacity.
- **Other watercourses** – all other watercourses use the LiDAR terrain to define channel shape. Depending on the watercourse, this will underestimate channel capacity to differing extents. This is listed as a limitation to address at further stages of model development.
  - Minor channel terrain modifications were required to support the inclusion of surveyed structures which have inverts below the LiDAR terrain. Sluggish Drain and Koputaroa Drain channel levels were lowered by 1.8 m and 0.65 m respectively to match the inverts of the floodgates. These channel modifications were included only in the immediate upstream vicinity (200 metres) of the floodgates to support the function of the structure.

Land Cover and represented surface roughness

The Land Cover Database (LCDB) v5.0 was used to define Manning's *n* surface roughness for the model grid, representing the resistance to flow within the model terrain (Table 2-4). Figure 2-5 shows the spatial coverage of the material roughness implemented within the model.

The following modifications to the grid were made:

- Minor watercourses were not picked up by LCDB v5.0. Polygons were buffered along the minor watercourse centreline and material 21 was applied.
- The area immediately upstream of Moutoa gates is made up of a mix of baren land and concrete. To reflect this, was Manning's n value was reduced from 0.09 (Material 41) to 0.03.

Table 2-4 Land Cover material and Manning's n surface roughness.

Material	LCDB V5.0 ID	Manning's N
Built-up area	1	0-0.05 m Depth – 0.015 0.05-0.1 m Depth – linearly interpolated 0.015 to 0.05 >0.1 m Depth – 0.05
Urban parkland/open space	2	0.033
Transport infrastructure	5	0.016
Surface mine	6	0.028
Coastal sand and gravel	10	0.025

Landslide - bare surfaces	12	0.025
Alpine gravel and rock	15	0.039
River and lakeshore gravel and rock	16	0.039
Lake and pond	20	0.02
River	21	0.035
Estuarine open water	22	0.022
Short-rotation cropland	30	0.1
Orchard and other perennial crops, vineyard	33	0.06
High producing exotic grassland	40	0.05
Low producing grassland	41	0.09
Herbaceous freshwater vegetation	45	0.1
Herbaceous saline vegetation	46	0.1
Flaxland	47	0.1
Fernland	50	0.16
Gorse and broom	51	0.125
Manuka and or kanuka	52	0.1
Broadleaved indigenous hardwoods	54	0.1
Mixed exotic shrubland	56	0.08
Forest harvested	64	0.16
Deciduous hardwoods	68	0.125
Indigenous forest	69	0.15
Other Exotic Forest	71	0.15
Manawatū Gates Upstream Floodplain	903	0.03

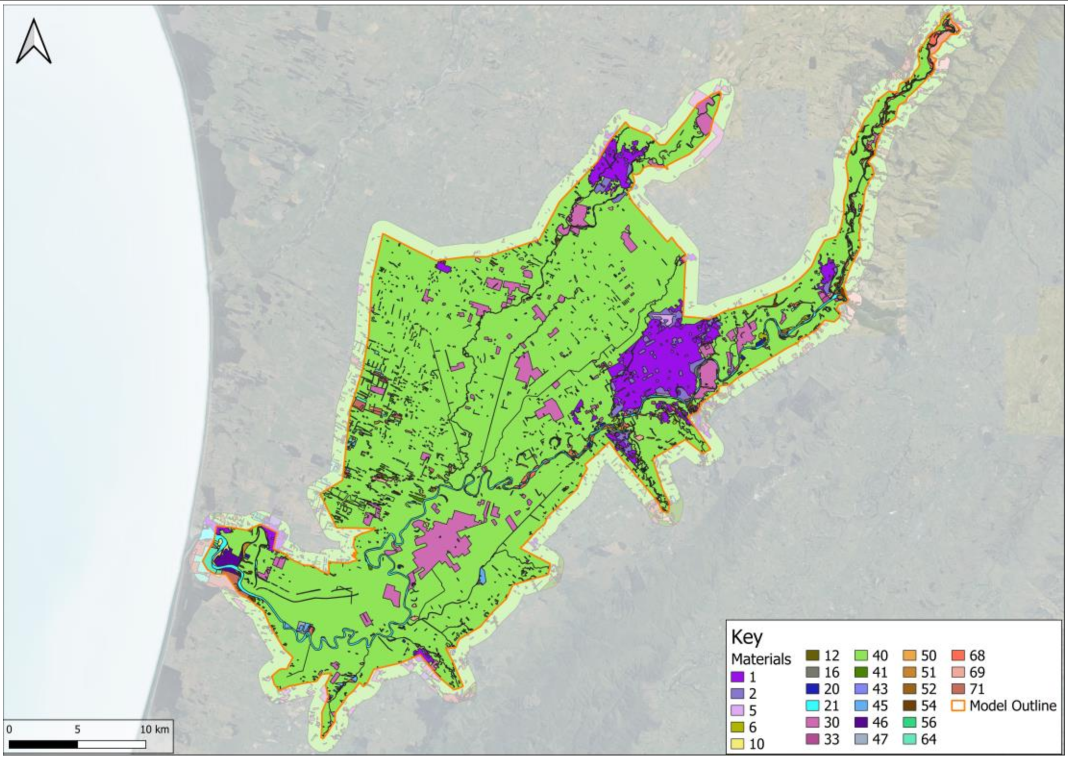

Figure 2-5 Spatial distribution of Land Cover Materials.

2.5.2 STRUCTURES

At this stage of the model build, key structures were identified by HRC for inclusion in the model. Table 2-5 details how they were represented in the model.

Table 2-5 Modelled Structures.

Feature	Details
Moutoa Sluice Gates	— **Background** – Doull (2015) provides a detailed breakdown of the Moutoa Sluice Gates and their importance in the operation of the Lower Manawatū River Scheme. Figure 2-6 shows Moutoa Gates during higher flows, where the gates are closed, top of gate height of 8.34 m NZVD2016 (white marker Gate 1).  Figure 2-6 Moutoa Sluice Gates during high flows. The white dash against Gate 1 indicates the maximum design water level of 8.34m NZVD2016. Source 'Moutoa Sluice Gate & Floodway – Helping keep our Region safe'. — **Manawatū Scheme Operation** – fundamentally the gates are used as a means of flood protection and sediment management by diverting up to 60% of the design flows down a 'shortcut' known as the Moutoa Floodway. Once the gates are open in a high flows scenario, water is diverted down the Moutoa Floodway from the main channel. This is a 10 km diversion which re-joins the Manawatū upstream of Foxton. Figure 2-7 shows how the Moutoa Floodway diverts flow from the Moutoa Sluice Gates to re-join location downstream on the Manawatū River.

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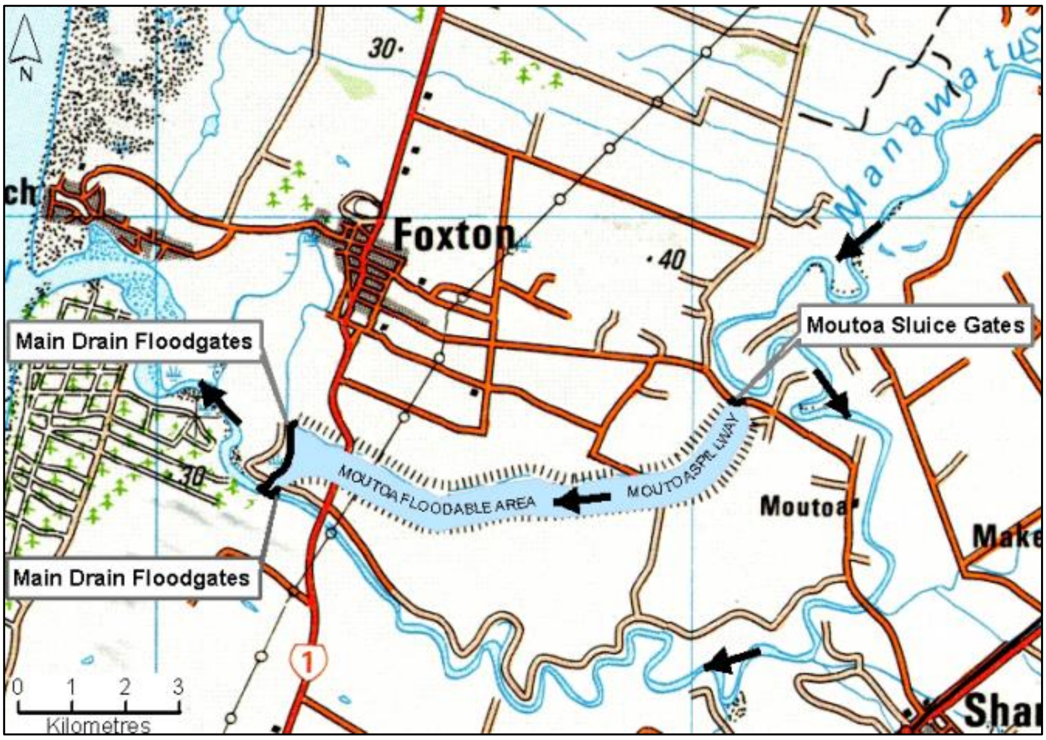

Figure 2-7 Moutoa Floodway downstream of the Moutoa Gates. *Source 'Moutoa Sluice Gate & Floodway – Helping keep our Region safe.'*

- **Dimensions** – There are 9 sluice gates that are individually represented as 15.24 m wide 1D objects, all of which are connected to the 2D domain via SX connections on both sides of the structure. The invert of the sluice gates was taken as the sill level immediately upstream of the closed gates, 3.8 m NZVD2016.
- **Model Gate Operations** – defined through the TOC file, which controls the opening from the ground level to the bottom of the gate. For each simulation event, the gate opens assuming an opening procedure using the key trigger level 7.85 m NZVD2016 (8.25m WLG53). The following rules have been implemented to mimic a hypothetical opening/closing sequence to match the design events simulated:
  - Gate opening speed is set to 0.0675 metres per minute, which would take 67 minutes to open to 4.54m (full open) from fully closed position (assuming continuous opening).
  - The gate opens in 150 mm increments if the water level increases above 7.85m. Openings are separated by a minimum of 10 minutes between incremental openings to prevent oscillations in water levels at the gates.
  - The gate closes by 150 mm increments if the water level falls below 7.7 m NZVD2016.
  - Between 7.7 m NZVD2016 and 7.85 m NZVD2016, the gate remains in the same position as its current opening.
  - The maximum gate height is set to 4.54 m, based on the assumption that the gate-bottom lifts to the crest of the closed gate. The recommendation in future iterations of the model is to include up-to-date survey information on maximum gate open height during 'Fully Open' conditions.

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<td>Bridges</td>
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- **Non-Modelled Bridges** – explicit representation of most bridges has not been included. Abutments adjacent to the banks are automatically represented by the terrain grid, but losses associated with piers and bridge decks are not included.
  - This includes the 60 channel connections implemented where the LIDAR had not filtered out the road (see Section 2.5.1).

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- **Modelled Bridges** – as per HRC request, selected bridges have been included on the Mangaone watercourse. Where structure surveys are unavailable, HRC requested that estimated dimensions be included. Hydraulic parameters (pier and superstructure FLCs) have been estimated using guidance from Guide to Bridge Technology Part 8: Hydraulic Design of Waterway Structures (Austroads, 2018) and Bridge Deck Afflux Modelling – Benchmarking of CFD and SWE Codes to Real-World Data (Collecutt, Baeumer, Gao, & Syme, 2022).
- **Campbell Road Bridge (Bunnythorpe)** – HRC Drawing A-2017-5b_2011-1 had insufficient information to allow levels to be converted to NZVD2016.
  - The deck parapet slopes from 52.73 m right bank NZVD2016 to 52.2m left bank (2019 survey, file no. 19047).
  - Bridge rail depth and soffit was estimated from site photos as survey was not available (Figure 2-8). These values were applied relative to the deck parapet levels.
  - Pier FLC 0.06, Superstructure FLC 0.4.

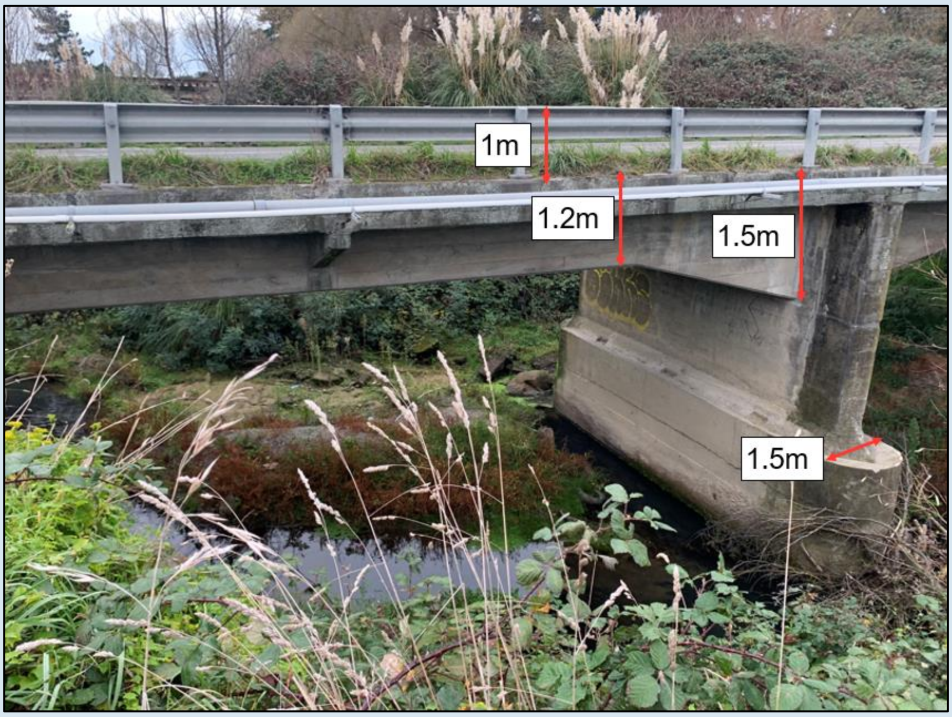


Figure 2-8 Campbell Road estimated bridge dimensions.

- **Bunnythorpe Railway Bridge** – HRC Drawing 166-1 and 124-5 assumed to be in Toogood VD, but conversions to NZVD2016 are unclear. Dimensions assumed instead from recent LiDAR and observations from site photos.
  - The deck parapet is flat at 53.85 m NZVD2016 (level of railway on banks either side, using 2018 LINZ LIDAR).
  - Bridge soffit was estimated from site photos, as per Figure 2-9. These values were applied relative to the deck parapet levels.
  - Pier FLC 0.06, Superstructure FLC 0.28.

Figure 2-9 Railway estimated bridge dimensions of deck height and pier width.

- **Milson Line Bridge** – HRC Drawing 1575-2 was used to define dimensions (Figure 2-10), assuming datum offset from Toogood VD to NZVD2016 of 18.97ft, followed by conversion to metres.
  - Deck parapet is flat at 36.53m (100.86ft Toogood VD).
  - Bridge soffit is 35.01m (95.85ft Toogood VD).
  - No Piers, Superstructure FLC 0.35.

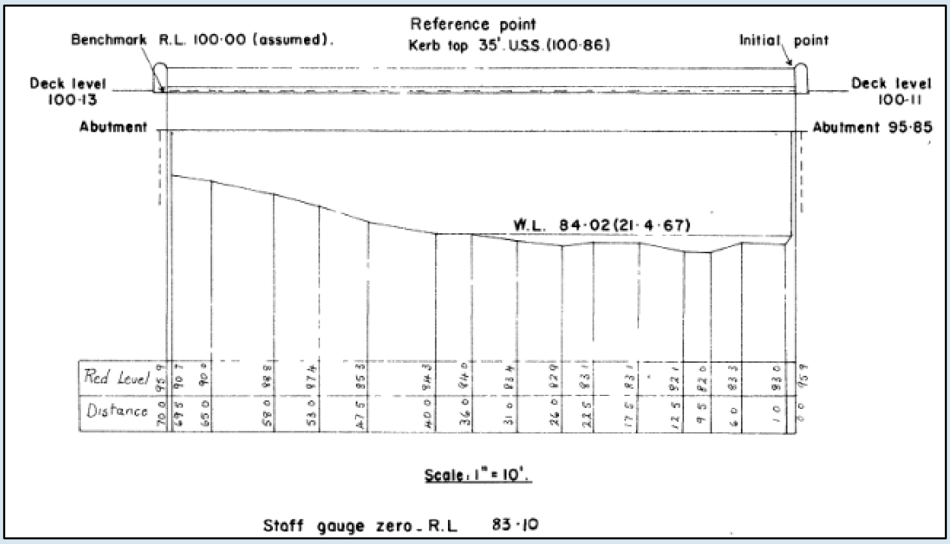


Figure 2-10 HRC Drawing 1575-2 Milson Line Bridge.

- **Flygers Line Bridge** – no drawing available.
  - The deck parapet is flat at 34.65 m NZVD2016 (level of road both banks, using 2018 LINZ LiDAR).

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

— Bridge soffit, rail depth and pier width were estimated from site photos, as per Figure 2-11. These values were applied relative to the deck parapet levels from LiDAR.
— Pier FLC 0.06, Superstructure FLC 0.2.

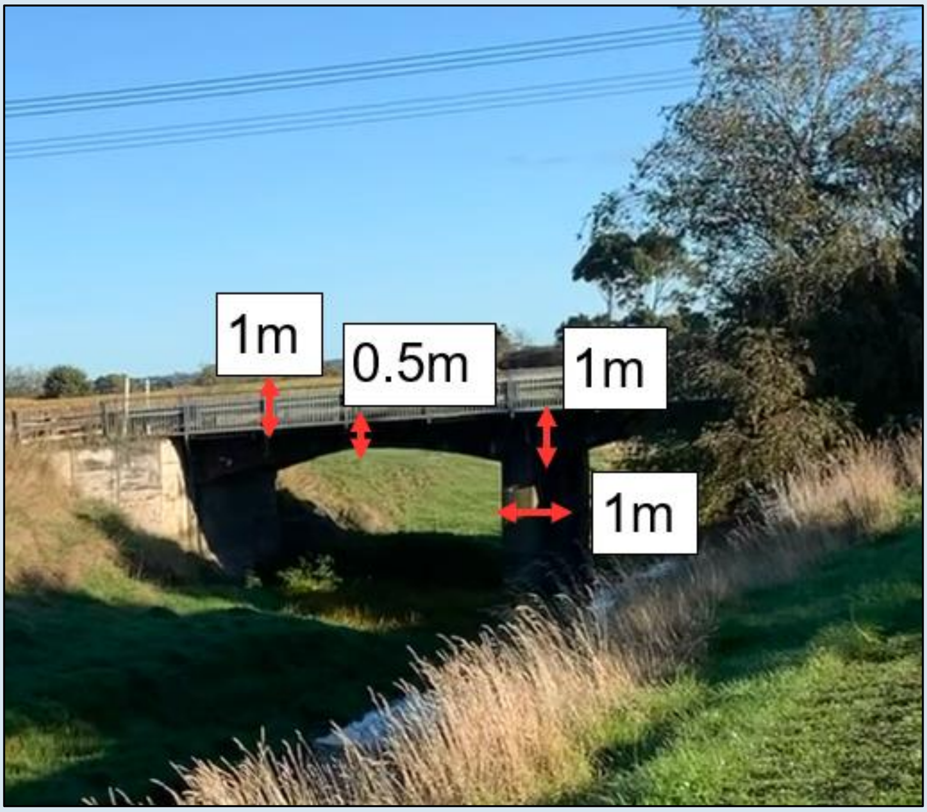


Figure 2-11 Flygers Line estimated bridge dimensions of rail height, central deck height, pier deck height and pier width.

— **Other Bridges:**
— Future stages of work should continue to identify key bridges and include them within the model, as well as refining bridge data with new and existing survey.

</td></tr>
<tr><td>Floodgates</td><td>

— **Overview** – there are four main floodgate structures in the catchment vicinity of Moutoa Gates: Rangiotu Gates (Sluggish Drain), Burkes Gates, Koputaroa Gates, Okuku Gates (Makerua Drain).
— All gates were modelled as 1D flapped rectangular culverts (Type ‘RU’), meaning that only a positive pressure head from the upstream minor drain allows flow to discharge into the main downstream channel.
— A 2d_zsh region is used to block the 2D flowpath of the potential spilling mechanism. In future, 1D weir objects should be used to represent flow over the top of the open gates if this scenario is required.
— **Rangiotu Gates** – 2 vertically aligned culverts modelled individually. Dimensions were modelled as per Figure 2-12.
— The structure parapet (spill) was estimated as 13.285 m NZVD2016, the average bank level adjacent to the structure (LiDAR, 2022-23).
— Sluggish Drain channel levels were lowered by 1.8 m match the inverts of the floodgates. This channel modifications were included only in the immediate upstream vicinity of the floodgates to support the function of the structure.

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

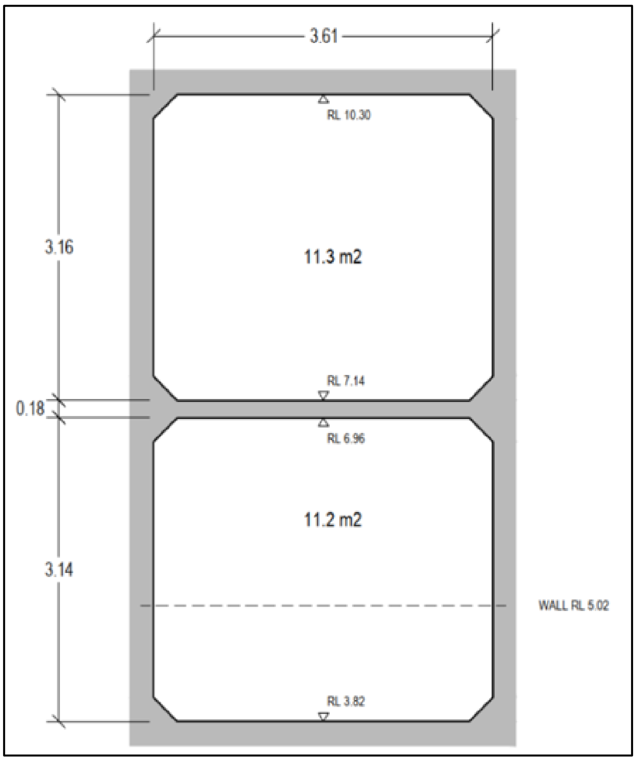


Figure 2-12 Rangiotu Gate dimensions.

- **Burkes Gates** – 6 floodgates each comprising 2 unidirectional doors, 3 gates top and 3 gates bottom. Dimensions were modelled as per HRC Drawing 613-9, after converting from ft to metres and from WLG53 to NZVD2016. The original drawing is shown in Figure 2-13.
  - Bottom 3 gates – 3.39 m wide, 3.35 m high
  - Top 3 gates – 3.39 m wide, 2.36 m wide
  - The structure parapet (spill) was estimated as 13.5 m NZVD2016, the average bank level adjacent to the structure (LiDAR, 2022-23).

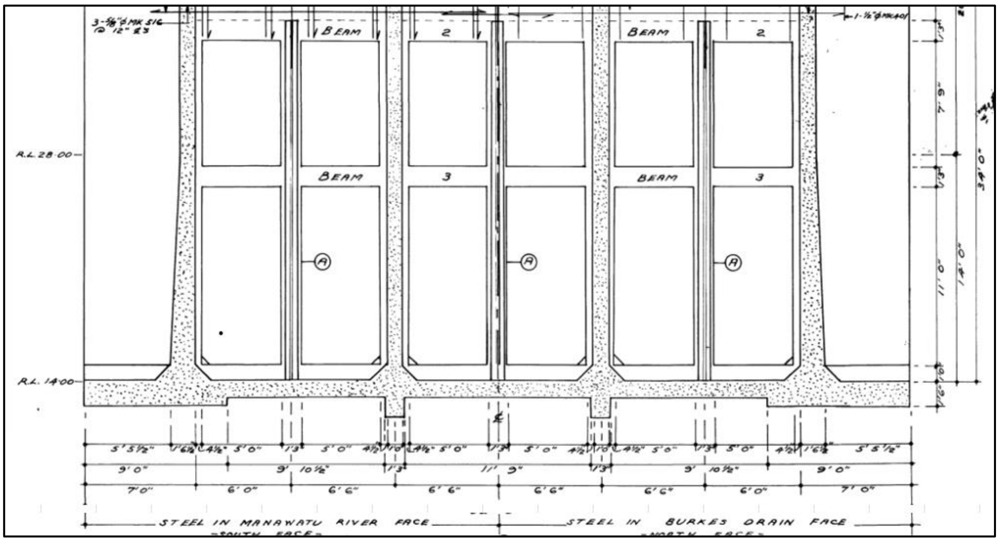


Figure 2-13 Burkes Gate Dimensions – HRC Drawing 613-9.

- **Koputaroa Gates** – 2 vertically aligned culverts modelled individually. Dimensions were modelled as per HRC Drawing 333-6, after converting from ft to metres and from WLG53 to NZVD2016. The original drawing is shown in Figure 2-14.
  - Bottom gate – 3.66 m wide, 3.05 m high
  - Top gate – 3.66 m wide, 3.05 m high
  - Structure parapet (spill) – 7.22 m NZVD2016
  - Koputaroa Drain channel levels were reduced by 0.65 m to match the inverts of the floodgates. this channel modification was included only in the immediate upstream vicinity of the floodgates to support the function of the structure.

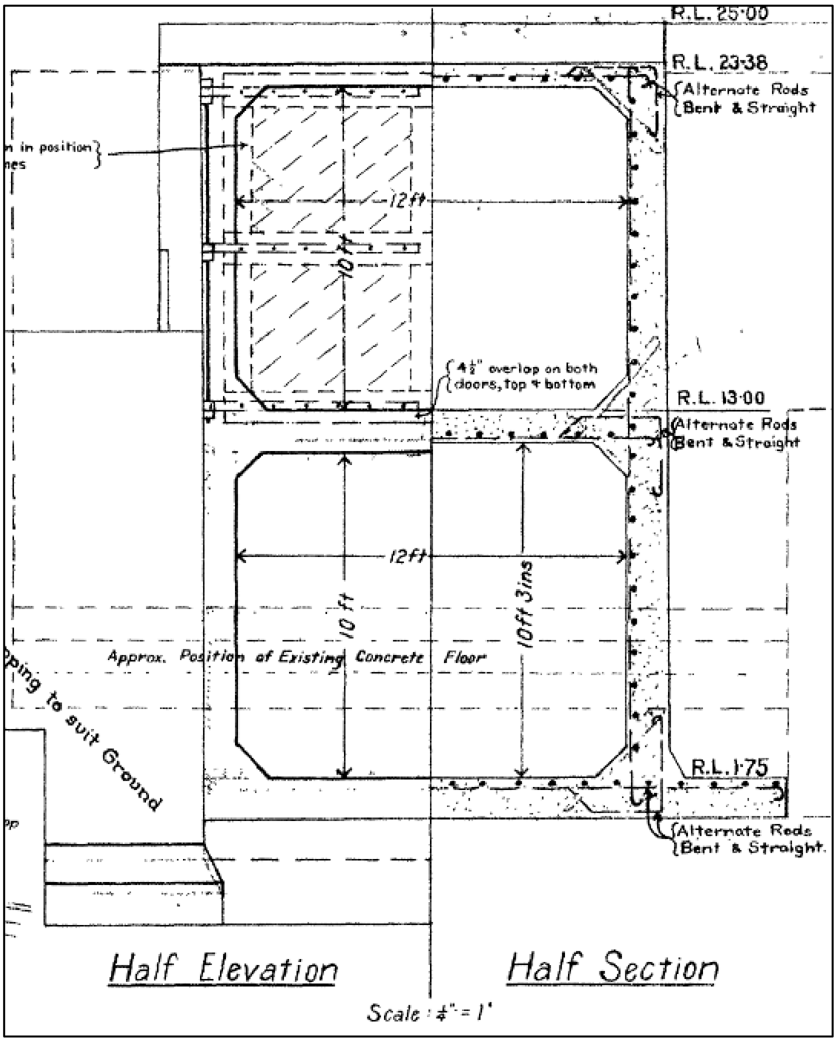


Figure 2-14 Koputaroa Gate Dimensions – HRC Drawing 333-6.

- **Okuku Gates** – drawings were unavailable. HRC correspondence indicated a single set of gates 3 m wide and 3 m high.
  - Inverts were assumed to be the same as the LiDAR level at 1.1 m NZVD2016 upstream, and 1.05 m NZVD2016 downstream assuming a 1 in 100 fall.
  - The structure parapet (spill) was estimated as 7.292 m NZVD2016, the average bank level adjacent to the structure (LiDAR, 2022-23).
- **Linton Drain Gates** – drawings were unavailable. Dimensions were assumed to be the same as the Okuku Gates, 3 m wide and 3 m high.
  - Inverts were assumed to be the same as the LiDAR level at 3.05 m NZVD2016 upstream, and 3 m downstream assuming a 1 in 100 fall.

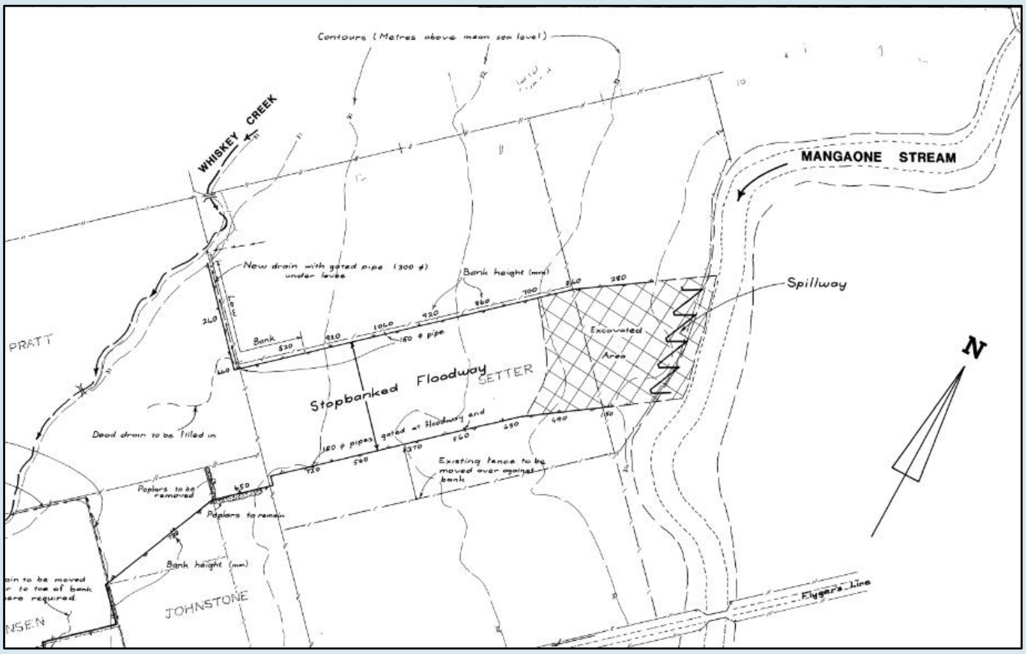
<table>
<tr><td></td><td>— The structure parapet (spill) was estimated as 8.2 m NZVD2016, the average bank level adjacent to the structure (LiDAR, 2022-23).</td></tr>
<tr><td>Flygers Line Spillway</td><td>— Overview – the Flygers Line Spillway operates as an overflow mechanism (with 320mm hinged spill gates) on the Mangaone to discharge flood volumes to the Whiskey Creek, eventually discharging towards the Manawatū via the Burkes Gates and pumping station. Figure 2-15 shows how the spillway works.
— The spillway was included as a 2d_zsh line and points. Dimensions were modelled as per HRC Drawing 2469-3, after converting from Moturiki Vertical Datum 1953 (MVD53) to NZVD2016.
— The operational component of the gates was not represented in the model owing to the uncertainty associated with the channel data represented by LiDAR on the Mangaone where exact heights are required to accurately represent the spilling level / flow triggered at Milson Line gauge.
— Overall the modelled representation represents a slightly conservative estimate of downstream flow on the Mangaone towards Palmerston North.


Figure 2-15 Flygers Line Spillway – HRC Drawing 2496-1.</td></tr>
</table>

2.6 MOUTOA GATES 2025 MODEL VALIDATION

The Moutoa Gates model (WSP, 2025b) covered a significant extent of this updated Lower Manawatū model, from Oroua at Kopane Bridge and the Manawatū at Teacher's College down to the outlet at Foxton. To ensure consistency between the two models, it was decided to apply the validated parameters of the Moutoa Gates model to this Lower Manawatū model.

The Moutoa Gates model validation was summarised as:

> *The aim of the exercise [was] to finetune key parameters to better represent the fundamental behaviour of the catchment being modelled. The model was validated to June 2021 (26-29 June 6pm-6pm) and February 2022 (6-8 February 12am-12am) events, both of which were single peaks hydrographs. Neither event required the Moutoa Sluice Gates to open, allowing this model component to remain fixed and therefore removing the uncertainty associated with the estimation of gate opening timings and flow rates.*

The Moutoa Model validated well to two of the most important dynamics of the Lower Manawatū catchment; 1) travel time of the flood wave from Teacher's College to Moutoa Gates, and 2) gauged river levels at Moutoa Gates. This was achieved by varying the key controls on travel time and Moutoa levels, which were determined to be watercourse roughness (Manning's n) and turbulence formulation (controlled by Wu formulation 3D parameter). The following conclusion was made on the model validation:

> *Across the two events assessed against two validation parameters (roughness, turbulence formulation) the model matches closely, demonstrating a reasonable reflection of the Lower Manawatū system's hydraulic behaviour. Although some uncertainties remain (inflows, channel representation, location-specific roughness), the results give good confidence that the model setup is well-represented at the catchment-scale.*

For more detail on the validation exercise of the lower catchment, consult the Moutoa Gates report (WSP, 2025b). It was accepted that at a catchment-scale the model results represented a suitable validation for this stage of assessment. For this updated Lower Manawatū model, the same parameters were carried through to the wider catchment:

- Channel Roughness – Manning's n of 0.035
- Turbulence Formulation – 3D parameter of 3, 2D parameter of 0.25.

2.7 FINAL MODEL FILES

The final model files are listed below:

- TCF – Lower Manawatū_~s1~_~s2~_~e1~_~e2~_~e3~_014.tcf
  - Scenario 1 (s1) – Baseline (BAS)
  - Scenario 2 (s2) – 9 Moutoa Sluice gates Open (SG9)
  - Event 1 (e1) – Fluvial Return Period (50yr, 100yr, 200yr)
  - Event 2 (e2) – Tidal Scenario (MHWS)
  - Event 3 (e3) – Climate Change Scenario (CC0c, CC3c)
- TGC – LowerManawatū_014.tgc
- ECF – LowerManawatū_009.ecf
  - TOC – Moutoa_GateOpen_Trig7p85m_Incremental_003.toc
- TBC – LowerManawatū_011.tbc
- QCF – LowerManawatū_012.qcf
- TEF – LowerManawatū_002.tef
- Boundary Control Database – bc_dbase_LowerManawatū_003.csv

3 INFLOW HYDROLOGY

3.1 BACKGROUND

The outputs from the NIWA Regional Flood Modelling (NIWA, 2025) were used as the source of design event inflows to the Lower Manawatū model. For background and methodology to the derivation of these flows, consult NIWA (2025). Figure 3-1 shows the mapped locations of the extracted hydrographs.

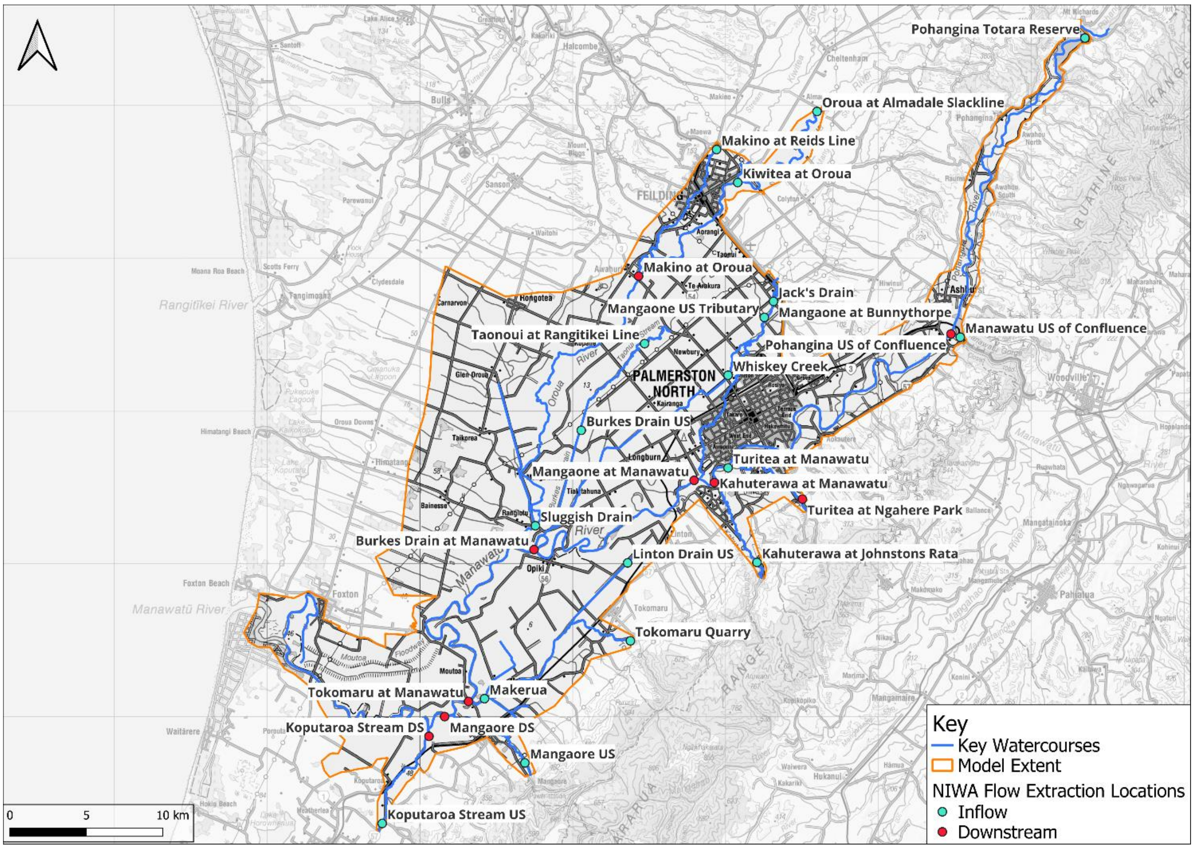


Figure 3-1 Locations of NIWA Hydrographs.

Table 3-1 lists the REC2 NZ Segment IDs of the corresponding inflow locations, noting whether it is a direct inflow or a downstream location required for the calculation of intervening inflows.

Table 3-1 Locations of hydrograph extraction from NIWA regional modelling.

Location	NZSegment ID (River Environment Classification, REC2)	Inflow or Downstream Location
Burkes Drain at Manawatū	7240287	Downstream
Burkes Drain US	7238232	Inflow
Jack's Drain	7236300	Inflow
Kahuterawa at Johnstons Rata	7241033	Inflow

Location	NZSegment ID (River Environment Classification, REC2)	Inflow or Downstream Location
Kahuterawa at Manawatū	7239679	Downstream
Kiwitea at Oroua	7234256	Inflow
Koputaroa Stream DS	7244246	Downstream
Koputaroa Stream US	7245763	Inflow
Linton Drain US	7240697	Inflow
Makerua	7243010	Inflow
Makino at Oroua	7235817	Downstream
Makino at Reids Line	7233017	Inflow
Manawatū US of Confluence	7237177	Inflow
Mangaone at Bunnythorpe	7236034	Inflow
Mangaone at Manawatū	7239012	Downstream
Mangaone US Tributary	7236705	Inflow
Mangaore DS	7243859	Downstream
Mangaore US	7244661	Inflow
Oroua at Almadale Slackline	7232926	Inflow
Pohangina Totara Reserve	7231250	Inflow
Pohangina US of Confluence	7236991	Downstream
Sluggish Drain	7240258	Inflow
Taonui at Rangitikei Line	7237188	Inflow
Tokomaru at Manawatū	7243547	Downstream
Tokomaru Quarry	7242415	Inflow
Turitea at Manawatū	7239408	Inflow
Turitea at Ngahere Park	7239943	Downstream
Whiskey Creek	7237457	Inflow

3.2 INFLOW EVENTS

Within the NIWA regional flood modelling exercise (NIWA, 2025), the 60-hour rainfall storm was selected as the critical duration for all inflow hydrographs across the Lower Manawatū catchment. As a design hydrograph, each modelled inflow has a similar shape with a varying timing and magnitude based on location and event AEP. The following return periods were selected to simulate by extracting outputs from the NIWA model:

- 1 in 50-year no climate change (CC0c) present day
- 1 in 100-year no climate change (CC0c) present day
- 1 in 100-year with 3 degree climate change (CC3c)
- 1 in 200-year no climate change (CC0c) present day
- 1 in 200-year with 3 degree climate change (CC3c)

For the updated Lower Manawatū model, the 60-hour storm was assumed to be consistent across the catchment. Future stages of model development might include a more detailed hydrological analysis to determine critical storm duration across the catchment, as well as higher return periods such as the 1 in 500-year or 1 in 1000-year.

3.3 INFLOW HYDROGRAPHS

Figure 3-3 shows the inflow hydrographs for the Manawatū inflow upstream of the confluence with the Pohangina. Appendix A Input Hydrographs shows each of the upstream and downstream locations noted in Table 3-1. Table 3-2 shows the peak flow for each location at each event modelled.

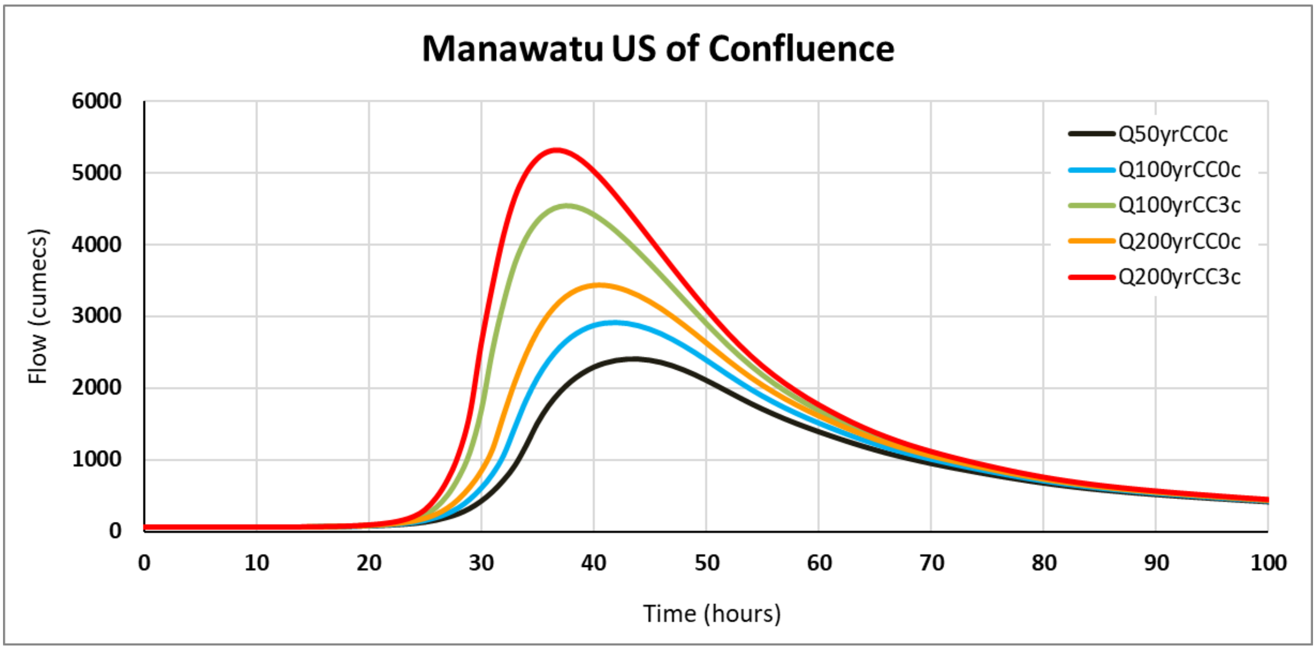


Figure 3-2 Selected inflow hydrographs for the 200year CC3°C event.

Table 3-2 Flow peaks from NIWA for each location.

Location	50-year – present day	100-year – present day	100-year – 3-degree CC	200-year – present day	200-year – 3-degree CC
Burkes Drain at Manawatū	50.2	60.3	99.0	70.0	114.9
Burkes Drain US	8.8	10.8	17.6	12.7	20.3
Jack's Drain	9.5	11.6	18.9	13.7	21.6
Kahuterawa at Johnstons Rata	13.0	15.9	29.5	19.0	35.3
Kahuterawa at Manawatū	20.4	25.4	45.7	30.4	54.3
Kiwitea at Oroua	68.4	92.1	172.9	121.8	224.6
Koputaroa Stream DS	22.6	28.2	50	33.6	57.7
Koputaroa Stream US	7.5	9.3	16.2	11.0	18.5
Linton Drain US	13.3	16.4	29	19.3	33.7
Makerua	13.3	16.8	30.9	20.1	35.6
Makino at Oroua	65.6	86.1	150.6	107.0	178.1
Makino at Reids Line	18.8	24	40.8	29.5	48.5
Manawatū US of Confluence	2410.2	2919.8	4540.6	3430.5	5310.6
Mangaone at Bunnythorpe	40.1	51.4	84.9	64.0	103.5
Mangaone at Manawatū	85.0	104.5	167.3	124.9	197.2
Mangaone US Tributary	9.1	11.6	20.8	14.2	24.5
Mangaore DS	20.0	25.2	44.4	30.4	53.6
Mangaore US	12.8	15.8	26.1	18.7	30.9
Oroua at Almadale Slackline	288.9	341.3	504.6	396.7	583.6
Oroua at Kopane Bridge	407.2	504	812.6	610.1	973.8
Pohangina Totara Reserve	483.1	565.3	813.6	646.9	922.8

Location	50-year – present day	100-year – present day	100-year – 3-degree CC	200-year – present day	200-year – 3-degree CC
Pohangina US of Confluence	591.8	703.4	1031.5	817.2	1181.9
Sluggish Drain	22.5	26.7	44.4	31.2	52.2
Taonui at Rangitikei Line	0.9	1.0	1.7	1.1	2.0
Tokomaru at Manawatū	80.8	101.3	183.4	121.4	214.8
Tokomaru Quarry	31.5	38.3	60.8	44.7	71.4
Turitea at Manawatū	14.2	18.2	31.5	22.2	37.7
Turitea at Ngahere Park	11.9	15.1	25.5	18.2	30.2
Whiskey Creek	1.8	2.0	3.2	2.3	3.6

3.3.1 INTERVENING HYDROGRAPHS

For the 'Downstream' locations shown in Figure 3-1, intervening hydrographs were calculated to ensure continuity of total inflow volume to the model. For example, the main inflow on the Pohangina River is at Totara Reserve but the catchment between here and the confluence of the Manawatū River would otherwise not be accounted for. The following methodology was used to calculate hydrographs for intervening inflows:

1. Determine the inflow peak as a proportion of the downstream peak. For example, the 200yr with 3°C Climate Change peak for Pohangina River at Totara Reserve was 923 m^3/s, compared to 1182 m^3/s at Pohangina River US of the Manawatū River Confluence ('Downstream').
2. The upstream inflow peak is 80% of the downstream peak, giving a proportion of 0.8.
3. Calculate the scaling factor by subtracting the proportion from 1. For example, the Pohangina River upstream of confluence scaling factor would be 1 minus 0.8, which is 0.2.
4. Multiply the downstream hydrograph by the scaling factor.
5. Apply intervening hydrograph at the 'Downstream location' (Figure 3-1).

This method means that the volume between the upstream inflow location and downstream location is represented. It also uses the downstream hydrograph shape, which means it is a sensible approximation of expected timing of hydrograph rising limbs, peaks and falling limbs. At this stage, a detailed hydrological assessment was not undertaken to determine appropriate distribution volumes and hydrograph timings between the two inflow points. This approach is conservative with respect to downstream flooding by underestimating the volume in the sub-catchment between the upstream and downstream inflow points. This mostly affects only the smaller watercourses and has no effect on larger watercourses like the Manawatū and the Oroua.

Table 3-3 shows the scaling factors used to calculate the intervening hydrographs at each location. Figure 3-3 shows how this was applied on the Pohangina River.

Table 3-3 Intervening Inflow Scaling Factors.

Inflow Location (Downstream)	Upstream Inflow Location(s)	Scaling Factor
Burkes Drain at Manawatū	Burkes Drain, Taonui Stream, Whiskey Creek	0.82
Kahuterawa at Manawatū	Kahuterawa at Johnstons Rata	0.36
Koputaroa Stream DS	Koputaroa US	0.67
Makino at Oroua	Makino at Reids Line	0.72
Mangaone at Manawatū	Mangaone at Bunnthorpe, Jack's Drain, Magaone US Tributary	0.27
Mangaore DS	Mangaore US	0.39
Pohangina US of Confluence	Pohangina at Totara Reserve	0.20
Tokomaru at Manawatū	Tokomaru Quarry, Makerua, Linton Drain US	0.31
Turitea at Manawatū	Turitea at Ngahere Park	0.18

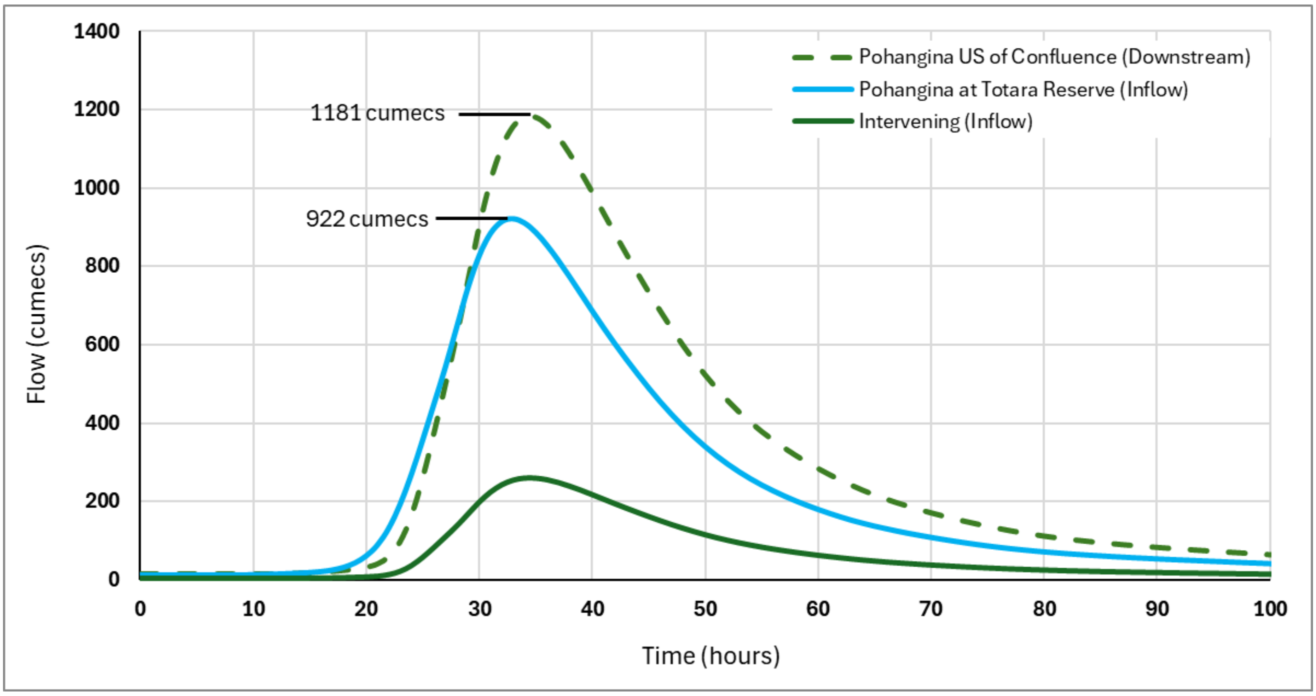


Figure 3-3 200-year CC 3°C Hydrographs for Pohangina.

3.4 DOWNSTREAM BOUNDARY

The downstream boundary is set as Mean High Water Spring (MHWS), and the same profile used across all 5 simulation events (Figure 3-4). This has been applied as a boundary line perpendicular to flow at the Manawatū at Foxton gauge location (see Figure 2-1). Future stages of model development should look at join probability of rainfall-river-tidal peaks, as well as high-tide events for a flood risk assessment in the lower reaches of the Lower Manawatū catchment.

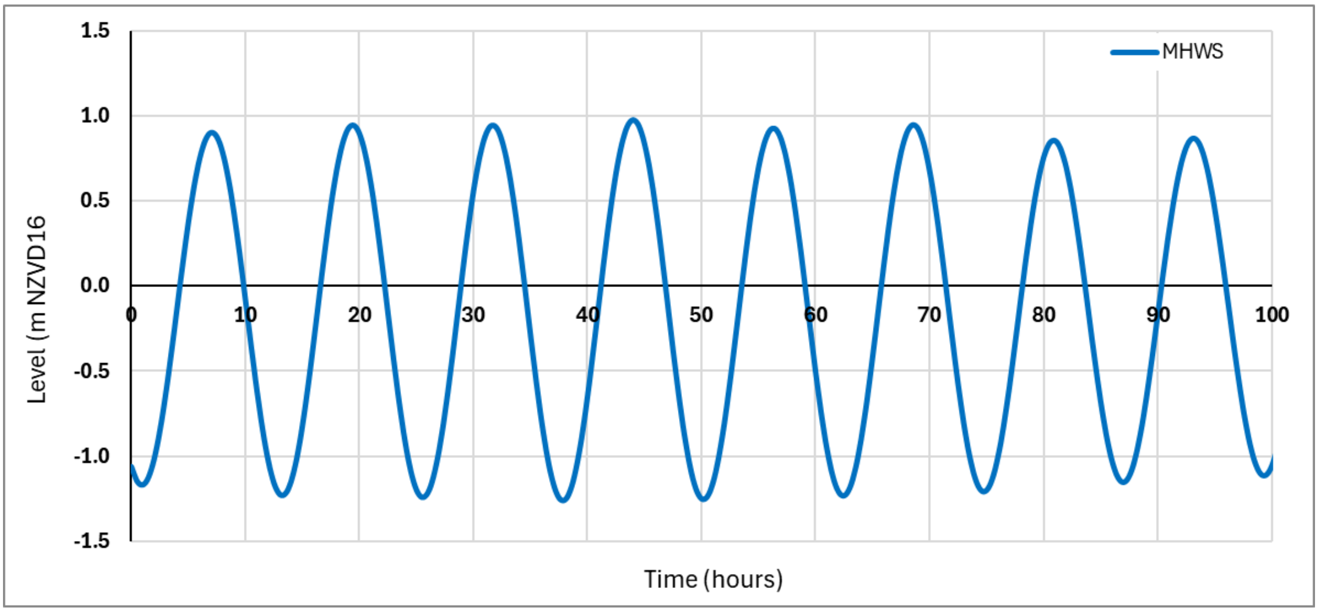


Figure 3-4 Downstream Tidal Boundary at Manawatū at Foxton.

3.5 INITIAL CONDITIONS

Initial conditions were generated by simulating a constant inflow from each upstream 'Inflow' location listed in Table 3-3. The mean annual flood peak (QMAF) was extracted from 'New Zealand Flood Statistics' for each inflow and multiplied by 0.05 to get an approximate low-flow condition for the model.

Future stages of model development should focus on establishing more realistic or scenario-dependant initial conditions by analysing relevant gauge information.

4 RESULTS AND MAPPING

4.1 FLOODING OBSERVATIONS

Simulated events are summarised in Section 3.2. To describe the catchment-scale flooding for each event, the following focus locations were used to split out the catchment:

- Feilding – to the right-bank of the Oroua, right-bank of the Kiwitea and bisected by the Makino Stream.
- Palmerston North – enclosed by the Mangaone left-bank and Manawatū right-bank.
- Oroua South Floodplain – enclosed by the Oroua left-bank to the West, Manawatū right-bank to the South, Rangioutu Road / State Highway 56 (SH56) to the South and East, and Rangitikei Line to the North under which the Taonui continues.
- Oroua North Floodplain – enclosed by the Oroua left-bank to the West, Bunnythorpe to the East, Reid Line East to the North and Rangitikei Line to the South under which the Taonui stream continues.
- Mangaone Floodplain – enclosed by Campbell Road to the North, Rongotea Road to the South, Palmerston North to the East, Kairanga airstrip to the West.
- Linton Drain Floodplain – enclosed by Opiki Road to the South and West, Makerua Road to the East and the Manawatū left-bank to the North.
- Southern Moutoa Floodplain – south of the Moutoa Floodway enclosed by the Manawatū right-bank.
- Eastern Moutoa Floodplain – east of the stopbanks downstream of Moutoa Gates enclosed by the Manawatū left-bank and Opiki Road.
- Aratangata Drain Floodplain – situated east and west of Aratangata Drain to the south of the Manawatū left-bank, west of Palaka Road.

Figure 4-1 indicates the boundaries of each location, which are shown in more detail in Appendix B Flood Maps. Table 4-1 details the flooding mechanisms for the five modelled events at each catchment location – each location includes identifiers which are included in the mapping of Appendix B Flood Maps (for example 'FE1' or 'ORS1').

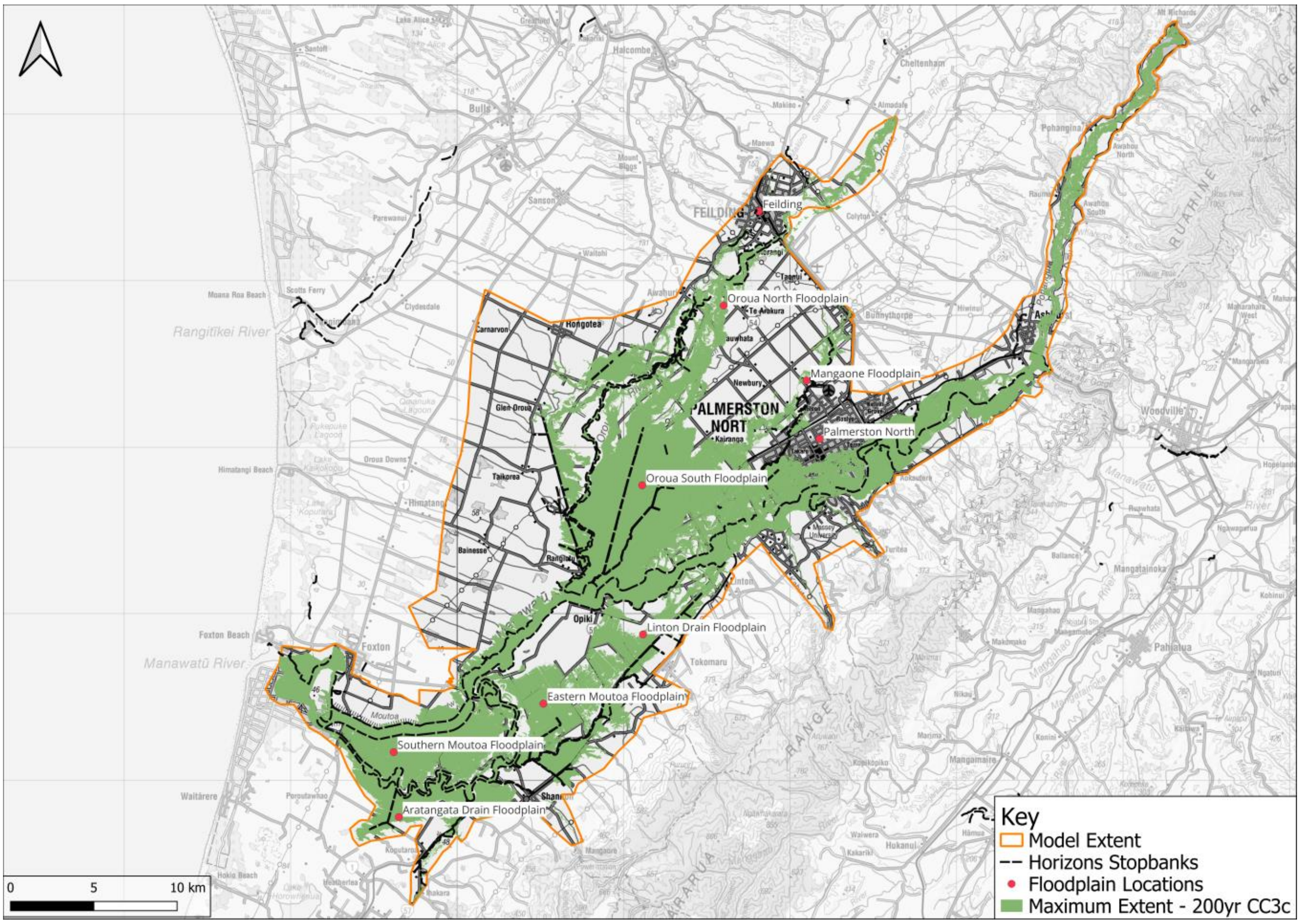


Figure 4-1 Floodplain Locations for reporting.

Table 4-1 Flooding Observations.

<table>
<tr><th>Simulation Event</th><th>Flooding</th></tr>
<tr><td>50-year Present Day</td><td>Feilding
— No flooding through town centre from Makino Stream
— Out of-bank flooding of Makino Stream at Awahuri Scenic Reserve from low stopbanks in LiDAR data, overtops along Kawakawa Road (FE1)
— No flooding from the Kiwitea Stream and Oroua River
Palmerston North
— No flooding
Oroua North Floodplain
— Minor overtopping from the Oroua River left-bank by the Te Arakura road results in water flowing towards SH3 Rangitikei Line, which overtops and water flows towards the Oroua South Floodplain and Taonui Stream (ORN1)
— Oroua River left stopbank overtops approximately 800 m upstream of the SH3 Rangitikei Line roadbridge, flow is directed further east towards Hansen Line where it overtops the SH3 Rangitikei Line and flows south towards the Oroua South Floodplain and the Taonui Stream (ORN2)
— Upstream of Reid Line East road, flow overtops the Oroua left bank and a small volume of water flows south-east on the north side of the road. Water overtops the Reid Line East road and flows south as part of the Taonui Stream. Some flow continues south-east and joins the tributary adjacent to the Mangaone on the south side of Reid Line East – this flow joins the ‘Mangaone US Tributary’ approximately 5 km downstream on the south side of Campbell Road (ORN5)
Oroua South Floodplain
— Overtopping of Oroua left-bank opposite River Road. This flow is directed east and further overtops Oroua Road to the East and flows towards Rongotea Road which is also overtopped (ORS1)
— Significant overtopping on left-bank downstream of Rongotea Road (located 0-900 m downstream and 2000-3000 m downstream). Water flows south towards Burkes Drain and over Lockwood Road towards Rangioutu Road, where it ponds and does not overtop (ORS2)
— Overtopping of Oroua River right-bank opposite the Kopane airstrip results in ponding east of Leen Road. Further overtopping of the Oroua River right-bank overtops of Kaimatarau Road, which flows south-east towards Sluggish Drain over Sanders Road (ORS3)
— Flooding on floodplain between Whiskey Creek right bank and Burkes Drain left-bank, as a result of small stop-bank overtopping on Burkes drain left-bank
— Overtopping of Oroua River left-bank between 800-2000 m upstream of Rangioutu Road results in extensive flooding but not sufficient to overtop the Rangioutu Road (ORS4)
— Floodplain water levels pond at 9.1 m (NZVD2016), extending up to Lockwood Road east of Linton Drain (ORS6)
Mangaone Floodplain
— Minor flooding either side of Kairanga Bunnythorpe Road originating from the Mangaone Stream and the Mangaone Western Tribtuary, which is likely accentuated without the modelling of local-scale drainage features (MAN1)
— Flygers Line spillway not active because water levels remain below the spill level</td></tr>
</table>

Simulation Event	Flooding
	Linton Drain Floodplain — Minor Flooding to the Makerua Swamp Wildlife Management Reserve from Linton Drain left-bank overtopping — No overtopping of Manawatū River left-bank to the North **Southern Moutoa Floodplain** — Minor overtopping on Manawatū River right-bank 5-7 km downstream of Moutoa results in small volume of water overtopping Foxton – Shannon Road and ponding on floodplain **(SM1)** — Minor overtopping on Manawatū River right-bank south of Kere Kere Road results in small volumes of water ponding on floodplain **(SM2)** **Eastern Moutoa Floodplain** — Overtopping of Manawatū River left-bank approximately 1 km upstream of the Foxton-Shannon roadbridge results in ponding on floodplain **(EM1)** — Minor overtopping from the Makerua Drain and Tokomaru River **Aratangata Drain Floodplain** — Overtopping of Manawatū River left-bank adjacent to Whirokino Road down to Levin Road (2 km in length) **(AD1)** results in ponding across large extent of floodplain

100-year CC0c	**Feilding**
	— Very similar flooding mechanisms to the 50-year results, summarised as:
	    — No flooding through town centre from Makino Stream
	    — Out of-bank flooding from Makino Stream at Awahuri Scenic Reserve from low stopbanks in LiDAR data, overtops Kawakawa Road **(FE1)**
	    — No flooding from the Kiwitea Stream and Oroua River
	Palmerston North
	— Very similar flooding mechanisms to the 50 year plus climate change scenario, summarised as:
	    — No flooding to residential areas
	    — Southern end of Manawatū River 8.5 km right stopbank from Raukawa Road to Koehlers Road is overtopped, resulting in localised flooding **(PN1)**
	    — Manawatū River right stopbank overtopping near Walkers Road results in floodwaters spilling over NIMT, flowing towards the Oroua South Floodplain **(PN5)**.
	Oroua North Floodplain
	— Very similar flooding mechanisms to the 50-year results, summarised as:
	    — Slight increase volume of overtopping from the Oroua River left-bank upstream of the Te Arakura Road results in water flowing towards SH3 Rangitikei Line, which overtops and water flows towards the Oroua South Floodplain and Taonui Stream **(ORN1)**
	    — Oroua left stopbank overtops approximately 800 m upstream of the SH3 Rangitikei Line roadbridge, flow is directed further east towards Hansen Line where it overtops the SH3 Rangitikei Line and flows south towards the Oroua South Floodplain and the Taonui Stream **(ORN2)**.
	    — Upstream of Reid Line East road, more flow continues to overtop the Oroua left bank and water flows south-east on the north side of the road. Water overtops the Reid Line East road and flows south as part of the Taonui Stream. Some flow continues south-east and joins the tributary adjacent to the Mangaone on the south side of Reid Line East – this flow joins the 'Mangaone US Tributary' approximately 5km downstream on the south side of Campbell Road **(ORN5)**.

Simulation Event	Flooding
	Oroua South Floodplain — Similar flooding mechanisms to the 50-year results, summarised as: — Overtopping of Oroua left-bank 1500m upstream of Rongotea roadbridge as well as left-bank opposite River Road. This flow is directed east and further overtops Oroua Road to the East and flows towards Rongotea Road which is also overtopped **(ORS1)** — Further overtopping on left-bank downstream of Rongotea Road (located 0-900 m downstream and 2000-3000 m downstream). Water flows south towards Burkes Drain and over Lockwood Road towards Rangiotu Road **(ORS2)** — Overtopping of Oroua River right-bank opposite the Kopane airstrip results in ponding east of Leen Road. Further overtopping of the Oroua River right-bank overtops of Kaimatarau Road, which flows south-east towards Sluggish Drain over Sanders Road **(ORS3)** — Overtopping of Oroua left-bank between 800-2000 m upstream of Rangiotu Road results in extensive flooding which is sufficient enough to overtop the Rangioutu Road **(ORS4)** — Manawatū River right-bank immediately downstream of Burkes Gates overtops and spills into Oroua South Floodplain, adding to overall flood volume accumulation **(ORS5)** — Floodplain water levels pond at 9.57 m (NZVD2016), extending north of Lockwood Road east of Linton Drain **(ORS6)** — The levels on the Oroua watercourse downstream of Kopane Bridge are the same (+/-10 mm) as the 50-year event, because additional inflows results in further overtopping of stopbanks **(ORS7)** **Mangaone Floodplain** — Very similar flooding mechanisms to the 100 year plus climate change scenario, summarised as: — Slightly increased flooding either side of Kairanga Bunnythorpe Road originating from the Mangaone and the Mangaone Western Tributary, which is likely accentuated without the modelling of local-scale drainage features **(MAN1)** — Flygers Line spillway not active because water levels remain below the spill level **Linton Drain Floodplain** — Very similar flooding mechanisms to the 50-year results, summarised as: — Minor Flooding to the Makerua Swamp Wildlife Management Reserve from Linton Drain left-bank overtopping — No overtopping of Manawatū River left-bank to the North **Southern Moutoa Floodplain** — Very similar flooding mechanisms to the 50-year results, summarised as: — More significant overtopping of Manawatū River right-bank 1-3 km and 5-7 km downstream of Moutoa results in larger volumes of water overtopping Foxton – Shannon Road and ponding on floodplain **(SM1)** — Further overtopping on Manawatū River right-bank south of Kere Kere Road results in more extensive water ponding on floodplain **(SM2)** — Floodplain generally fills slowly in a ‘bucket-like’ mechanism, without modelling local-scale drainage features **(SM3)**

Simulation Event	Flooding
	Eastern Moutoa Floodplain — Very similar flooding mechanisms to the 50-year results, summarised as: — Further overtopping of Manawatū River left-bank approximately 1km upstream of the Foxton-Shannon roadbridge results in ponding on floodplain **(EM1)** — Short reaches of stopbank begin to overtop on the Manawatū left-bank near Moutoa Gates, water flows south-east towards floodplain **(EM2)** — Minor overtopping from the Makerua Drain and Tokomaru Stream **Aratangata Drain Floodplain** — Very similar flooding mechanisms to the 50-year results, summarised as: — Overtopping of Manawatū River left-bank adjacent to Whirokino Road down to Levin Road (2 km in length) results in ponding across large extent of floodplain, which extends east towards the Koputaroa Stream but there is no interaction **(AD1)**
200-year CC 0°C	**Feilding** — Very similar flooding mechanisms to the 100-year results, summarised as: — No flooding through town centre from Makino Stream — Out of-bank flooding from Makino Stream at Awahuri Scenic Reserve from low stopbanks in LiDAR data, overtops Kawakawa Road **(FE1)** — No flooding from the Kiwitea Stream and Oroua River **Palmerston North** — Very similar flooding mechanisms to the 100-year, summarised as: — No flooding to residential areas — Southern end of Manawatū River 8.5km right stopbank from Raukawa Road to Koehlers Road (approximately 8.5 km) overtopped, resulting in localised flooding **(PN1)** — SH3 south of Roberts Line is overtopped, directing flow to a small extent in the Terrace End area **(PN2)** — Manawatū River left stopbank north of Staces Road (approximately 2.5 km) completely overtopped **(PN6)** — Manawatū River right stopbank overtopping near Walkers Road results in floodwaters spilling over NIMT, flowing towards the Oroua South Floodplain **(PN5)** **Oroua North Floodplain** — Similar flooding mechanisms to the 50-year results, summarised as: — Increase in volume of overtopping from the Oroua River left-bank upstream of the Te Arakura Road results in water flowing towards SH3 Rangitikei Line, which overtops and water flows towards the Oroua South Floodplain and Taonui Stream **(ORN1)** — Oroua left stopbank overtops approximately 800 m upstream of the SH3 Rangitikei Line roadbridge, flow is directed further east towards Hansen Line where it overtops the SH3 Rangitikei Line and flows south towards the Oroua South Floodplain and the Taonui Stream **(ORN2)**

Simulation Event	Flooding
	— Oroua left stopbank begins to overtop 1 km downstream of Rangitikei Line, flowing east towards Oroua Road and on to the Oroua South Floodplain and Taonui Stream **(ORN3)** — Oroua River right-bank begins to overtop just downstream of the Makino Stream confluence, which overtops the SH3 Rangitikei Line adjacent to Green Road **(ORN4)** — Upstream of Reid Line East road, more flow continues to overtop the Oroua left bank and water flows south-east on the north side of the road. Water overtops the Reid Line East road and flows south as part of the Taonui Stream. Some flow continues south-east and joins the tributary adjacent to the Mangaone on the south side of Reid Line East – this flow joins the 'Mangaone US Tributary' approximately 5km downstream on the south side of Campbell Road **(ORN5)** **Oroua South Floodplain** — Similar flooding mechanisms to the 100-year results, summarised as: — Further overtopping of Oroua left-bank 1500 m upstream of Rongotea roadbridge as well as left-bank opposite River Road. This flow is directed east and further overtops Oroua Road to the East and flows towards Rongotea Road which is also overtopped **(ORS1)** — Further overtopping on left-bank downstream of Rongotea Road (located 0-900 m downstream and 2000-3000 m downstream). Water flows south towards Burkes Drain and over Lockwood Road towards Rangiotu Road **(ORS2)** — Overtopping of Oroua River right-bank opposite the Kopane airstrip results in ponding east of Leen Road. Further overtopping of the Oroua River right-bank overtops of Kaimatarau Road, which flows south-east towards Sluggish Drain over Sanders Road **(ORS3)** — Further overtopping of Oroua left-bank between 800-2000 m upstream of Rangiotu Road results in extensive flooding which is sufficient enough to overtop the Rangioutu Road **(ORS4)** — Manawatū River right-bank immediately downstream of Burkes Gates overtops and spills into Oroua South Floodplain, adding to overall flood volume accumulation **(ORS5)** — Floodplain water levels pond flat at 10.18 m (NZVD2016), entirely inundating Linton Drain and parts of Rangiotu Road, and extending beyond Lockwood Road to the North. This flat inundation level extends 10km north to the south of the Rongotea Road **(ORS6)** — The levels on the Oroua watercourse downstream of Kopane Bridge are the same (+/-10 mm) as the 50-year event, because additional inflows results in further overtopping of stopbanks **(ORS7)** **Mangaone Floodplain** — Very similar flooding mechanisms to the 100-year results, summarised as: — Increased flooding either side of Kairanga Bunnythorpe Road originating from the Mangaone and the Mangaone Western Tributary, which is likely accentuated without the modelling of local-scale drainage features **(MAN1)** — Minor Flooding upstream of SH3 Rangitikei Line downstream of the Flygers Line spillway **(MAN2)**

Simulation Event	Flooding
	— Flygers Line spillway active, overtopping crest by approximately 20-30 mm **(MAN3)** **Linton Drain Floodplain** — Very similar flooding mechanisms to the 100-year results, summarised as: — Minor Flooding to the Makerua Swamp Wildlife Management Reserve from Linton Drain left-bank overtopping — Minor overtopping to the Manawatū right-bank **(LD1, LD2)** but flow is contained locally **Southern Moutoa Floodplain** — Very similar flooding mechanisms to the 100-year results, summarised as: — More significant overtopping of Manawatū River right-bank 1-3 km and 5-7 km downstream of Moutoa results in larger volumes of water overtopping Foxton – Shannon Road and ponding on floodplain **(SM1)** — Further overtopping on Manawatū River right-bank south of Kere Kere Road results in more extensive water ponding on floodplain **(SM2)** — Floodplain generally fills slowly in a 'bucket-like' mechanism, without modelling local-scale drainage features **(SM3)** **Eastern Moutoa Floodplain** — Very similar flooding mechanisms to the 100-year results, summarised as: — Further overtopping of Manawatū River left-bank approximately 1 km upstream of the Foxton-Shannon roadbridge results in ponding on floodplain **(EM1)** — Short reaches of stopbank continue to overtop on the Manawatū left-bank near Moutoa Gates, water flows south-east towards floodplain **(EM2)** — Minor overtopping from the Makerua Drain and Tokomaru Stream **Aratangata Drain Floodplain** — Very similar flooding mechanisms to the 100-year results, summarised as: — Overtopping of Manawatū River left-bank adjacent to Whirokino Road down to Levin Road (2 km in length) **(AD1)** results in ponding across large extent of floodplain, which extends east towards the Koputaroa Stream but there is no interaction **(AD2)**
100-year CC 3°C	**Feilding** — Very similar flooding mechanisms to the 200-year present day scenario, summarised as: — No flooding through town centre from Makino Stream — Out of-bank flooding on Makino at Awahuri Scenic Reserve from low stopbanks in LiDAR data, overtops Kawakawa Road **(FE1)** — No flooding from the Kiwitea Stream and Oroua River **Palmerston North** — Similar flooding mechanisms to the 200-year present day scenario, summarised as: — Manawatū River right stopbank from Raukawa Road to Koehlers Road (approximately 8.5km) completely overtopped **(PN1)** — Manawatū River left stopbank north of Staces Road (approximately 2.5 km) completely overtopped **(PN6)**

Simulation Event	Flooding

	— Manawatū River right stopbank overtopping South of Roberts Line – Te Matai Road and adjacent to the Golf Course results in flooding in Hokowhitu **(PN2)**
	— Manawatū River right stopbank overtopping along the entire right-bank reach starting at He Ara Kotahi Bridge, past Awatapu college and ending near Ahimate Reserve (3 km total). This results in significant flooding to Awapuni **(PN3)**
	    — This overbank flooding from the Manawatū is directed South-West through Palmerston North centre towards the Mangaone stream. The Mangaone Stream right-bank overtops and flow is directed towards the Oroua South Floodplain over Shirrifs Road, SH56 and the NIMT **(PN4)**
	— Manawatū River right stopbank overtopping near Walkers Road results in floodwaters spilling over NIMT, flowing towards the Oroua South Floodplain **(PN5)**.
	Oroua North Floodplain
	— Similar flooding mechanisms to the 200-year present day scenario, summarised as:
	    — Greater volume of overtopping from the Oroua River left-bank upstream of the Te Arakura Road results in water flowing towards SH3 Rangitikei Line, which overtops and water flows towards the Oroua South Floodplain and Taonui Stream **(ORN1)**
	    — Oroua River left stopbank overtops approximately 800 m upstream of the Rangitikei Line roadbridge, flow is directed further east towards Hansen Line where it overtops the Rangitikei Line and flows south towards the Oroua South Floodplain and the Taonui Stream **(ORN2)**
	    — Oroua left stopbank overtops 1 km downstream of Rangitikei Line, flowing east towards Oroua Road and on to the Oroua South Floodplain and Taonui Stream **(ORN3)**
	    — Oroua River right-bank overtops just downstream of the Makino Stream confluence, which overtops the SH3 Rangitikei Line adjacent to Green Road **(ORN4)**
	    — Upstream of Reid Line East road, more flow continues to overtop the Oroua left bank and water flows south-east on the north side of the road. Water overtops the Reid Line East road and flows south as part of the Taonui Stream. Some flow continues south-east and joins the tributary adjacent to the Mangaone on the south side of Reid Line East – this flow joins the 'Mangaone US Tributary' approximately 5km downstream on the south side of Campbell Road **(ORN5)**
	Oroua South Floodplain
	— Similar flooding mechanisms to the 200-year present day scenario, summarised as:
	    — Overtopping of Oroua left-bank 1500 m upstream of Rongotea roadbridge as well as left-bank opposite River Road. This flow is directed east and further overtops Oroua Road to the East and flows towards Rongotea Road which is also overtopped **(ORS1)**
	    — Further significant overtopping on left-bank downstream of Rongotea Road (located 0-900 m downstream and 2000-3000 m downstream). Water flows south towards Burkes Drain and over Lockwood Road towards Rangiotu Road **(ORS2)**
	    — Overtopping of Oroua River right-bank opposite the Kopane airstrip results in ponding east of Leen Road. Further overtopping of the Oroua River right-bank overtops of Kaimatarau Road, which flows south-east towards Sluggish Drain over Sanders Road **(ORS3)**
	    — Overtopping of Oroua River left-bank between 800-2000 m upstream of Rangiotu Road results in extensive flooding which is sufficient enough to overtop the Rangiotu Road **(ORS4)**

Simulation Event	Flooding
	— Manawatū River right-bank immediately downstream of Burkes Gates overtops and spills into Oroua South Floodplain, adding to overall flood volume accumulation **(ORS5)** — Floodplain water levels pond flat at 11.75 m (NZVD2016), entirely inundating Linton Drain and parts of Rangiotu Road, and extending beyond Lockwood Road to the North. This flat inundation level extends 10 km north to the south of Rongotea Road **(ORS6)** — The levels on the Oroua watercourse downstream of Kopane Bridge are the same (+/-10 mm) as the 50 year present day scenario, because additional inflows results in further overtopping of stopbanks **(ORS7)** **Mangaone Floodplain** — Similar flooding mechanisms to the 200-year present day scenario, summarised as: — Slightly increased flooding either side of Kairanga Bunnythorpe Road originating from the Mangaone and the Mangaone Western Tributary, likely accenuated without local-scale drainage features **(MAN1)** — Minor flooding upstream of SH3 Rangitikei Line downstream of the Flygers Line spillway **(MAN2)** — Flygers Line spillway now active, overtopping crest by approximately 50-100 mm **(MAN3)** **Linton Drain Floodplain** — Similar flooding mechanisms to the 200-year present day scenario, summarised as: — Overtopping of Manawatū River left-bank north of Akers Road, water flows towards Linton Drain. Flow also directed on wider floodplain, overtopping Lochmaigh Road and pooling north of Tane Road **(LD1)** — Overtopping of Manawatū River left-bank upstream of Opiki Road bridge, which spills over Tane Road and fills floodplain north of Opiki Road **(LD2)** **Southern Moutoa Floodplain** — Similar flooding mechanisms to the 200-year present day scenario, summarised as: — Overtopping of Manawatū River right-bank 1-3 km and 5-7 km downstream of Moutoa results in large volumes of water overtopping Foxton – Shannon Road and ponding on floodplain **(SM1)** — Further overtopping on Manawatū River right-bank south of Kere Kere Road results in more extensive water ponding on floodplain **(SM2)** — Floodplain generally fills slowly in a 'bucket-like' mechanism, without modelling local-scale drainage features **(SM3)** **Eastern Moutoa Floodplain** — Similar flooding mechanisms to the 200-year present day scenario, summarised as: — Further overtopping of Manawatū River left-bank approximately 1 km upstream of the Foxton-Shannon roadbridge results in ponding on floodplain **(EM1)** — Short reaches of stopbank continue to overtop on the Manawatū left-bank near Moutoa Gates, water flows south-east towards floodplain **(EM2)** — Minor overtopping from the Makerua Drain and Tokomaru **Aratangata Drain Floodplain** — Similar flooding mechanisms to the 200-year present day scenario, summarised as: — Overtopping of Manawatū River left-bank adjacent to Whirokino Road down to Levin Road (2 km in length) **(AD1)** results in ponding across large extent of

Simulation Event	Flooding
	floodplain, which extends east towards the Koputaroa Stream but there is no interaction **(AD2)**

200-year CC3c	**Feilding**
	— Very similar flooding mechanisms to the 100-year plus climate change scenario, summarised as:
	  — No flooding through town centre from Makino Stream
	  — Out of-bank flooding from Makino Stream at Awahuri Scenic Reserve from low stopbanks in LiDAR data, overtops Kawakawa Road **(FE1)**
	  — No flooding from the Kiwitea Stream and Oroua River
	Palmerston North
	— Very similar flooding mechanisms to the 100-year plus climate change scenario, summarised as:
	  — Manawatū River right stopbank from Raukawa Road to Koehlers Road (approximately 8.5 km) completely overtopped **(PN1)**
	  — Manawatū River left stopbank north of Staces Road (approximately 2.5 km) completely overtopped **(PN6)**
	  — Manawatū River right stopbank overtopping South of Roberts Line – Te Matai Road and adjacent to the Golf Course results in flooding in Hokowhitu **(PN2)**
	  — Manawatū River right stopbank overtopping along the entire right-bank reach starting at He Ara Kotahi Bridge, past Awatapu college and ending near Ahimate Reserve (3 km total). This results in significant flooding to Awapuni **(PN3)**
	    — This overbank flooding from the Manawatū is directed South-West through Palmerston North centre towards the Mangaone stream. The Mangaone Stream right-bank overtops and flow is directed towards the Oroua South Floodplain over Shirrifs Road, SH56 and the NIMT **(PN4)**
	  — Manawatū River right stopbank overtopping near Walkers Road results in floodwaters spilling over NIMT, flowing towards the Oroua South Floodplain **(PN5)**
	Oroua North Floodplain
	— Very similar flooding mechanisms to the 100-year plus climate change scenario, summarised as:
	  — Greater volume of overtopping from the Oroua River left-bank upstream of the Te Arakura Road results in water flowing towards SH3 Rangitikei Line, which overtops and water flows towards the Oroua South Floodplain and Taonui Stream **(ORN1)**
	  — Oroua left stopbank overtops approximately 800 m upstream of the SH3 Rangitikei Line roadbridge, flow is directed further east towards Hansen Line where it overtops the SH3 Rangitikei Line and flows south towards the Oroua South Floodplain and the Taonui Stream **(ORN2)**
	  — Oroua left stopbank overtops 1 km downstream of Rangitikei Line, flowing east towards Oroua Road and on to the Oroua South Floodplain and Taonui Stream **(ORN3)**
	  — Oroua River right-bank overtops just downstream of the Makino Stream confluence, which overtops the SH3 Rangitikei Line adjacent to Green Road **(ORN4)**
	  — Upstream of Reid Line East road, more flow continues to overtop the Oroua left bank and water flows south-east on the north side of the road. Water overtops the Reid Line East road and flows south as part of the Taonui Stream. Some flow continues south-east and joins the tributary adjacent to the Mangaone on the south side of Reid Line East – this flow joins the 'Mangaone US Tributary' approximately 5 km downstream on the south side of Campbell Road **(ORN5)**

Oroua South Floodplain

- Very similar flooding mechanisms to the 100-year plus climate change scenario (3°C), summarised as:
  - Overtopping of Oroua left-bank 1500 m upstream of Rongotea roadbridge as well as left-bank opposite River Road. This flow is directed east and further overtops Oroua Road to the East and flows towards Rongotea Road which is also overtopped **(ORS1)**
  - Further significant overtopping on left-bank downstream of Rongotea Road (located 0-900 m downstream and 2000-3000 m downstream). Water flows south towards Burkes Drain and over Lockwood Road towards Rangiotu Road **(ORS2)**
  - Overtopping of Oroua River right-bank opposite the Kopane airstrip results in ponding east of Leen Road. Further overtopping of the Oroua River right-bank overtops of Kaimatarau Road, which flows south-east towards Sluggish Drain over Sanders Road **(ORS3)**
  - Overtopping of Oroua left-bank between 800-2000 m upstream of Rangiotu Road results in extensive flooding which is sufficient enough to overtop the Rangioutu Road **(ORS4)**
  - Manawatū River right-bank immediately downstream of Burkes Gates overtops and spills into Oroua South Floodplain, adding to overall flood volume accumulation **(ORS5)**
  - Floodplain water levels pond flat at 12.82 m (NZVD2016), entirely inundating Linton Drain and parts of Rangiotu Road, and extending beyond Lockwood Road to the North. This flat inundation level extends 11 km north to the south of Rongotea Road **(ORS6)**
  - The levels on the Oroua watercourse downstream of Kopane Bridge are the same (+/-10 mm) as the 100yr climate change, because additional inflows results in further overtopping of stopbanks **(ORS7)**

Mangaone Floodplain

- Very similar flooding mechanisms to the 100-year plus climate change scenario, summarised as:
  - Slightly increased flooding either side of Kairanga Bunnythorpe Road originating from the Mangaone and the Mangaone Western Tributary, likely occurring without local-scale drainage features **(MAN1)**
  - Minor Flooding upstream of SH3 Rangitikei Line downstream of the Flygers Line spillway **(MAN2)**
  - Flygers Line spillway active, overtopping crest by approximately 150-200 mm **(MAN3)**

Linton Drain Floodplain

- Very similar flooding mechanisms to the 100-year plus climate change scenario, summarised as:
  - Overtopping of Manawatū River left bank north of Akers Road, water flows towards Linton Drain. Flow also directed on wider floodplain, overtopping Lochmaigh Road and pooling north of Tane Road **(LD1)**
  - Overtopping of Manawatū River left bank upstream of Opiki Road bridge, which spills over Tane Road and fills floodplain north of Opiki Road **(LD2)**

Southern Moutoa Floodplain

- Very similar flooding mechanisms to the 100-year plus climate change scenario, summarised as:
  - Overtopping of Manawatū River right-bank 1-3 km and 5-7 km downstream of Moutoa results in large volumes of water overtopping Foxton – Shannon Road and ponding on floodplain **(SM1)**

Simulation Event	Flooding
	— Further overtopping on Manawatū River right-bank south of Kere Kere Road results in more extensive water ponding on floodplain **(SM2)** — Floodplain generally fills slowly in a 'bucket-like' mechanism, without modelling local-scale drainage features **(SM3)** **Eastern Moutoa Floodplain** — Very similar flooding mechanisms to the 100-year plus climate change scenario, summarised as: — Further overtopping of Manawatū River left-bank approximately 1 km upstream of the Foxton-Shannon roadbridge results in ponding on floodplain **(EM1)** — Short reaches of stopbank continue to overtop on the Manawatū left-bank near Moutoa Gates, water flows south-east towards floodplain **(EM2)** — Minor overtopping from the Makerua Drain and Tokomaru Stream **Aratangata Drain Floodplain** — Very similar flooding mechanisms to the 100-year plus climate change scenario, summarised as: — Overtopping of Manawatū River left-bank adjacent to Whirokino Road down to Levin Road (2 km in length) **(AD1)** results in ponding across large extent of floodplain, which extends east towards the Koputaroa Stream but there is no interaction **(AD2)**

4.2 FLOOD FLOWS

The simulated model flows have been extracted for the Manawatū River Channel at Teachers College for the 5 simulated events in this model. These flows are from the active Manawatū channel contained within the stopbanks and do not include any flows outside of the stopbanks when these are overtopped in the larger events.

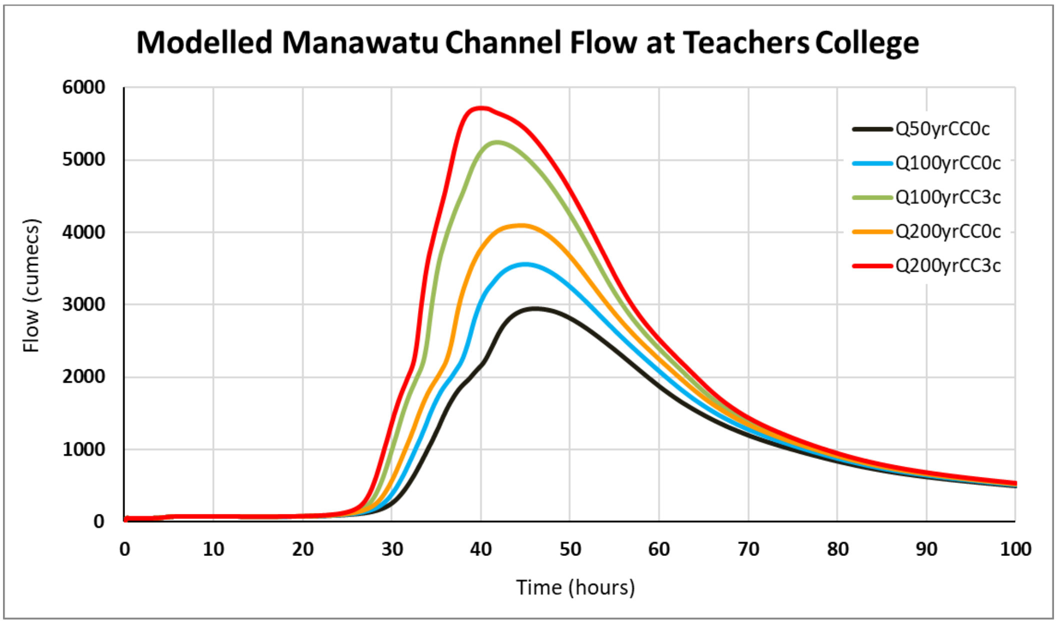


Figure 4-2: Simulated Manawatū River flows at Teachers College

4.3 FLOOD MAPPING

Flood mapping is provided in Appendix B Flood Maps showing flood extents, depths and velocities for each location. The following notes should be considered when viewing the maps:

- Extent Maps – all outputs use high-resolution TUFLOW outputs at the 2m resolution, based on SGS settings.
- Depth Maps – all outputs use high-resolution ('d_HR') TUFLOW outputs at the 2 m resolution, based on SGS settings. Hazard categories are indicated using the Depth (m) as a proxy, based on the Australian Rainfall-Runoff guide (Book 6) (Ball J, 2019). In areas of higher velocities flood hazard could be underestimated.
- Velocity Maps – unlike depth and extent outputs, velocity outputs use the flood size resolution and are not available for the sub-grid resolution. Velocities are therefore cell-averaged velocities at the 8, 16 or 32 m resolution. Extents of flooding should not be interpreted from the velocity maps as they reflect the full cell and not necessarily the high-resolution output.

5 OVERVIEW, ASSUMPTIONS, LIMITATIONS AND RECOMMENDATIONS

5.1 OVERVIEW

The aim of this report was to develop an updated catchment-scale hydraulic model of the Lower Manawatū catchment to support HRC's future operational and design-use purposes. To achieve this aim, a Level B methodology was developed for Phase 1 to represent the main channels and tributaries, model key assets such as stopbanks, roads and floodgates.

An overview of the work undertaken is given below:

— TUFLOW HPC model developed to represent catchment-scale flood risk mechanisms.

— Model terrain defined mostly by LiDAR, with 2023 watercourse survey used to create an interpolated channel surface on the Manawatū River.

— Main watercourses and flowpaths included in areas of refined, small cell sizes.

— Stopbanks and Roads modelled as breaklines along their crests to represent key spilling mechanisms.

— Key structures modelled including Moutoa Gates, Flygers Line Spillway, Mangaone Bridges.

— 29 inflows including 8 intervening inflows.

— Mean High Water Spring (MHWS) downstream boundary at Foxton.

— Five events simulated: 50 year present day, 100 year present day, 100 year 3°C climate change, 200 year present day, 200 year 3°C climate change.

— Nine key flood risk areas: Feilding, Palmerston North, Oroua South Floodplain, Oroua North Floodplain, Mangaone Floodplain, Linton Drain Floodplain, Southern Moutoa Floodplain, Eastern Moutoa Floodplain, Aratangata Drain Floodplain.

— Flood Mapping for extents and depths across five simulated events.

5.2 ASSUMPTIONS

The following assumptions were made in Lower Manawatū model build:

— Roughness – it was assumed that applying the watercourse roughness of 0.035 and Wu turbulence parameters of 3 and 0.25 (Moutoa Gates model validation) was appropriate for the wider Lower Manawatū model.

— LiDAR – it is assumed that the final LiDAR DTM surface has been sufficiently filtered by LINZ. Only basic checks of the surface in key locations were undertaken to ascertain that it represents the bare ground surface. Future work should identify areas of uncertain LiDAR filtering and seek to refine the terrain through survey or through surface modifications.

— Moutoa Gates – the maximum gate opening above the design maximum of 2.7 m (HRC Drawing 2809) was assumed to be 4.54 m, which lifts the gate out of the water. The TOC file assumes the gates continues to lift up to 4.54 m when the flood level upstream of Moutoa Gates remains above 7.85 m NZVD2016.

- Oroua Channel – it was assumed that dropping the Oroua channel by 1.5 m within the wetted perimeter (where the LiDAR levels indicate a ‘flat’ channel surface at the level of the water) was approximately representative of its channel capacity without survey available to calculate this. This 1.5 m is the same as that adopted for the Manawatū River in the Moutoa Gates Model (WSP, 2025b) where the Manawatū River riverbed below the LiDAR water level was approximated by a 1.5 m rectangular-equivalent depth at the Oroua River confluence. This should be addressed in future model builds to get a more realistic understanding of its channel shape and capacity.
- Reid Line Spillway – as per HRC operational management procedure, when flows exceed 50 cumecs at the Makino bridge at Reid Line, flows are diverted towards the Kiwitea. Inflows from the NIWA Modelling (NIWA, 2025) showed that the flow peak at Makino Bridge Reids Line was 48 m^3/s in the 200-year plus 3-degrees warming. It was therefore assumed that the spillway mechanism between the Makino and Kiwitea was not required for modelling as this stage.
- Crest Breaklines – the crest profiles along stopbanks and roads were assumed to be well defined by using a 15 m radius from each vertex along the centreline of the stopbanks and roads.
- Structure Dimensions – where survey was not available, some structure dimensions were estimated and assumed from photos provided by HRC.
- Intervening Hydrographs – the intervening hydrograph assumes that the inflow volume for intervening watercourses is equal to the downstream hydrograph proportioned to the difference in peaks between the upstream and downstream locations.

5.3 LIMITATIONS

Phase 1 developed the updated Lower Manawatū model to Level B. The following limitations of the existing model are recognised as part of the wider aim to achieve Level C and Level D in future phases of the model build:

MODEL LIMITATIONS

- Validation and Calibration – the Lower Manawatū model has not been explicitly validated or calibrated. The model was limited to applying the validation parameters (roughness and turbulence) from the Moutoa Gates model (WSP, 2025b). It is recommended to undertake validation and/or calibration of the Lower Manawatū model in future to multiple high flow events.
- Channel roughness – the validation of the Moutoa Gates (WSP, 2025b) model was applied to the Lower Manawatū model. This validation indicated that a Manning’s *n* of 0.035 applied everywhere resulted in both a strong Travel Time response from Teacher’s College to Moutoa Gates and a good match to water levels. However, using a single channel roughness for all watercourses (n = 0.035) represents a catchment-scale approximation that was appropriate at this stage of the model development and validation. It is recommended to obtain more information and update Manning’s values in future for different reaches of the catchment.
- Interpolated Channel Surface – the interpolated channel surface on the Manawatū River is limited to interpolation of channel shape and levels between cross-sections. Whilst this is an improvement on using flat LiDAR surfaces within the channel wetted perimeter, the interpolated surface misses the natural variation in channel shape and capacity between cross-sections. Future work should consider the use of bathymetry for primary channels in the Lower Manawatū catchment.
- Channel Surface – the channel terrain is limited to LiDAR for most of the model, which underestimates channel capacity particularly in smaller watercourses. It is recommended that channels levels are approximated in future, either by creating an interpolated surface from new or existing survey or by calculating a depth to lower the channel profile to approximate its capacity.

- LiDAR Dates – because of data availability, the dates of flown LiDAR data varied from 2016-2024. It is possible that areas of the model with older LiDAR data have outdated or less representative terrain definition.
- Stopbank Levels – for most of the model, stopbank crest levels were limited to LiDAR levels without survey. A quick check was undertaken on 2021 stopbank survey, which generally showed close agreement (within +/- 50 mm). However, levels between Barber Road (Mile 19) and Foxton-Shannon Road bridge (Mile 18) were the exception, where the stopbank survey levels were approximately 250-300 mm lower than the LiDAR levels. There are other locations in the model where LiDAR defines stopbank profiles less well, especially Feilding. These discrepancies should be investigated further in future stages of model development.
- Floodplain Connectivity – a vast majority of drainage structures which connect floodplains and watercourses have not been modelled. This means that water that has overtopped the river banks and ponded on the floodplain is not able to drain back to the main watercourse. Therefore, it is possible that flood extents and levels are slightly overestimated on some floodplains that would typically drain more slowly following the peak of an event.
- Urban Flooding – flood risk to urban areas such as Palmerston North is highly simplified. Urban rainfall-runoff was not explicitly included and urban drainage assets and features have not been included (such as buildings, fences, stormwater networks, micro-scale flowpaths).
- Cell Size – the largest cell sizes have been used on predominantly volume-accumulating floodplains like Oroua South. At a finer scale (1-2 m) this simplifies flowpaths which are not explicitly represented at the sub-cell level. Although these cells are in areas of greatest ponding where water level drowns out the natural variation in finer scale terrain, areas of larger cells should be reviewed to identify locations where a more detailed representation might materially change the flooding mechanisms.
- Moutoa Gates – although flow through the Moutoa Gates indicated a sensible modelled representation, the flow and levels through Moutoa Gates was not calibrated explicitly against rating curves or flood events. Future work should focus on validating and/or calibrating the Moutoa Gates to historic events, including finetuning key elements such as model grid alignment and cell size, 1D parametrisation and 1D-2D boundary setup.
- Flygers Line Spillway – the operational component of the spillway (320 mm spilling gates) should be added for future calibration and design events
- Bridge Representation – the effect of most bridge structures has not been included, for example Opiki Bridge on the Manawatū River. Whilst the LiDAR terrain adequately represented the bank contraction losses (vena-contracta), the effects of piers, decks and superstructure losses have not been considered.

HYDROLOGICAL LIMITATIONS

The limitations of the input hydrology are broadly related to this assessment not undertaking a detailed hydrological assessment:

- Fluvial-only model – the Phase 1 model has not considered explicitly the impact of rainfall, which is especially relevant to areas such as Palmerston North. The current model outputs are limited to demonstrated the catchment-scale flood risk from fluvial sources only.
- Inflow Events – the current model results are limited to the 60-hour storm across the Lower Manawatū catchment.
- Inflows – some smaller and minor inflows have not been included at this stage of development, for example Ashhurst Stream. Future work should continue to refine the model by identifying inflows which contribute to catchment and/or local-scale flooding.

- Intervening Inflows – the current methodology could underestimate on the tributaries because intervening inflows are lumped at the confluence of the downstream watercourse. This means that some areas on minor watercourses, such as the Turitea or Kahuterawa, could show less flooding than might occur otherwise.
- Infiltration and Soakage – the model does not represent any losses to the ground, which might be more important on larger floodplains in the hours and days following a large event.

5.4 RECOMMENDATIONS

The current Lower Manawatū model represents fluvial flood risk mostly to a catchment-scale Level B. Higher resolution local-scale localised features such as minor drains, floodplain connection culverts and urban drainage features were not included explicitly or if at all not to a high resolution. To develop and refine this model towards Level C and Level D detail to support HRC's long-term goals, the following recommendations are made.

1 Establish Long-term Model Scope – this model and associated report have focussed on the catchment-scale fluvial flood risk in the Lower Manawatū catchment. A key component of future work will be to agree and establish the long-term scope and scale of this updated Lower Manawatū catchment model with respect to its wider goals and aims. This will dictate the identification of key areas and prioritisation of data collection. Some things to consider include:

- Source of Flood Risk – is the focus primarily on fluvial flood risk, or does surface water risk (pluvial) to and from urban areas need to be considered in more detail, and to what extent?
- Joint Probability – in areas of multiple flood risk sources such as Eastern Palmerston North (fluvial and pluvial flood risk), should this model be the go-to asset to consider the joint probability of flooding from surface water (pluvial) and rivers (fluvial)? How would the hydrology of joint pluvial-fluvial events be considered?
- Urban Flooding – to what extent should this model address flood risk to urban areas with no fluvial flood risk? What advantage is sought from including detailed urban drainage features with the associated slow-down in model simulation times, compared to individual smaller models of these areas?

2 Data Collection – data gaps should be identified by undertaking a prioritisation exercise to focus on key areas of the catchment. This should highlight the greatest uncertainties across the catchment where gaps exist in terrain definition, channel surfaces, structure dimensions and asset information. Data collection should include new and existing topographic survey, bathymetry and watercourse surveys. Initial high-level findings from this updated model indicate the following priorities:

- Stopbanks – updated stopbank survey covering key areas of stopbank overtopping, in particular along the Manawatū River near Moutoa Gates, around Palmerston North, and the Oroua River left-bank.
- Floodgates – updated channel and structure surveys for key floodgate channels in the lower extent of the catchment. Modelled accurate floodgate structure levels and associated channel levels are crucial for simulating the outflow and attenuation on these minor drain catchments (for example Sluggish Drain and Koputaroa Drain).
- Oroua River – updated watercourse survey or bathymetry to better represent channel capacity and shape.
- Survey and bathymetry – key watercourses and features that need to be modelled at a high resolution.

3 Calibration and Validation – the Lower Manawatū model has not been explicitly validated or calibrated. Future work should identify key flood events with which to calibrate the model, ideally recent events that are representative of the up-to-date datasets used to define model geometry (for example February 2023 Cyclone Gabrielle). The calibration should focus on gauged levels and travel time between upstream and downstream catchment locations (e.g. Teacher's College and Moutoa Gates).

4 Moutoa Gates – future work should focus on validating and/or calibrating the Moutoa Gates to historic events, including finetuning key elements such as model grid alignment and cell size, 1D parametrisation and 1D-2D boundary setup. This might include calibrating to rating curves.

5 Catchment Structures – the model should be continually refined to include floodplain connection structures, pumping stations and urban drainage features.
   - In particular, floodplain connection structures will be important for more representative drainage to and from main watercourses during and after events.
   - Pumping stations should be included with pumping capacity and rules agreed upon with HRC.

6 Assets and Infrastructure – key buildings and assets should be included with more detail, including the effects of flooding to and from these components. For example, the effect of residential buildings in Palmerston North might be considered through individual representation of building outlines and their associated losses.

7 Hydrological Assessment – this study considered a design 60-hour storm with direct inflows only (distributed inflow model) and simplified intervening inflows. Future work could focus on a more detailed hydrological assessment which considers joint probability between fluvial, pluvial and tidal flooding.
   - If required, particular attention should be given to the impact of multiple flood risk sources in urban centres such as Palmerston North, Feilding and Ashhurst because the interaction of rainfall-runoff and fluvial flood risk has not yet been considered in this model.
   - Hydrological calibration might be considered by using software such as HEC-HMS. If undertaken, this should focus on the routing of rainfall from upstream source (Upper Manawatū) to downstream sink (Lower Manawatū).
   - The intervening inflows should be the focus of a more detailed hydrological assessment which identifies appropriately distributed inflow volumes between the upstream inflow and the downstream confluence. Particular focus should be placed on watercourses with higher intervening inflow proportions.

8 Design and Scenario Testing – future modelling should focus on a range of scenario-based simulations, including stopbank upgrades, infrastructure developments, asset failure (for example pumping stations) and drainage scheme performance.

9 Detailed Operational Management Modelling – current modelling has not developed a comprehensive representation of catchment-scale operating rules, for example by linking levels and flows at Teacher's College to the opening of Moutoa Gates. There is an opportunity to refine and write the operating rules of key structures across the catchment within the hydraulic model to inform future operational management procedures.

10 Channel Roughness – it is recommended to take an individual approach to each watercourse to define channel roughness. This should be supported by site photographs and flood event observations.

11 Soakage and Infiltration – it is recommended to represent soakage and infiltration from floodplains. This will improve representation of flooding mechanisms on larger floodplains in the hours and days following a large event.

12 Minor Drain and Watercourse Representation – some drains are currently not explicitly represented at finer-scale resolution within the smaller cell sizes (Quadtree control file). It is recommended to identify key drains not currently modelled, for example Rongotea Road drain or Ashhurst Drain, and include higher resolution of cells around these features.

13 Quadtree Refinements – areas of larger cells should be reviewed to identify locations where a more detailed representation might materially change the flooding mechanisms.

14 Reporting and Visualisation – future work could include more detailed, local-scale mapping and visualisation outputs.

6 LIMITATIONS

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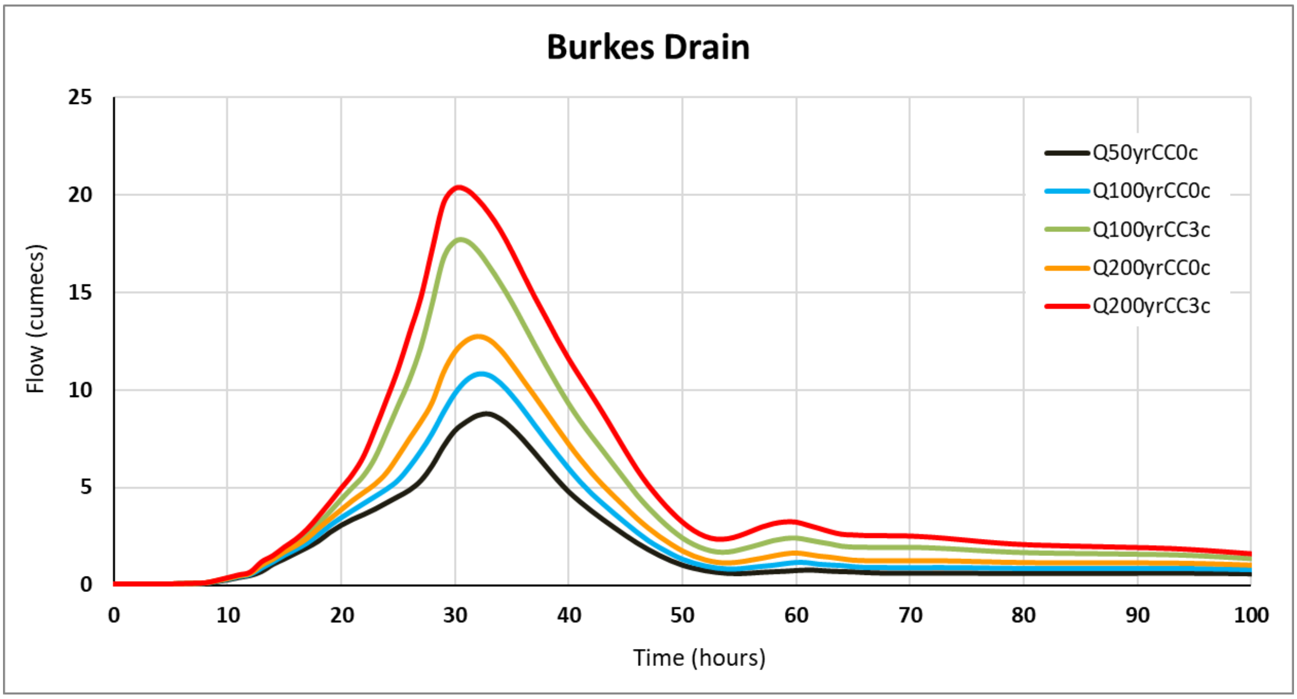
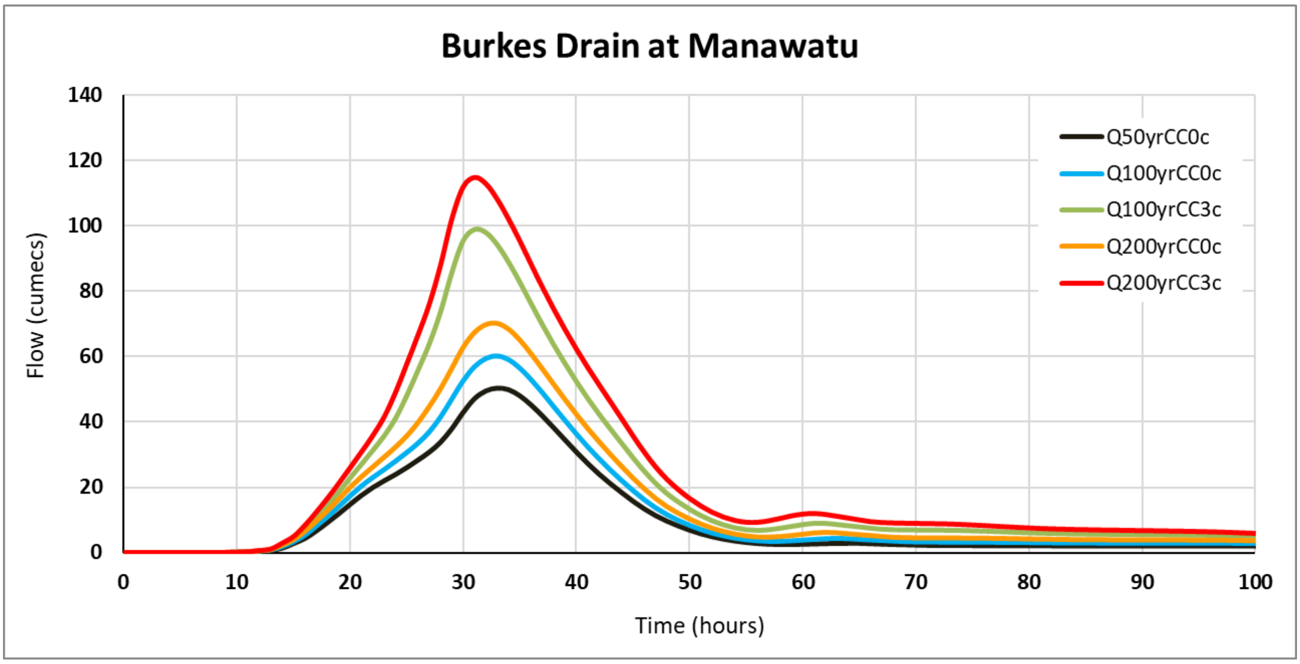
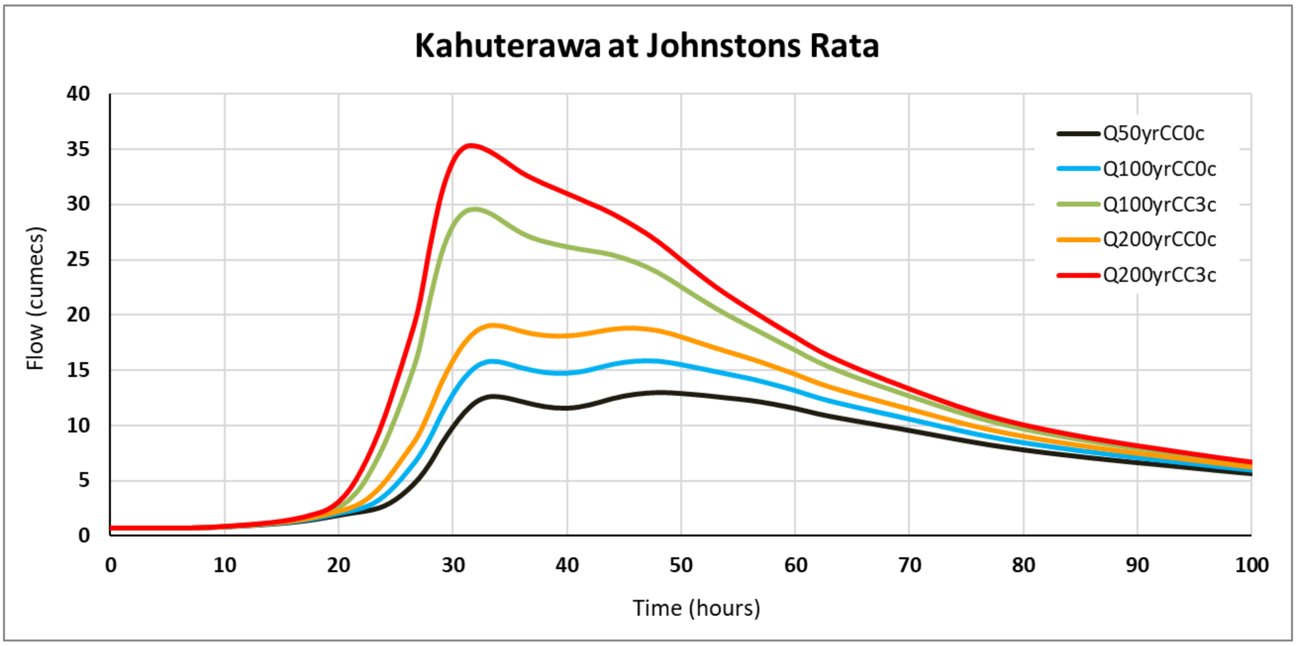
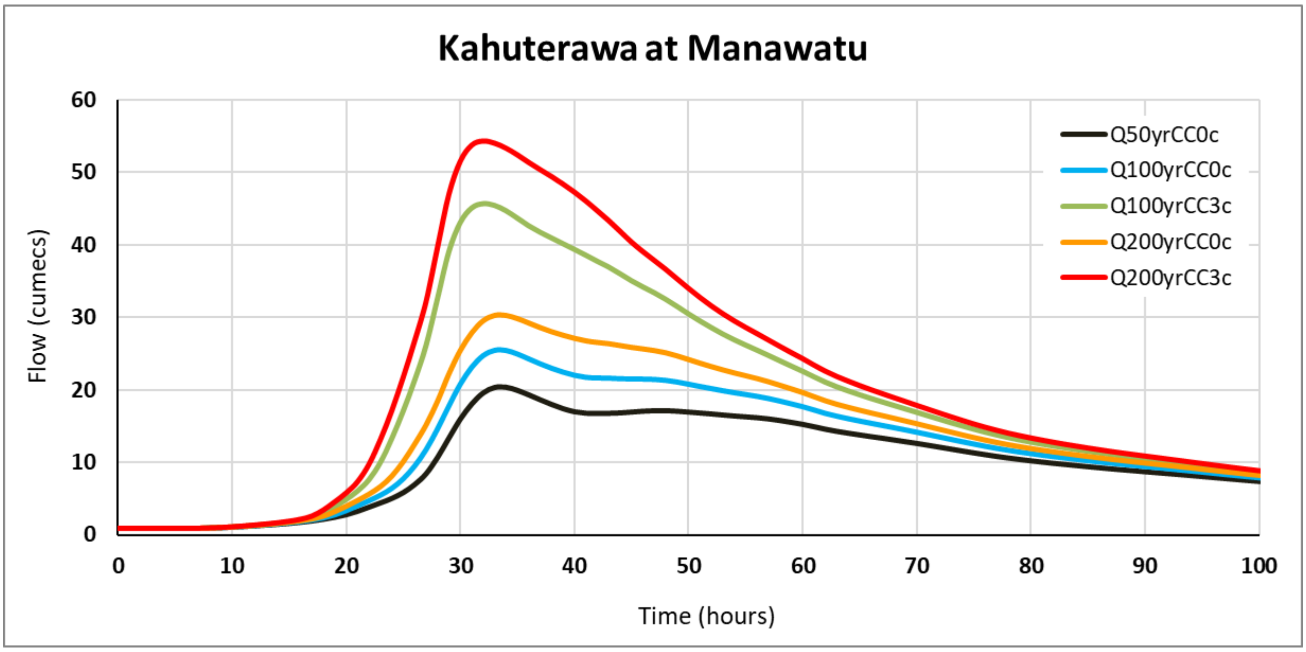
APPENDIX A INPUT HYDROGRAPHS



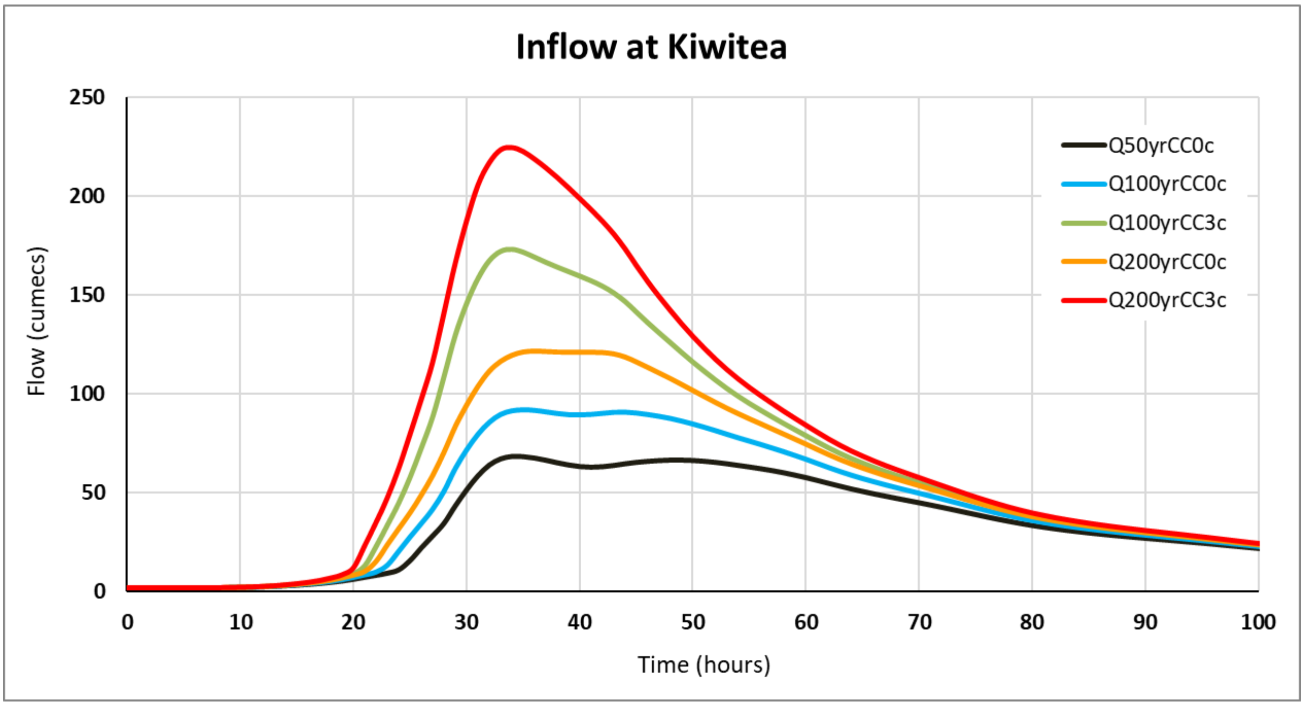




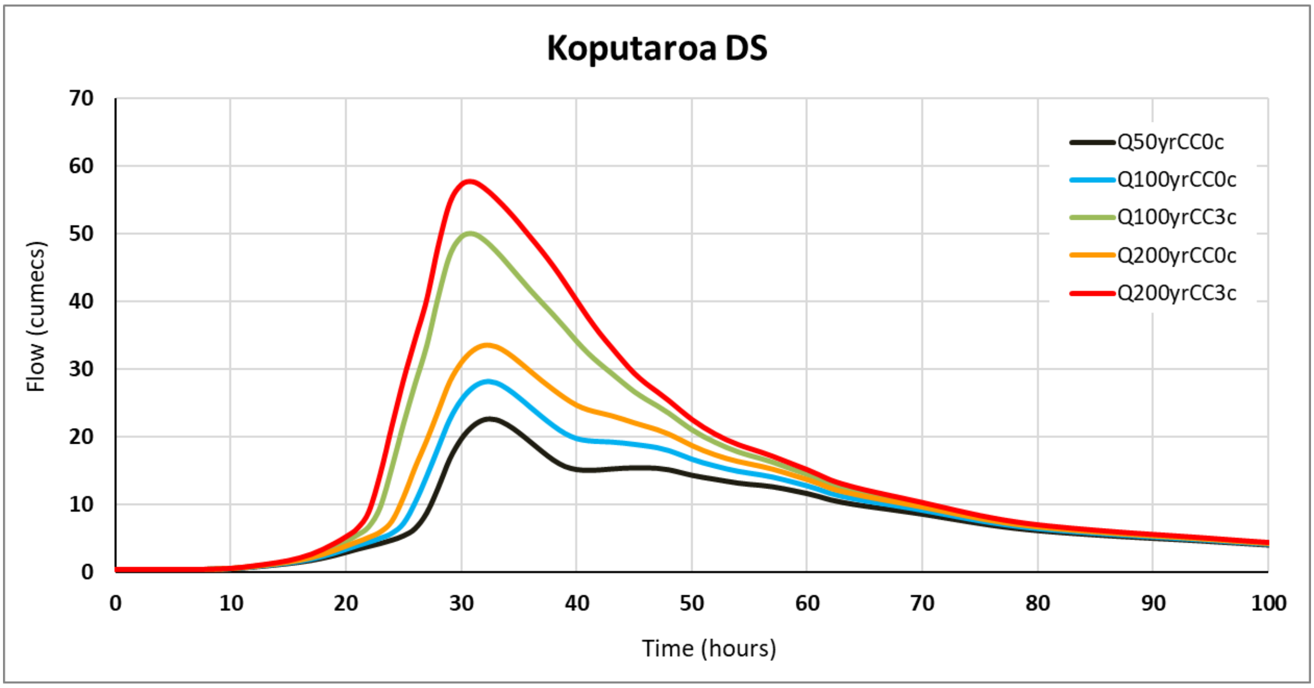
Kahuterawa at Johnstons Rata
Flow (cumecs)
0
5
10
15
20
25
30
35
40
0
10
20
30
40
50
60
70
80
90
100
Time (hours)
Q50yrCC0c
Q100yrCC0c
Q100yrCC3c
Q200yrCC0c
Q200yrCC3c



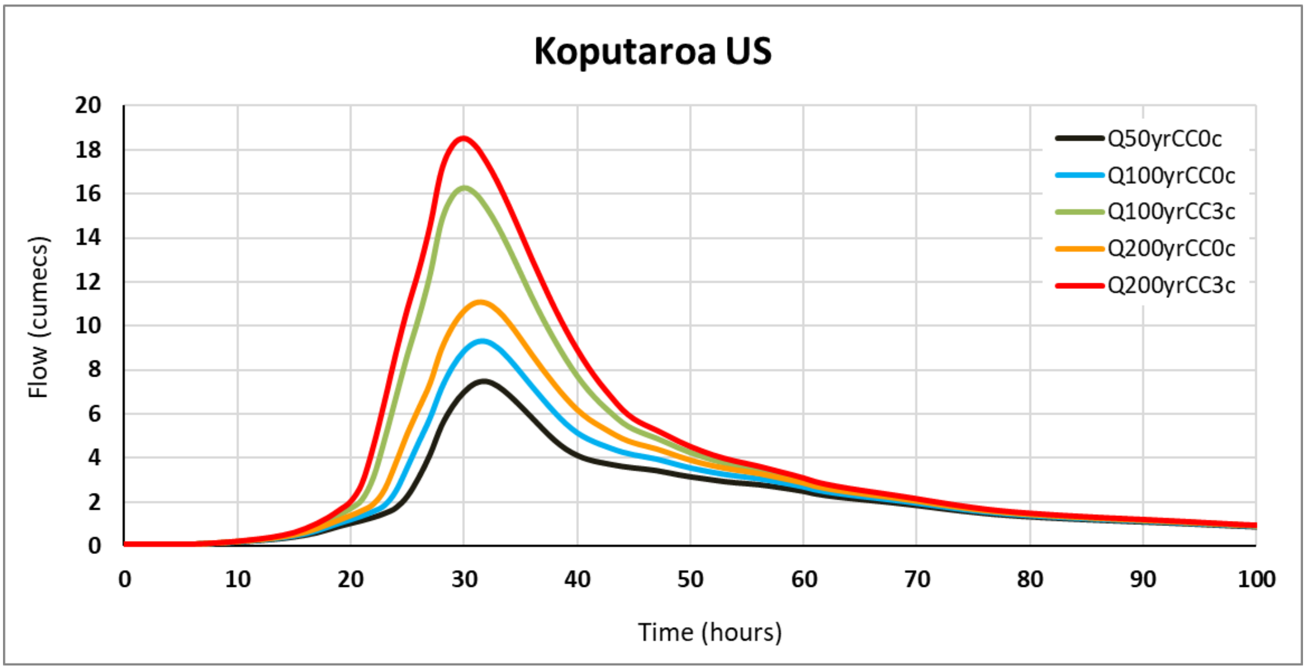
Kahuterawa at Manawatu
Flow (cumecs)
0
10
20
30
40
50
60
0
10
20
30
40
50
60
70
80
90
100
Time (hours)
Q50yrCC0c
Q100yrCC0c
Q100yrCC3c
Q200yrCC0c
Q200yrCC3c

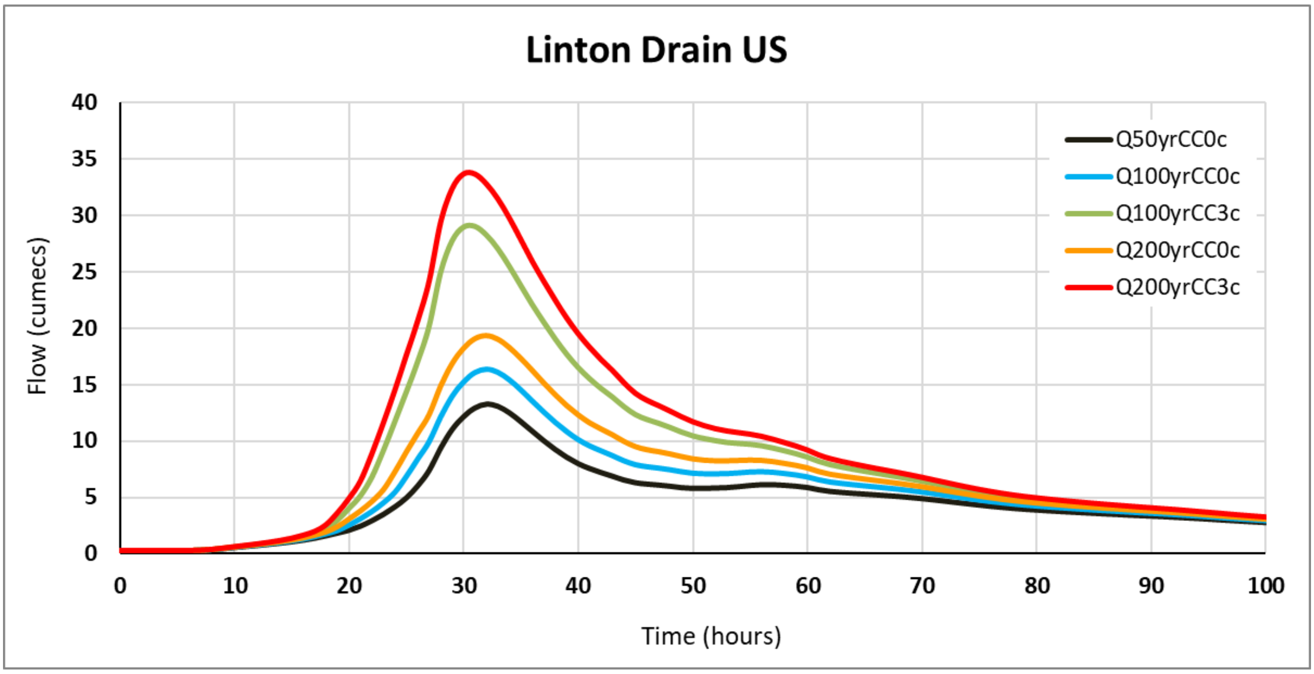


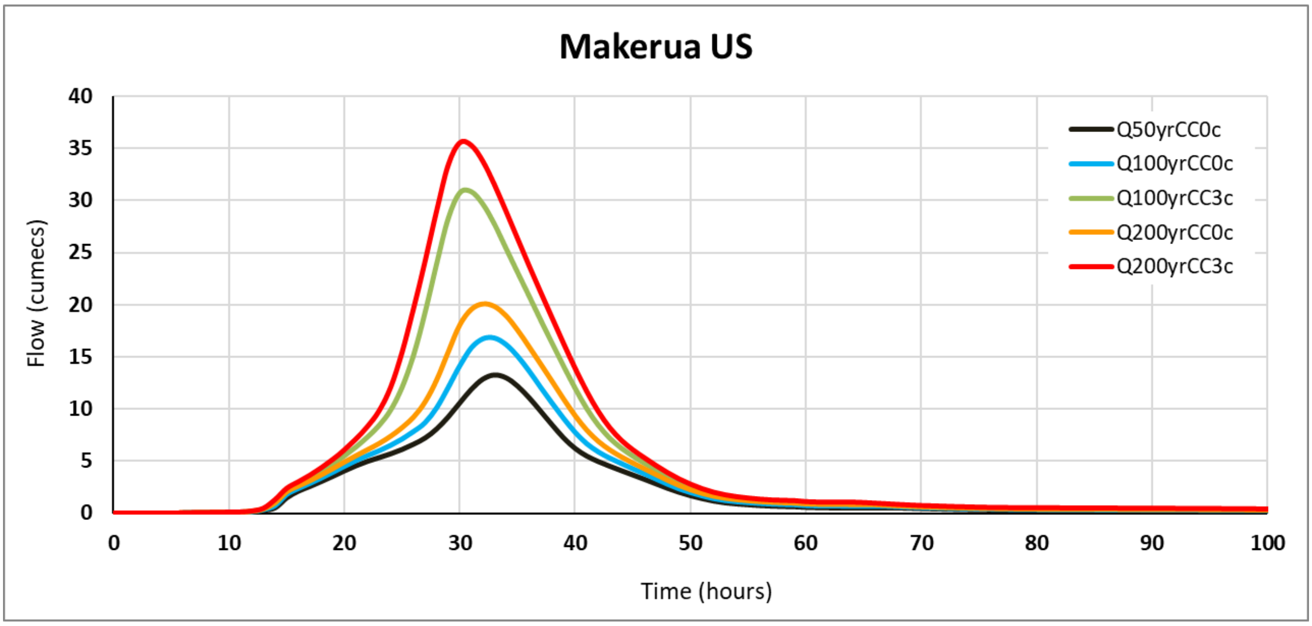
Inflow at Kiwitea
Flow (cumecs)
250
200
150
100
50
0
0
10
20
30
40
50
60
70
80
90
100
Time (hours)
Q50yrCC0c
Q100yrCC0c
Q100yrCC3c
Q200yrCC0c
Q200yrCC3c

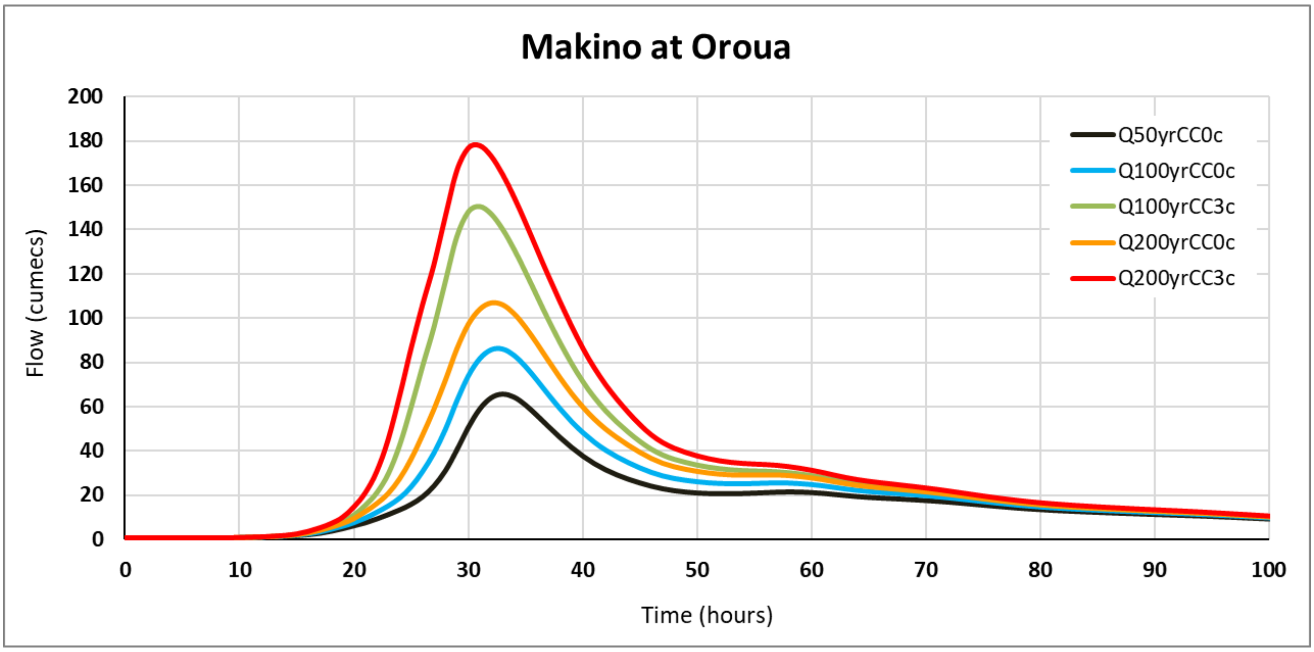


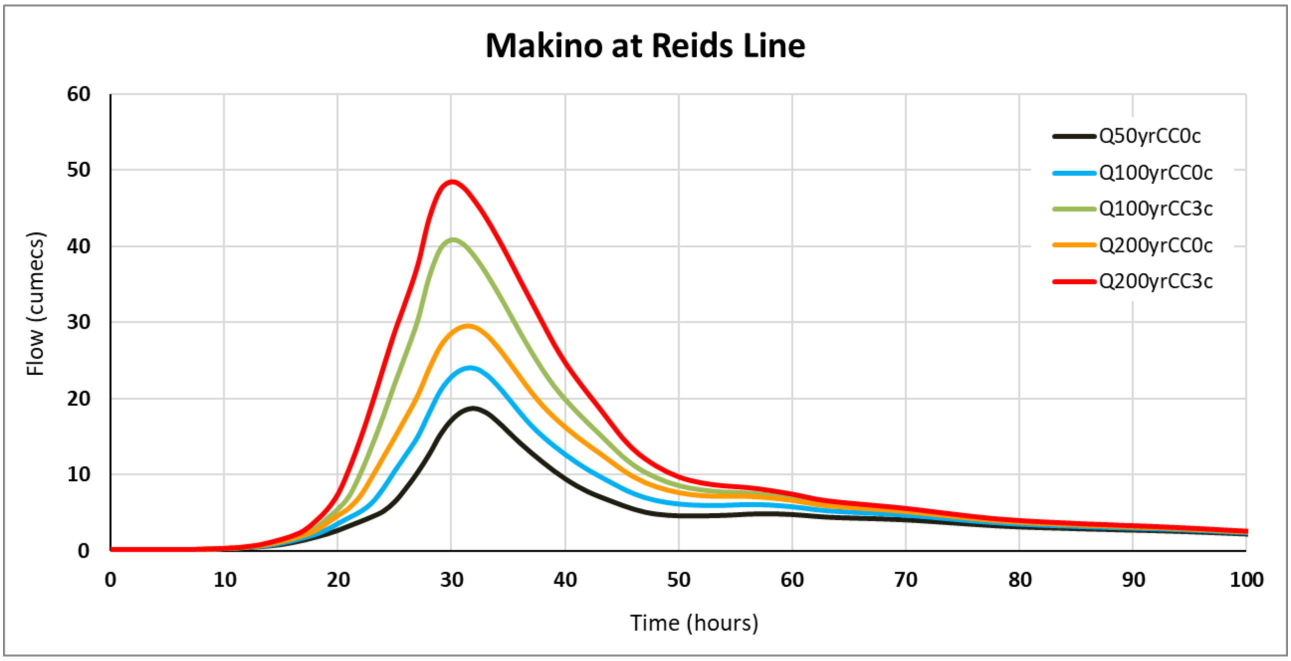
Koputaroa DS
Flow (cumecs)
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
90
100
Time (hours)
Q50yrCC0c
Q100yrCC0c
Q100yrCC3c
Q200yrCC0c
Q200yrCC3c

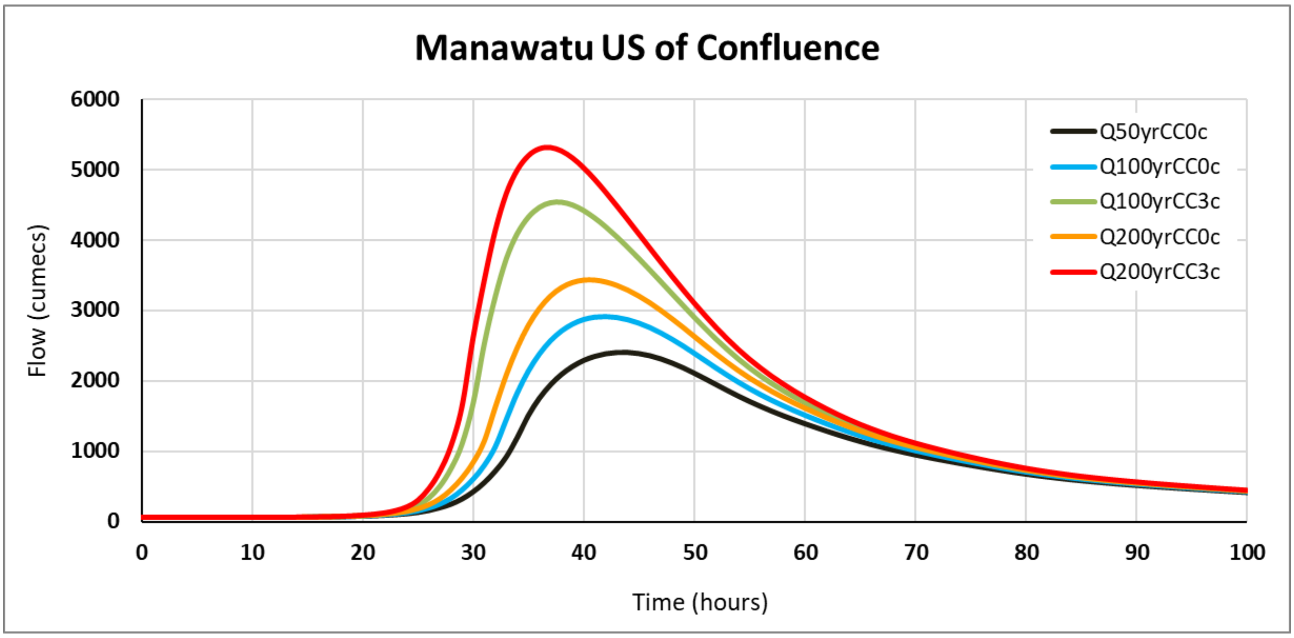

Koputaroa US
Flow (cumecs)
Time (hours)
Q50yrCC0c
Q100yrCC0c
Q100yrCC3c
Q200yrCC0c
Q200yrCC3c
0
2
4
6
8
10
12
14
16
18
20
0
10
20
30
40
50
60
70
80
90
100

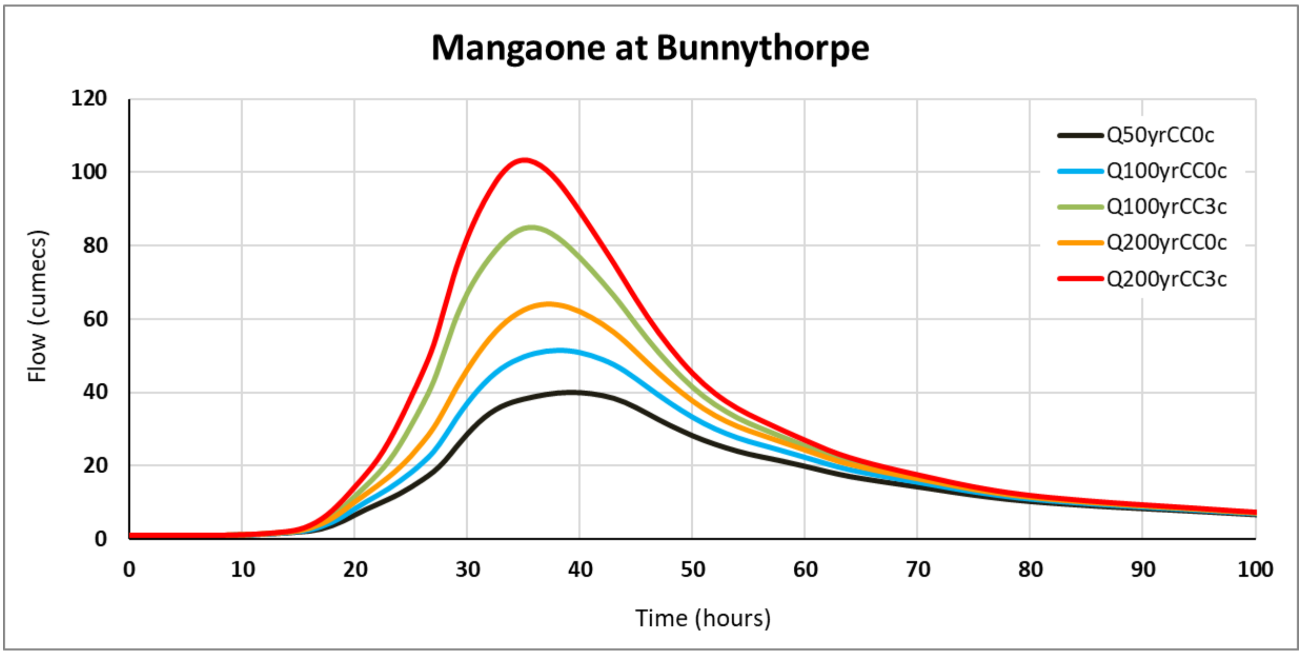

Linton Drain US
Flow (cumecs)
Time (hours)
Q50yrCC0c
Q100yrCC0c
Q100yrCC3c
Q200yrCC0c
Q200yrCC3c
0
5
10
15
20
25
30
35
40
0
10
20
30
40
50
60
70
80
90
100

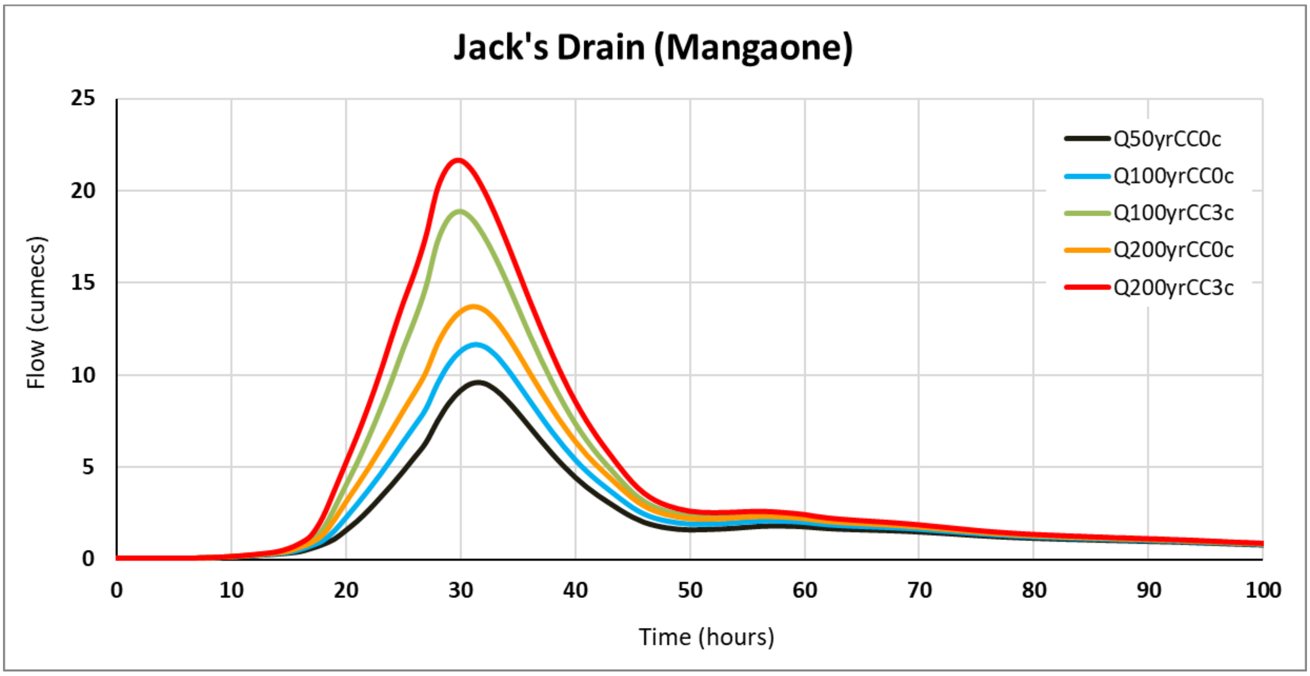

Makerua US
Flow (cumecs)
40
35
30
25
20
15
10
5
0
0
10
20
30
40
50
60
70
80
90
100
Time (hours)
Q50yrCC0c
Q100yrCC0c
Q100yrCC3c
Q200yrCC0c
Q200yrCC3c

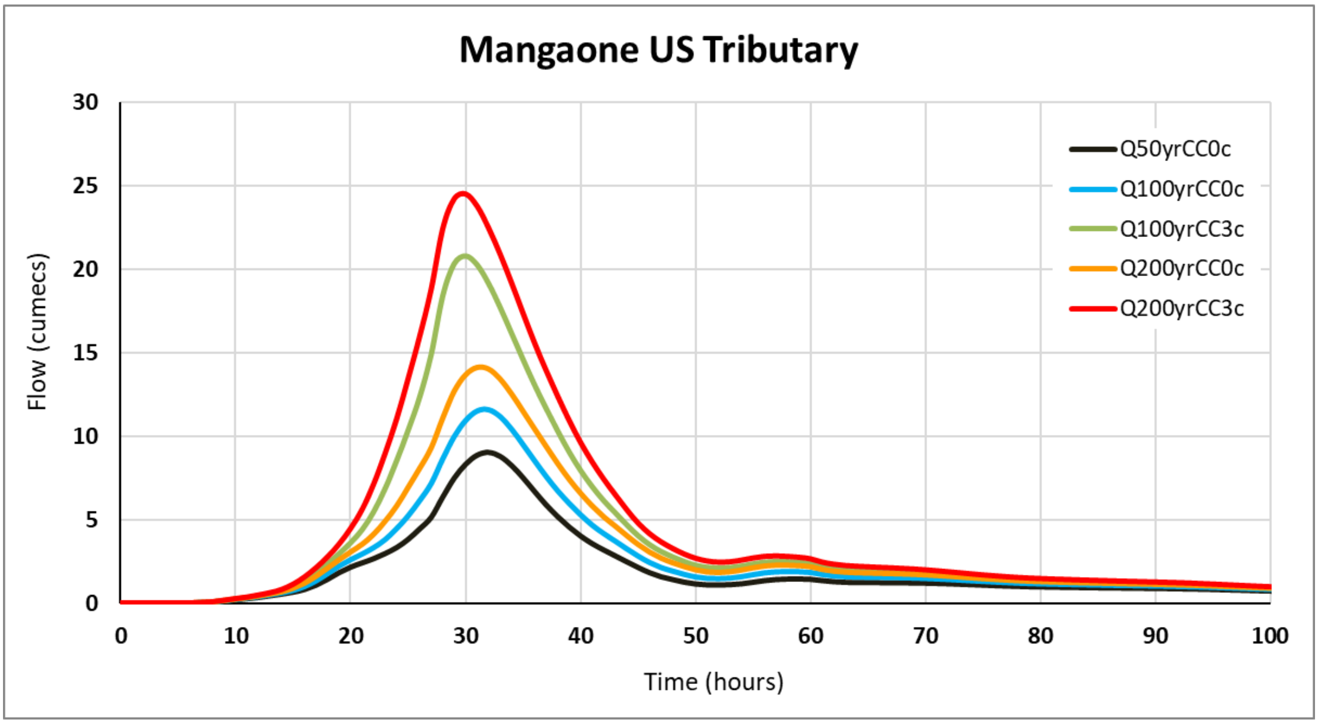

Makino at Oroua
Flow (cumecs)
200
180
160
140
120
100
80
60
40
20
0
0
10
20
30
40
50
60
70
80
90
100
Time (hours)
Q50yrCC0c
Q100yrCC0c
Q100yrCC3c
Q200yrCC0c
Q200yrCC3c

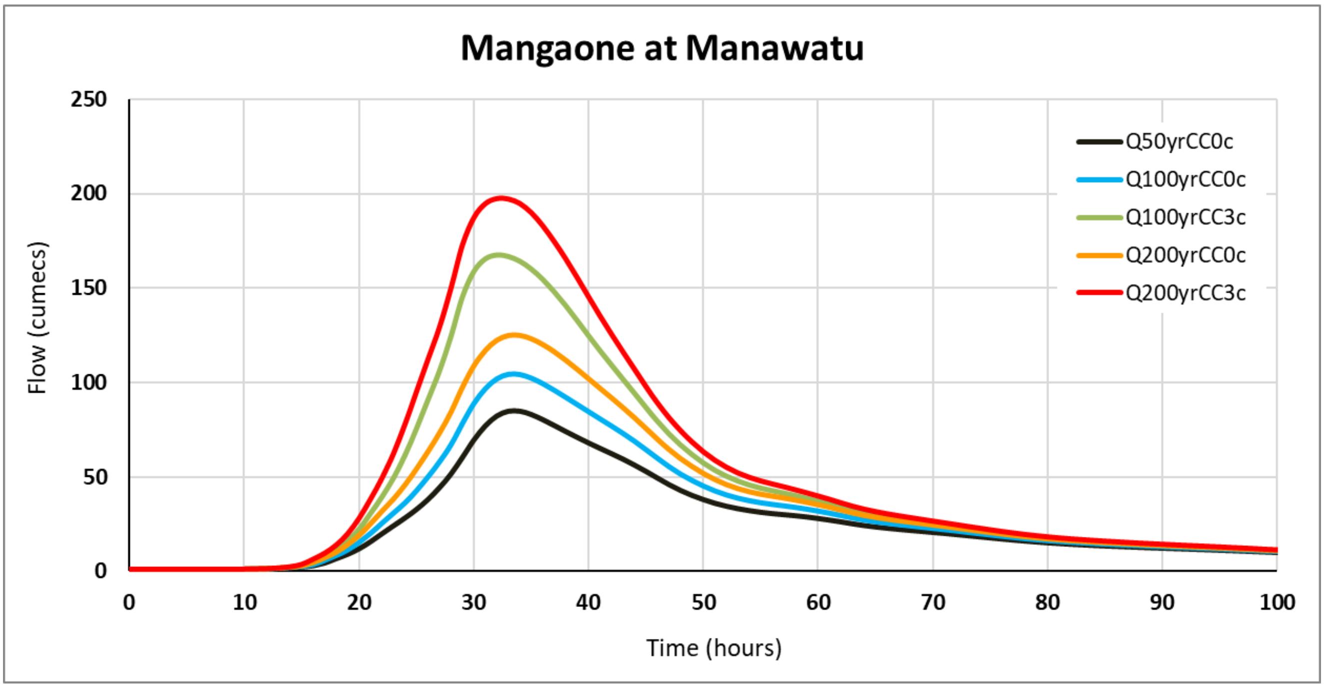

Makino at Reids Line
60
50
40
30
20
10
0
Flow (cumecs)
0
10
20
30
40
50
60
70
80
90
100
Time (hours)
Q50yrCC0c
Q100yrCC0c
Q100yrCC3c
Q200yrCC0c
Q200yrCC3c

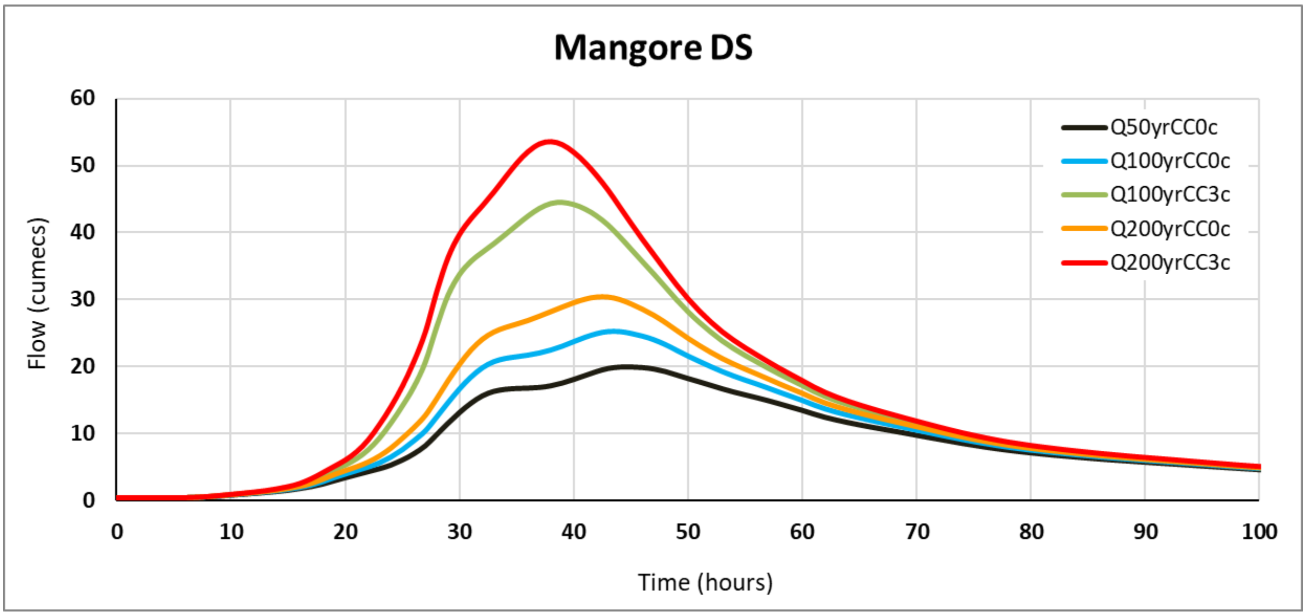

Manawatu US of Confluence
6000
5000
4000
3000
2000
1000
0
Flow (cumecs)
0
10
20
30
40
50
60
70
80
90
100
Time (hours)
Q50yrCC0c
Q100yrCC0c
Q100yrCC3c
Q200yrCC0c
Q200yrCC3c

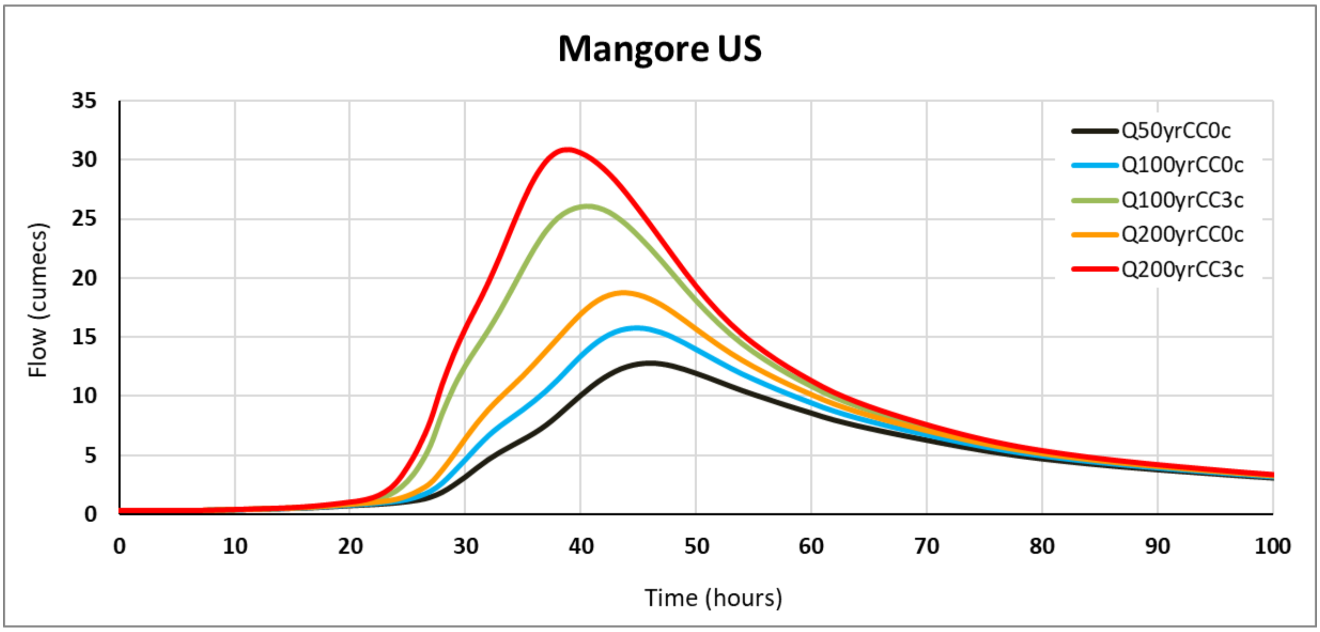

Mangaone at Bunnythorpe
Flow (cumecs)
120
100
80
60
40
20
0
0
10
20
30
40
50
60
70
80
90
100
Time (hours)
Q50yrCC0c
Q100yrCC0c
Q100yrCC3c
Q200yrCC0c
Q200yrCC3c

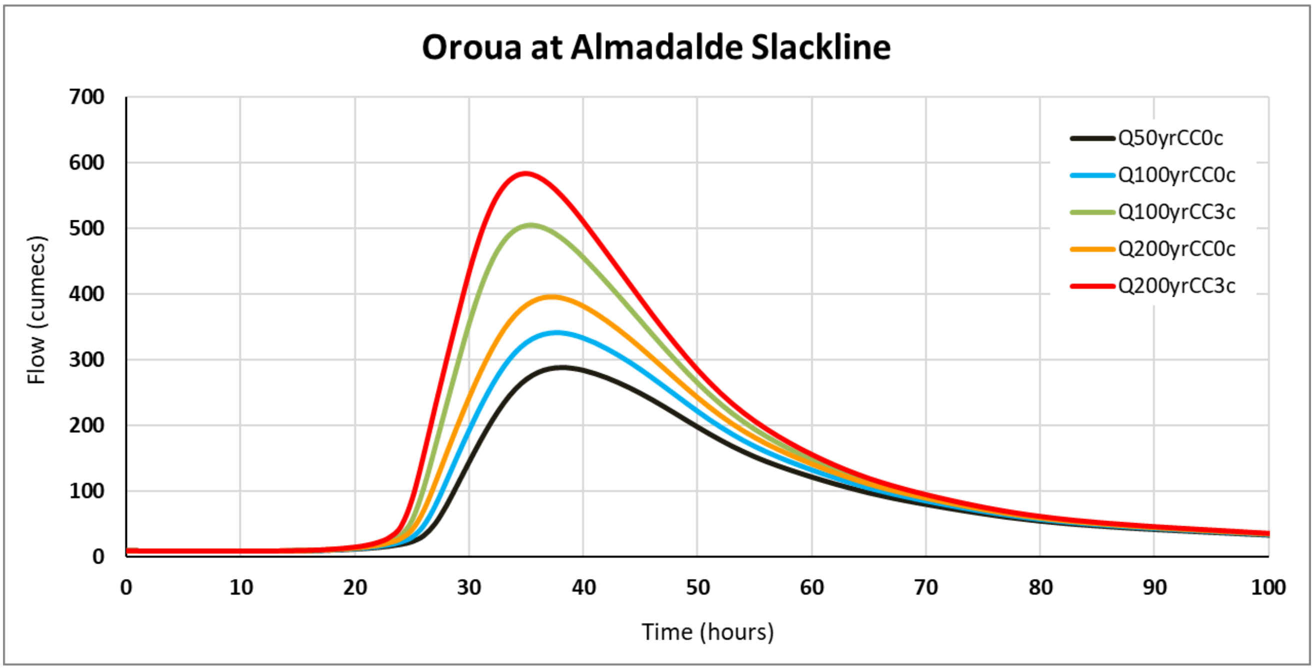

Jack's Drain (Mangaone)
Flow (cumecs)
25
20
15
10
5
0
0
10
20
30
40
50
60
70
80
90
100
Time (hours)
Q50yrCC0c
Q100yrCC0c
Q100yrCC3c
Q200yrCC0c
Q200yrCC3c

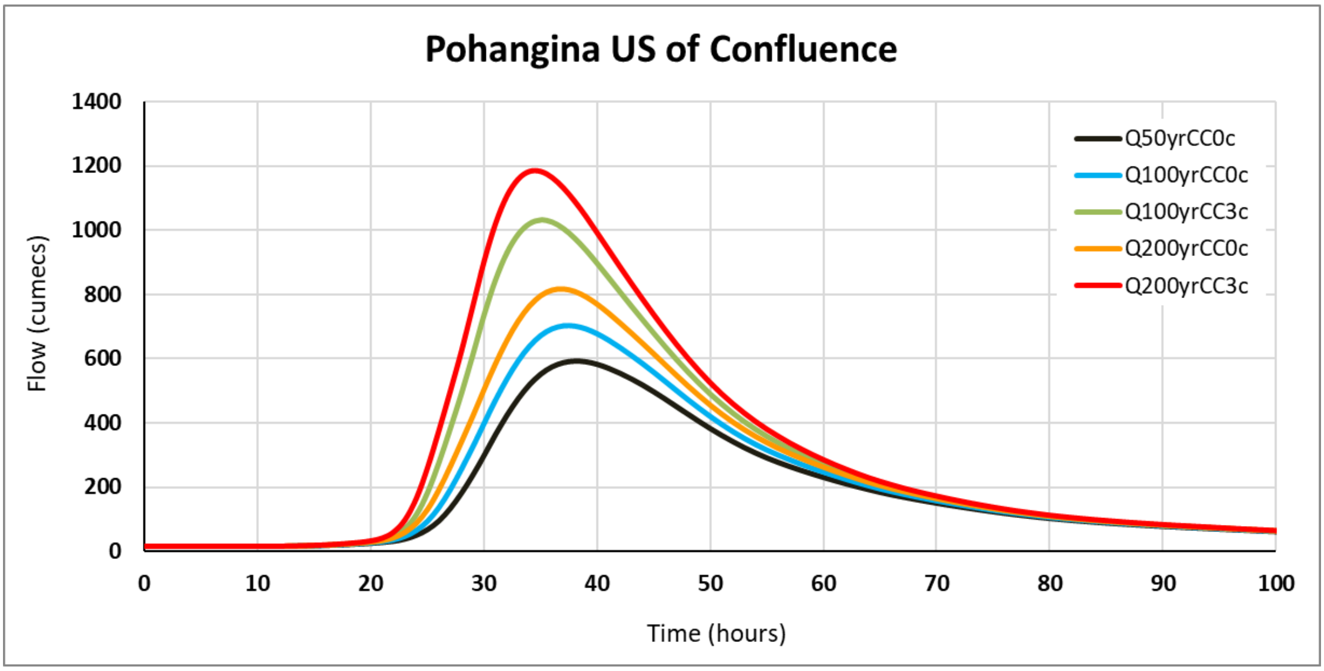

Mangaone US Tributary
30
25
20
15
10
5
0
Flow (cumecs)
0
10
20
30
40
50
60
70
80
90
100
Time (hours)
Q50yrCC0c
Q100yrCC0c
Q100yrCC3c
Q200yrCC0c
Q200yrCC3c


Mangaone at Manawatu
250
200
150
100
50
0
Flow (cumecs)
0
10
20
30
40
50
60
70
80
90
100
Time (hours)
Q50yrCC0c
Q100yrCC0c
Q100yrCC3c
Q200yrCC0c
Q200yrCC3c


Mangore DS
60
50
40
30
20
10
0
Flow (cumecs)
0
10
20
30
40
50
60
70
80
90
100
Time (hours)
Q50yrCC0c
Q100yrCC0c
Q100yrCC3c
Q200yrCC0c
Q200yrCC3c


Mangore US
35
30
25
20
15
10
5
0
Flow (cumecs)
0
10
20
30
40
50
60
70
80
90
100
Time (hours)
Q50yrCC0c
Q100yrCC0c
Q100yrCC3c
Q200yrCC0c
Q200yrCC3c


Oroua at Almadalde Slackline
Flow (cumecs)
0
100
200
300
400
500
600
700
Time (hours)
0
10
20
30
40
50
60
70
80
90
100
Q50yrCC0c
Q100yrCC0c
Q100yrCC3c
Q200yrCC0c
Q200yrCC3c


Pohangina US of Confluence
Flow (cumecs)
0
200
400
600
800
1000
1200
1400
Time (hours)
0
10
20
30
40
50
60
70
80
90
100
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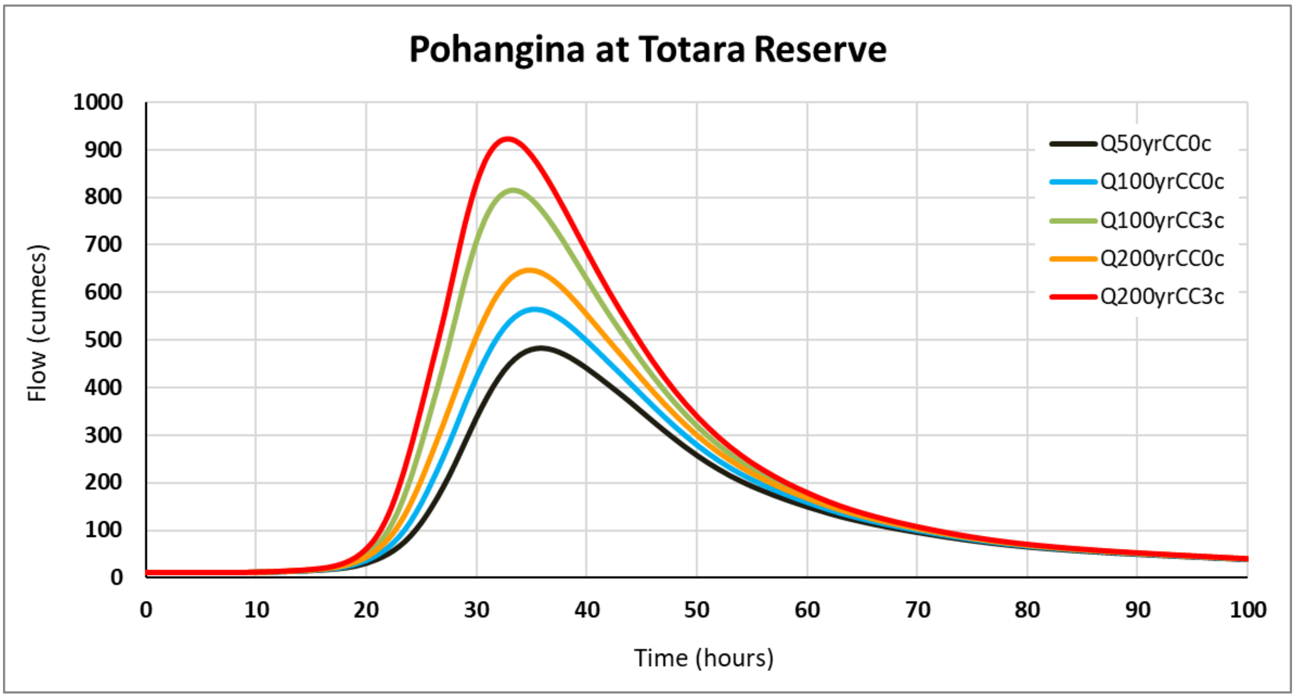
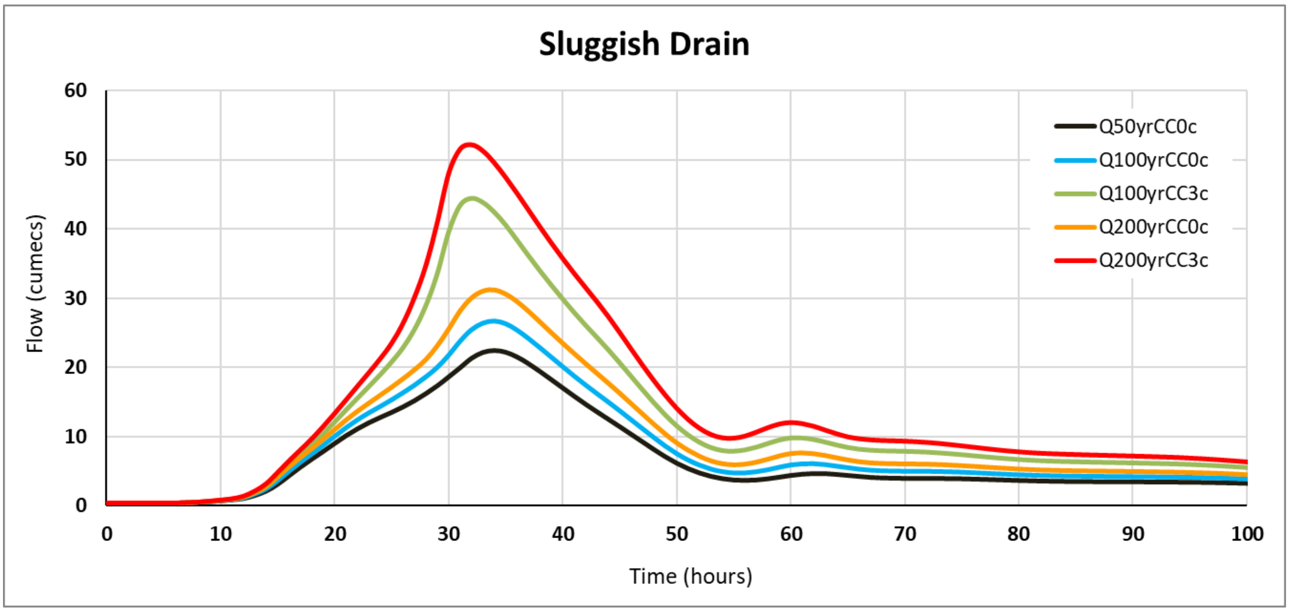
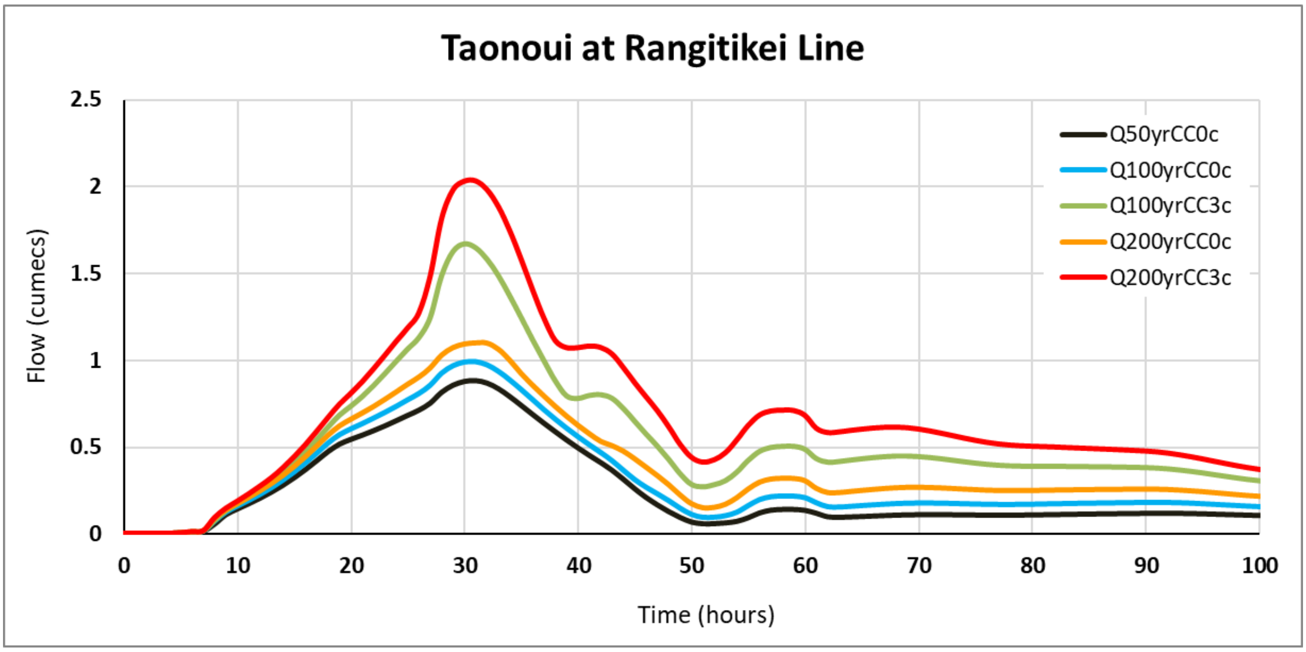
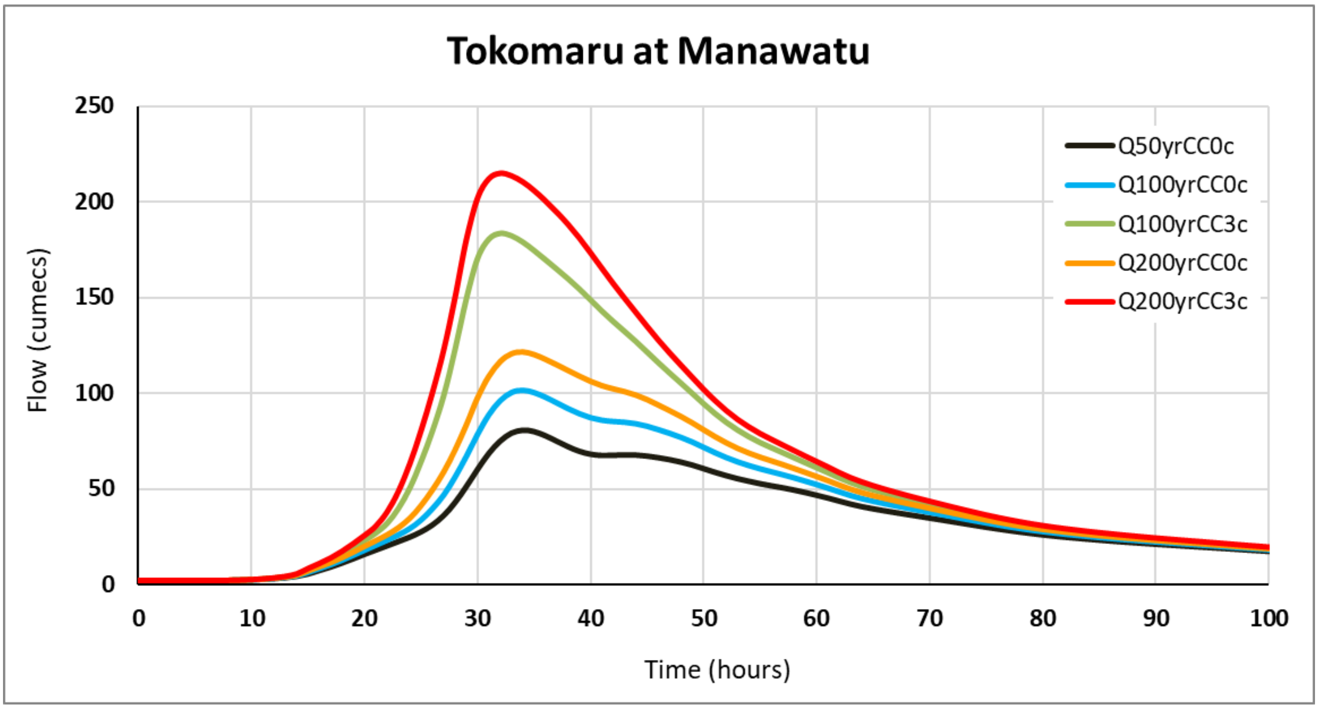
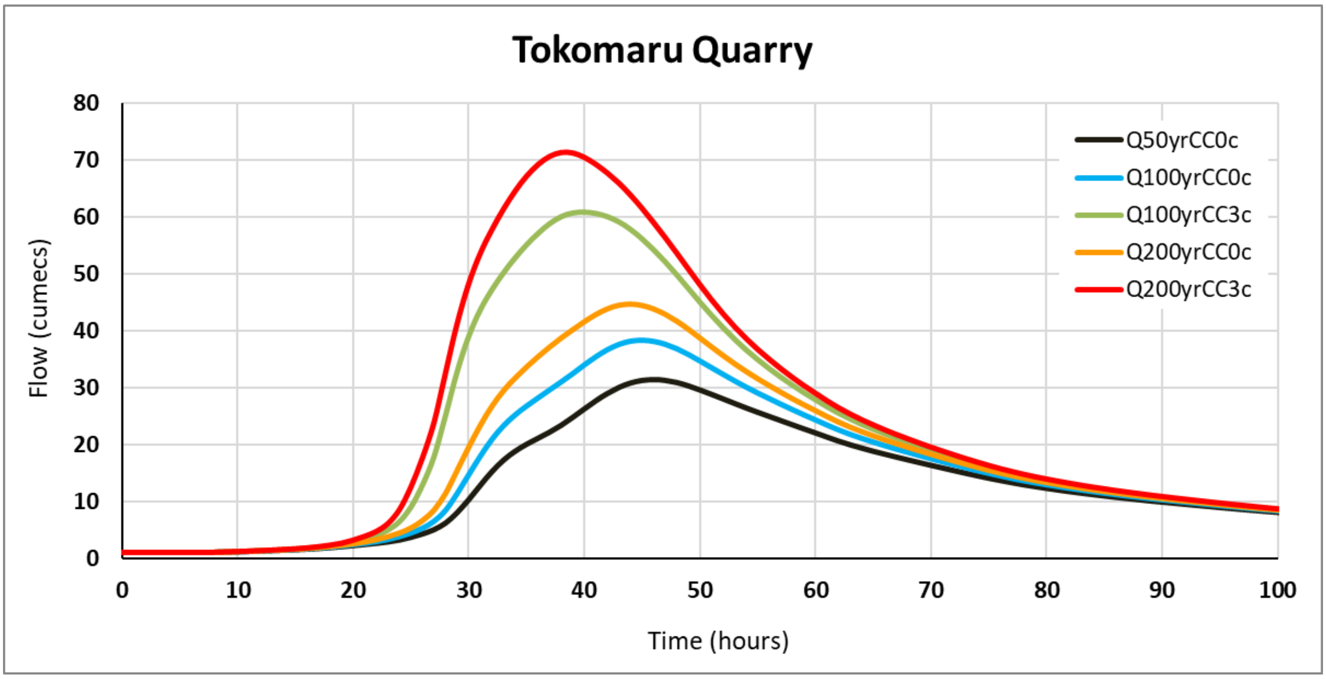
Q200yrCC0c
Q200yrCC3c

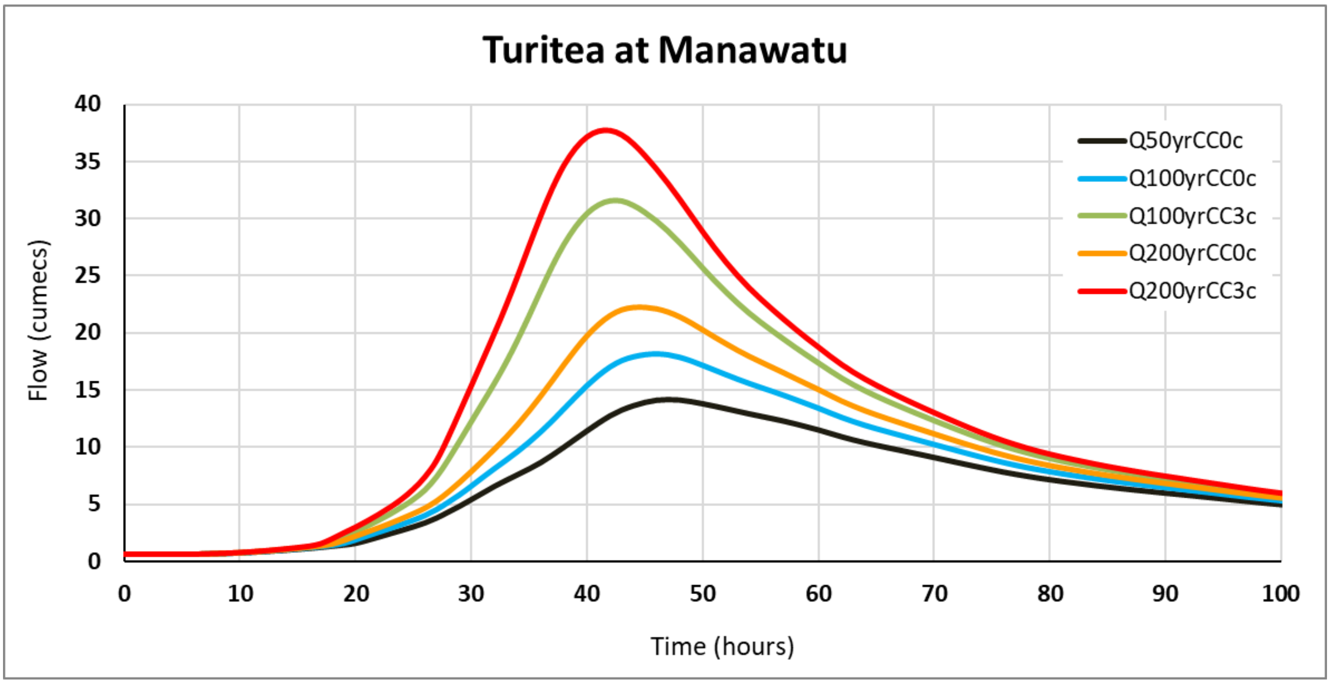

Pohangina at Totara Reserve
Flow (cumecs)
Time (hours)
0
100
200
300
400
500
600
700
800
900
1000
0
10
20
30
40
50
60
70
80
90
100
Q50yrCC0c
Q100yrCC0c
Q100yrCC3c
Q200yrCC0c
Q200yrCC3c

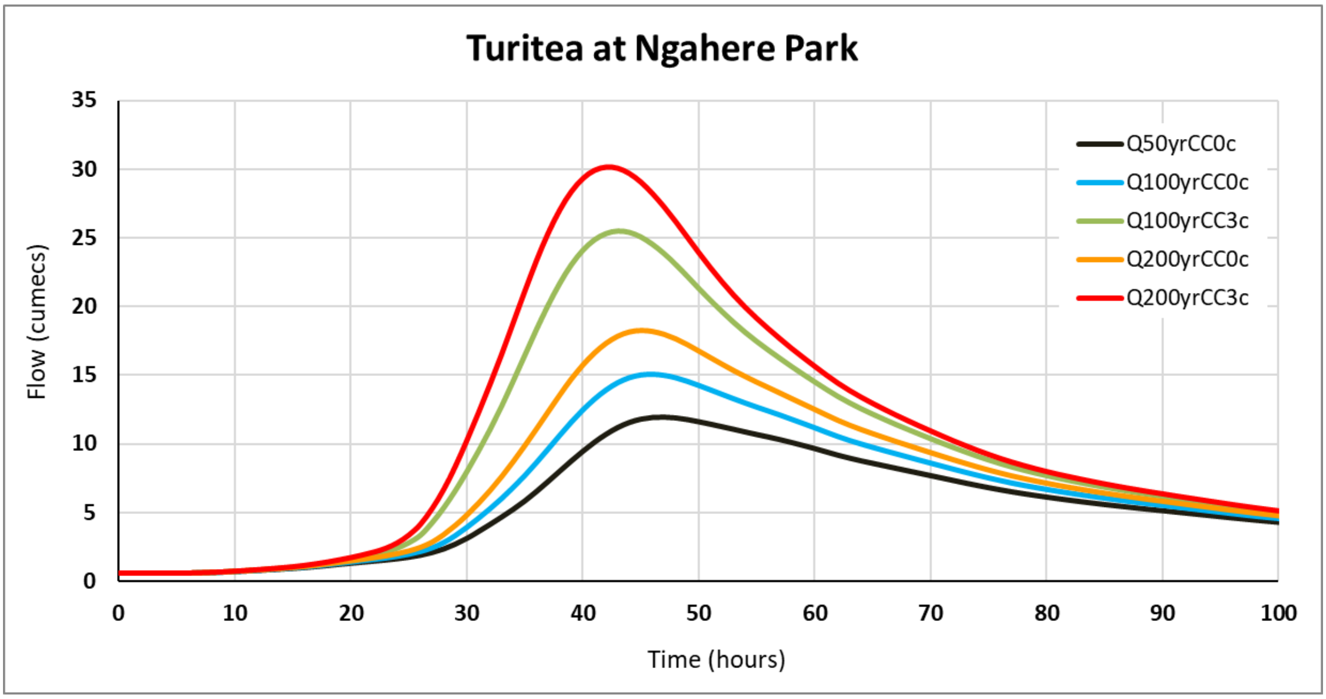

Sluggish Drain
Flow (cumecs)
Time (hours)
0
10
20
30
40
50
60
0
10
20
30
40
50
60
70
80
90
100
Q50yrCC0c
Q100yrCC0c
Q100yrCC3c
Q200yrCC0c
Q200yrCC3c


Taonoui at Rangitikei Line
Flow (cumecs)
Time (hours)
Q50yrCC0c
Q100yrCC0c
Q100yrCC3c
Q200yrCC0c
Q200yrCC3c
0
0.5
1
1.5
2
2.5
0
10
20
30
40
50
60
70
80
90
100

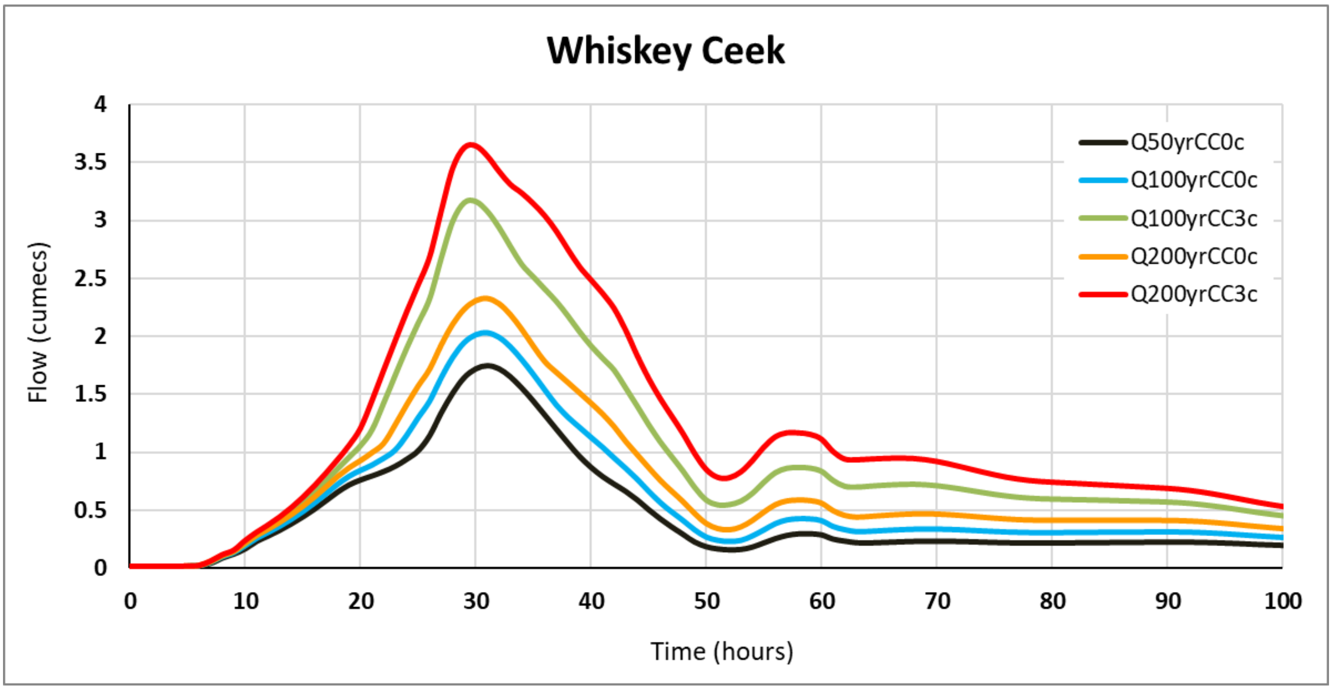

Tokomaru at Manawatu
Flow (cumecs)
Time (hours)
Q50yrCC0c
Q100yrCC0c
Q100yrCC3c
Q200yrCC0c
Q200yrCC3c
0
50
100
150
200
250
0
10
20
30
40
50
60
70
80
90
100


Tokomaru Quarry
Flow (cumecs)
Time (hours)
0
10
20
30
40
50
60
70
80
0
10
20
30
40
50
60
70
80
90
100
Q50yrCC0c
Q100yrCC0c
Q100yrCC3c
Q200yrCC0c
Q200yrCC3c


Turitea at Manawatu
Flow (cumecs)
Time (hours)
0
5
10
15
20
25
30
35
40
0
10
20
30
40
50
60
70
80
90
100
Q50yrCC0c
Q100yrCC0c
Q100yrCC3c
Q200yrCC0c
Q200yrCC3c

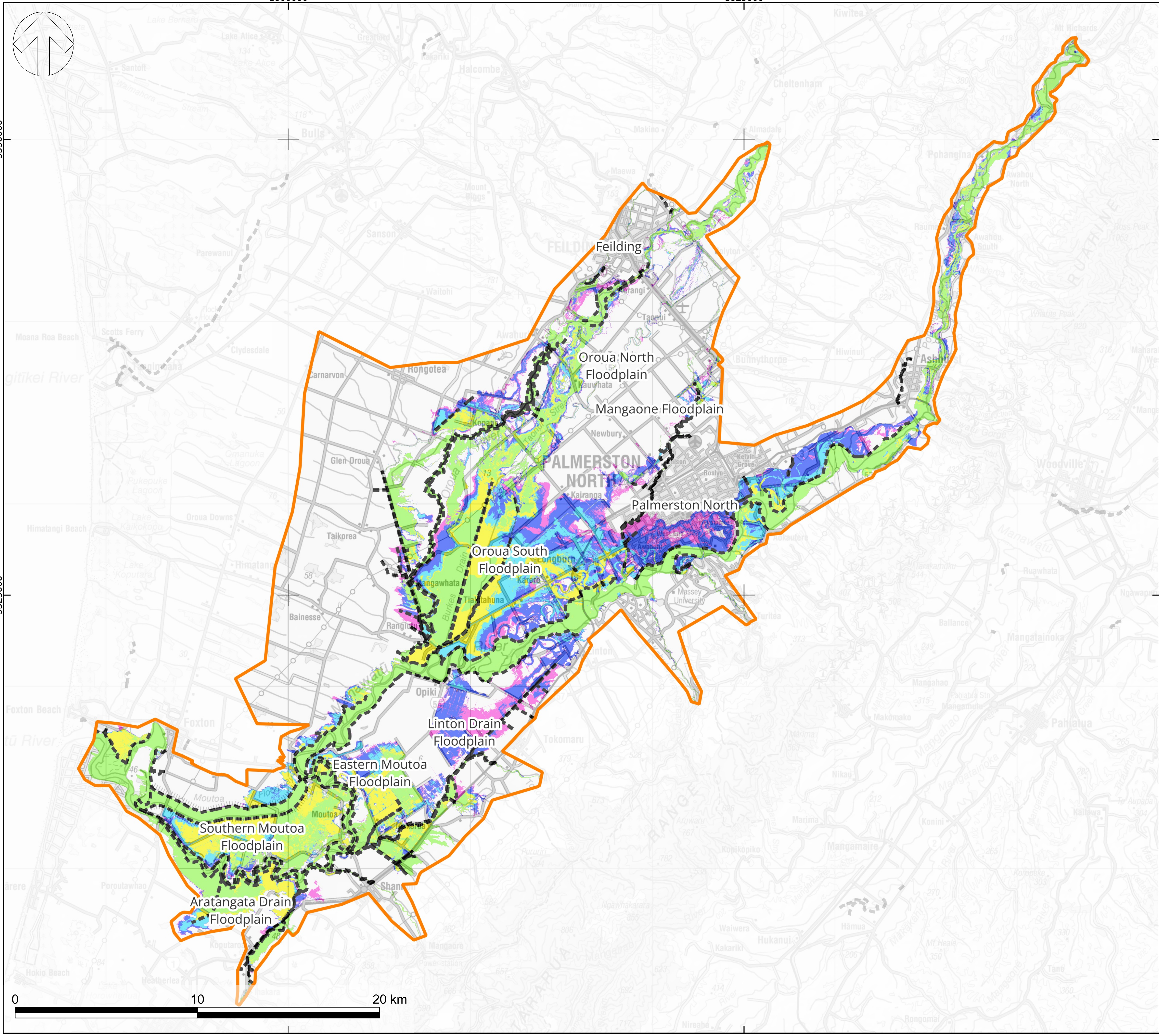


Turitea at Ngahere Park
Flow (cumecs)
Time (hours)
0
5
10
15
20
25
30
35
0
10
20
30
40
50
60
70
80
90
100
Q50yrCC0c
Q100yrCC0c
Q100yrCC3c
Q200yrCC0c
Q200yrCC3c



Whiskey Ceek
Flow (cumecs)
Time (hours)
0
0.5
1
1.5
2
2.5
3
3.5
4
0
10
20
30
40
50
60
70
80
90
100
Q50yrCC0c
Q100yrCC0c
Q100yrCC3c
Q200yrCC0c
Q200yrCC3c

APPENDIX B FLOOD MAPS



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Key:
- Model Outline
- Horizons Stopbanks
- 50-year CC0c Maximum Flood Extent
- 100-year CC0c Maximum Flood Extent
- 200-year CC0c Maximum Flood Extent
- 100-year CC3c Maximum Flood Extent
- 200-year CC3c Maximum Flood Extent

REV	DATE	BY	DESCRIPTION	CHK	APP
002	17/07/2025	EH	Final Maps	IF	RW
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Appendix B

TITLE:
Full Catchment
Maximum Flood Extents
All Flood Events

DRAWN:	CHECKED:	APPROVED:
EH	IF	RW
PROJECT No: 1-E0118.00	SCALE @A3: 1: 200000	DATE: 23/06/2025

DRAWING No: 1-E0118.00-DRW-1001
REV: 001

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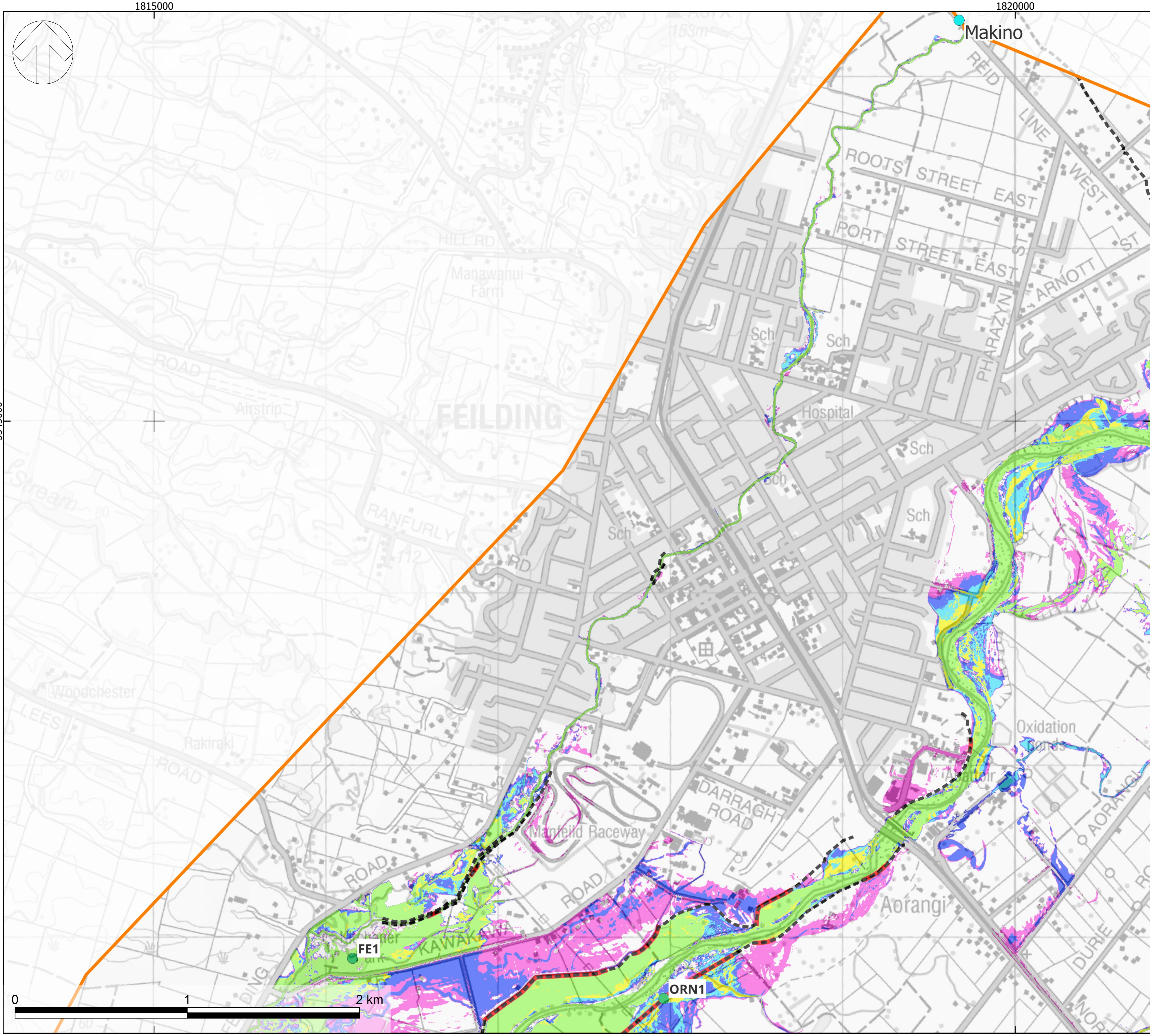

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Key:
- Model Outline
- Horizons Stopbanks
- Watercourse Upstream Inflows
- Flood Observation Locations
- Main Stopbank Overtopping Locations - 200yrCC3c
- 50-year CC0c Maximum Flood Extent
- 100-year CC0c Maximum Flood Extent
- 200-year CC0c Maximum Flood Extent
- 100-year CC3c Maximum Flood Extent
- 200-year CC3c Maximum Flood Extent

REV	DATE	BY	DESCRIPTION	CHK	APP
002	17/07/2025	EH	Final Maps	IF	RW
001	23/06/2025	EH	Issued Draft Version 001	IF	RW

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Appendix B

TITLE:
Feilding
Maximum Flood Extents
All Flood Events

DRAWN:	CHECKED:	APPROVED:
EH	IF	RW
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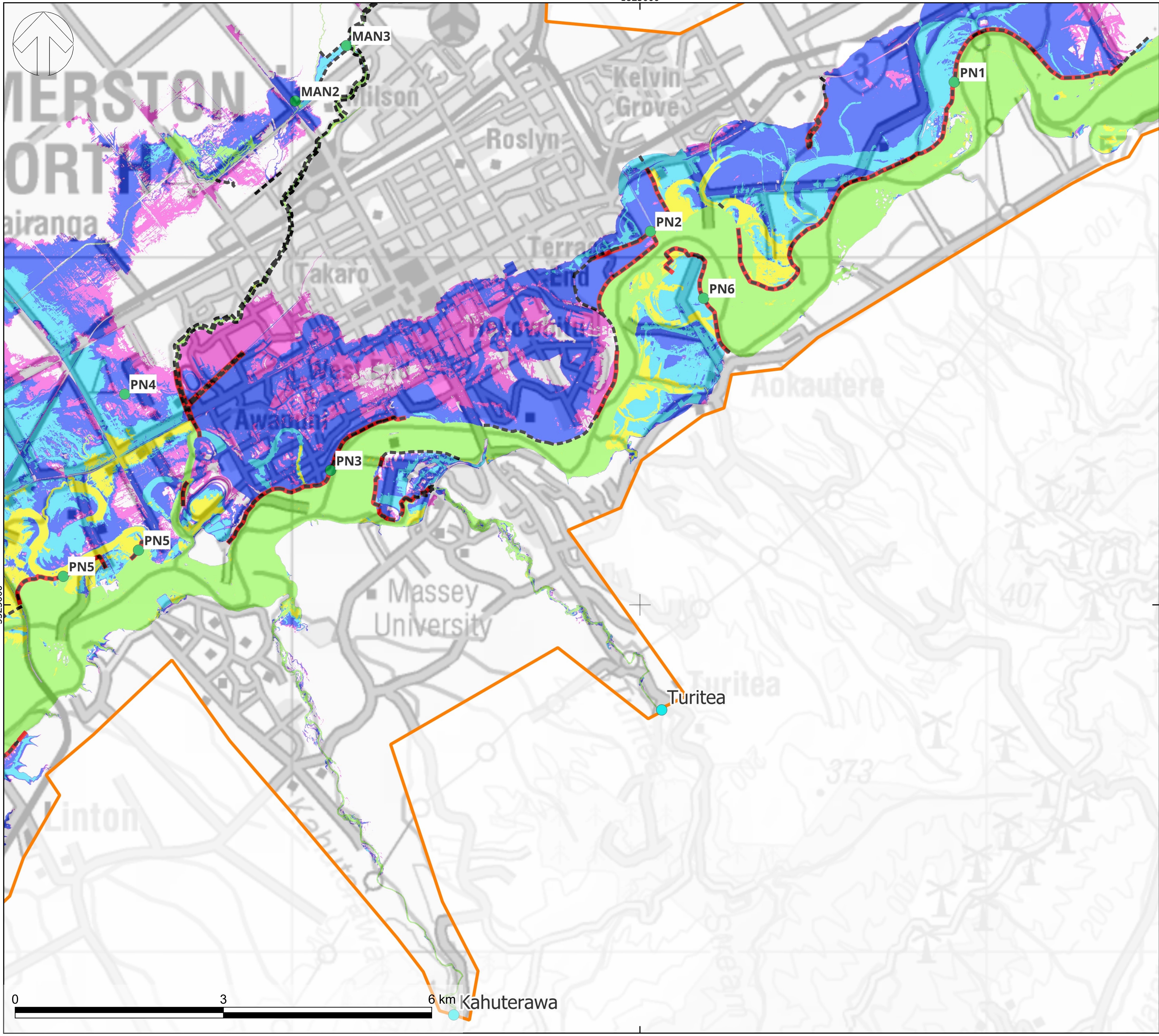
DRAWING No: 1-E0118.00-DRW-1002

REV: 001



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Key:
- Model Outline
- Horizons Stopbanks
- Watercourse Upstream Inflows
- Flood Observation Locations
- Main Stopbank Overtopping Locations - 200yrCC3c
- 50-year CC0c Maximum Flood Extent
- 100-year CC0c Maximum Flood Extent
- 200-year CC0c Maximum Flood Extent
- 100-year CC3c Maximum Flood Extent
- 200-year CC3c Maximum Flood Extent

REV	DATE	BY	DESCRIPTION	CHK	APP
002	17/07/2025	EH	Final Maps	IF	RW
001	23/06/2025	EH	Issued Draft Version 001	IF	RW

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Appendix B

TITLE:
Palmerston North
Maximum Flood Extents
All Flood Events

DRAWN:	CHECKED:	APPROVED:
EH	IF	RW
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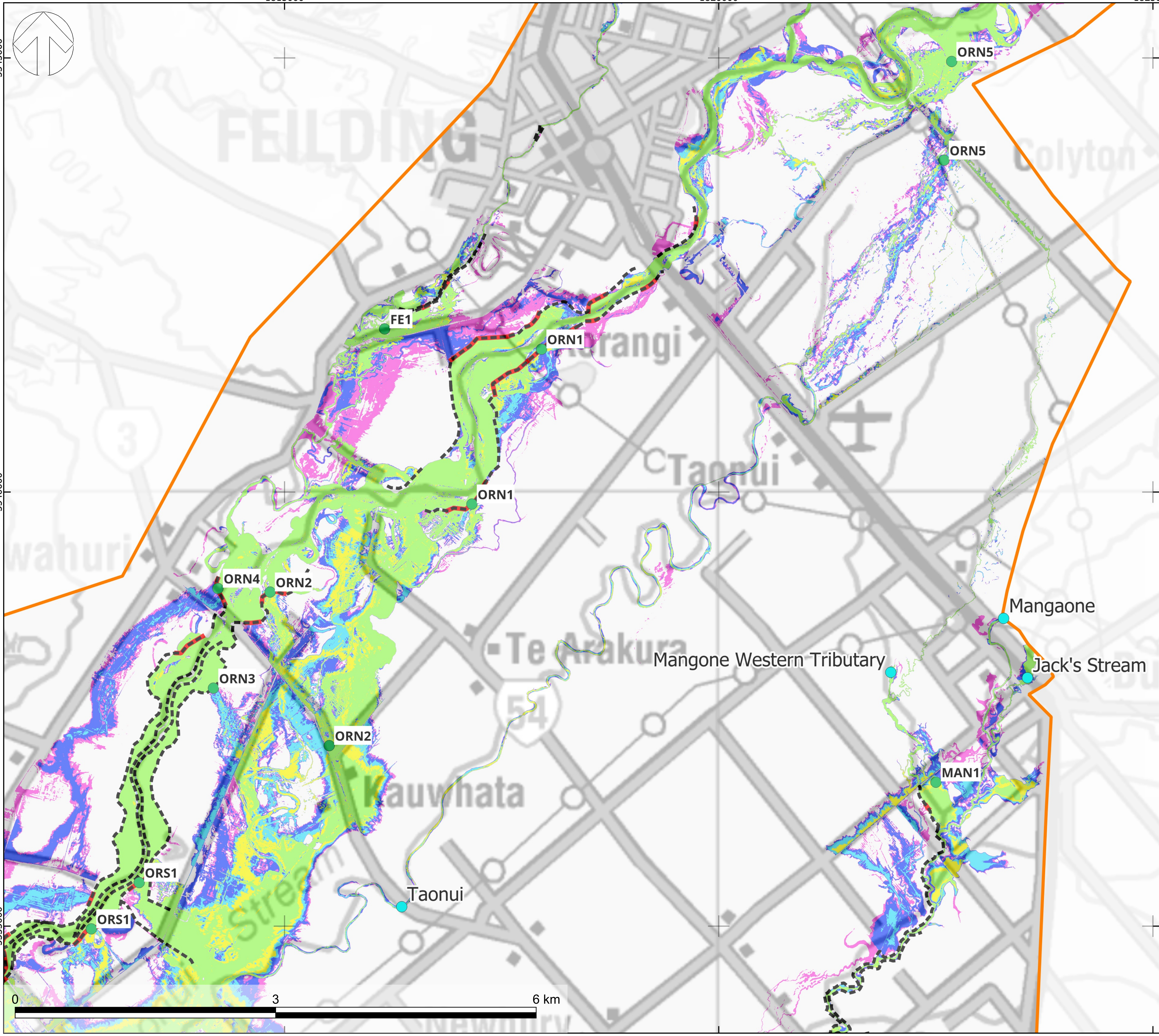
DRAWING No: 1-E0118.00-DRW-1003
REV: 001



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Key:
- Model Outline
- Horizons Stopbanks
- Watercourse Upstream Inflows
- Flood Observation Locations
- Main Stopbank Overtopping Locations - 200yrCC3c
- 50-year CC0c Maximum Flood Extent
- 100-year CC0c Maximum Flood Extent
- 200-year CC0c Maximum Flood Extent
- 100-year CC3c Maximum Flood Extent
- 200-year CC3c Maximum Flood Extent

REV	DATE	BY	DESCRIPTION	CHK	APP
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001	23/06/2025	EH	Issued Draft Version 001	IF	RW

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Appendix B

TITLE:
Oroua North
Maximum Flood Extents
All Flood Events

DRAWN:	CHECKED:	APPROVED:
EH	IF	RW
PROJECT No: 1-E0118.00	SCALE @A3: 1: 42000	DATE: 23/06/2025

DRAWING No:	REV:
1-E0118.00-DRW-1004	001

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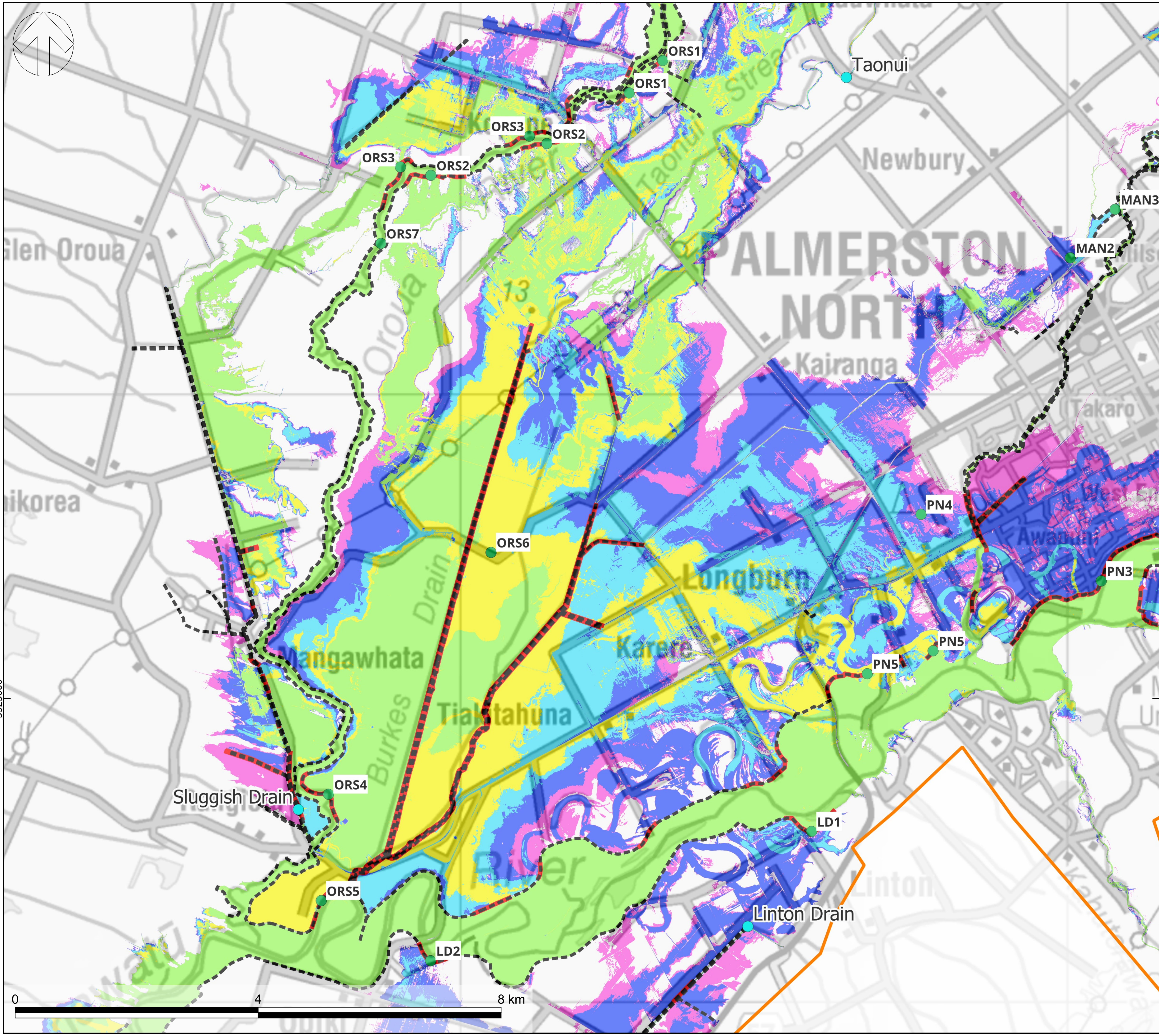

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Key:
- Model Outline
- Horizons Stopbanks
- Watercourse Upstream Inflows
- Flood Observation Locations
- Main Stopbank Overtopping Locations - 200yrCC3c
- 50-year CC0c Maximum Flood Extent
- 100-year CC0c Maximum Flood Extent
- 200-year CC0c Maximum Flood Extent
- 100-year CC3c Maximum Flood Extent
- 200-year CC3c Maximum Flood Extent

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PROJECT:
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Appendix B

TITLE:
Oroua South
Maximum Flood Extents
All Flood Events

DRAWN:	CHECKED:	APPROVED:
EH	IF	RW
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DRAWING No:	REV:
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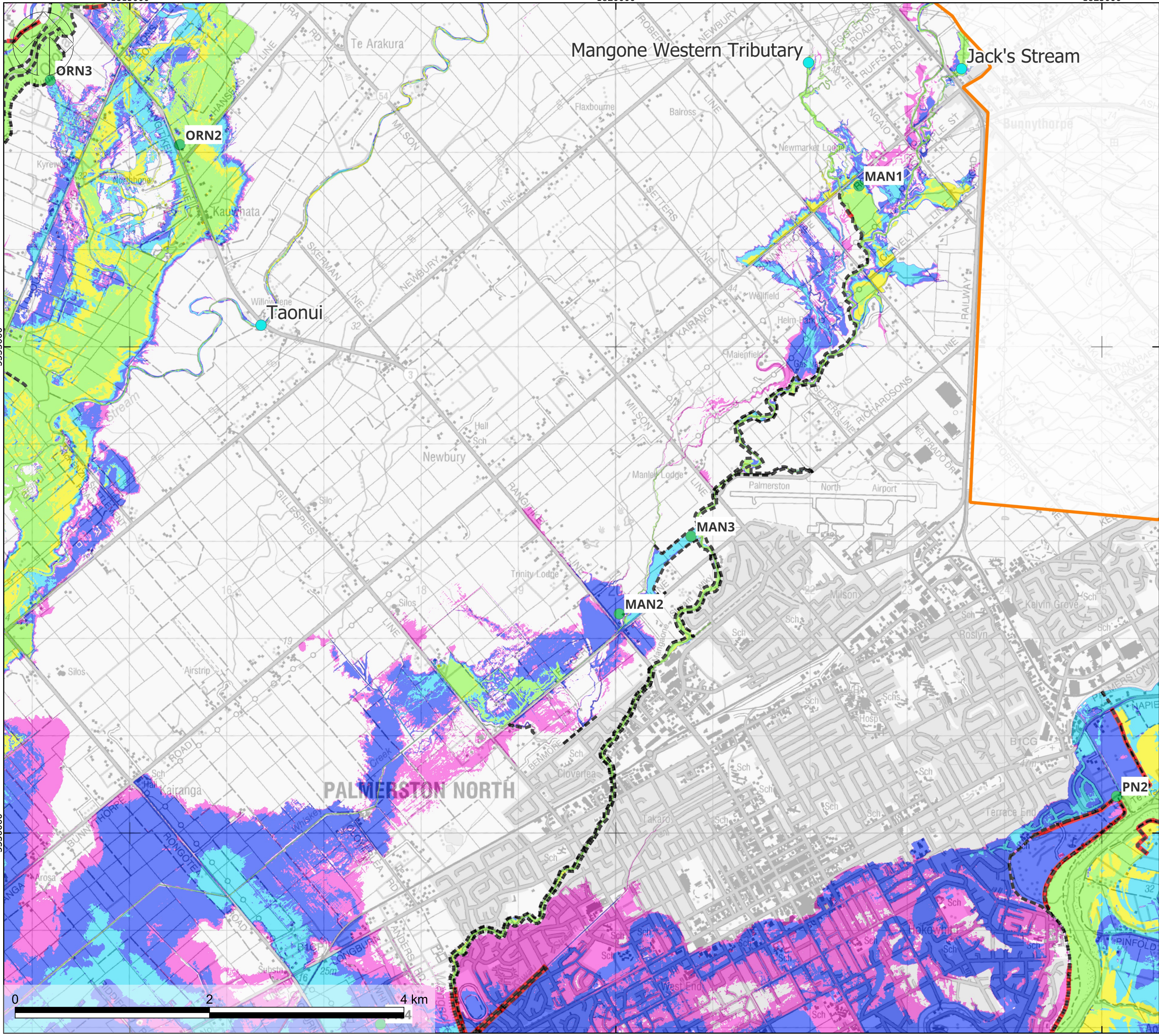

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Key:
- Model Outline
- Horizons Stopbanks
- Watercourse Upstream Inflows
- Flood Observation Locations
- Main Stopbank Overtopping Locations - 200yrCC3c
- 50-year CC0c Maximum Flood Extent
- 100-year CC0c Maximum Flood Extent
- 200-year CC0c Maximum Flood Extent
- 100-year CC3c Maximum Flood Extent
- 200-year CC3c Maximum Flood Extent

REV	DATE	BY	DESCRIPTION	CHK	APP
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001	23/06/2025	EH	Issued Draft Version 001	IF	RW

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Appendix B

TITLE:
Mangaone
Maximum Flood Extents
All Flood Events

DRAWN:	CHECKED:	APPROVED:
EH	IF	RW
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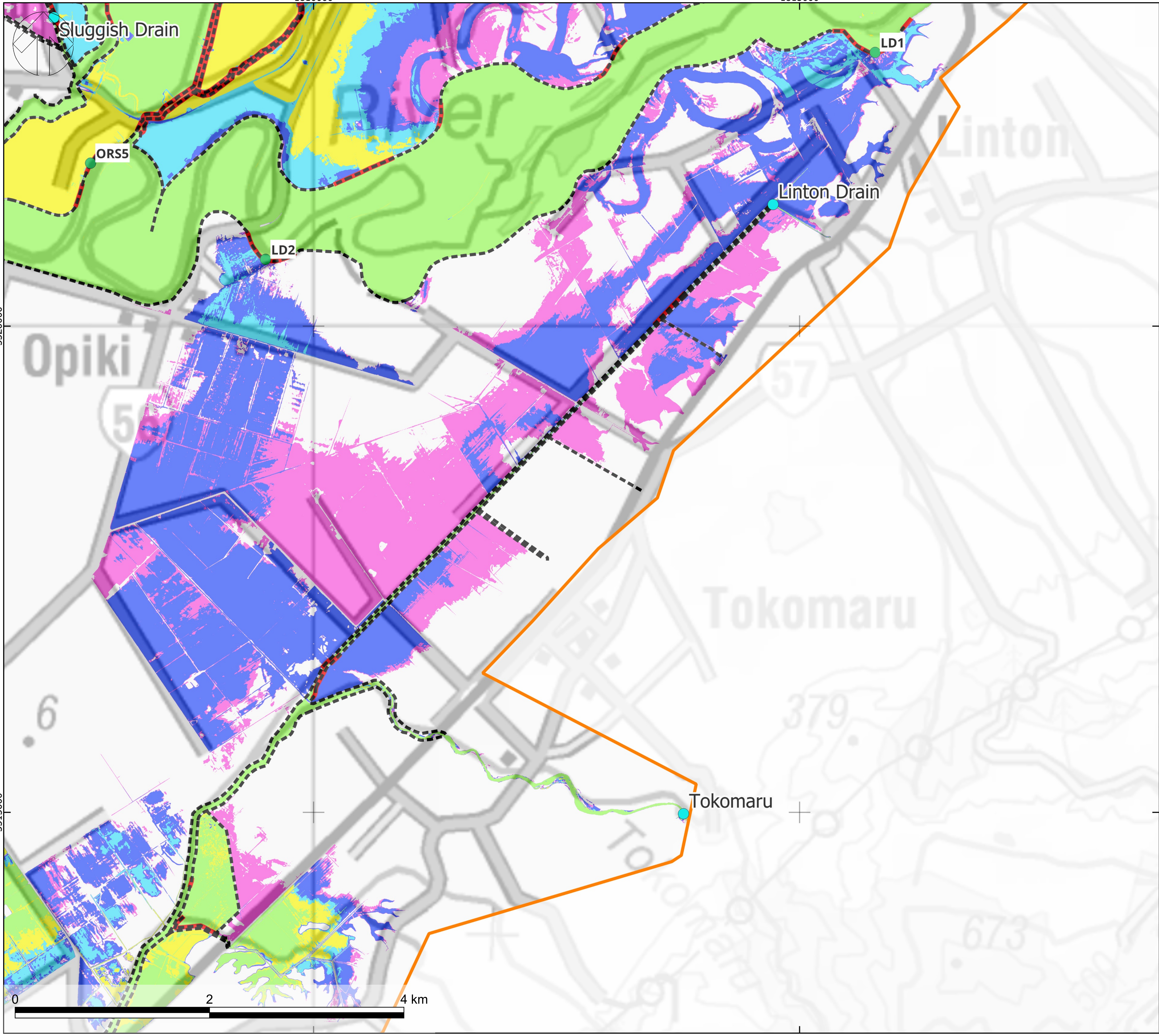
DRAWING No: 1-E0118.00-DRW-1006
REV: 001



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Key:
- Model Outline
- Horizons Stopbanks
- Watercourse Upstream Inflows
- Flood Observation Locations
- Main Stopbank Overtopping Locations - 200yrCC3c
- 50-year CC0c Maximum Flood Extent
- 100-year CC0c Maximum Flood Extent
- 200-year CC0c Maximum Flood Extent
- 100-year CC3c Maximum Flood Extent
- 200-year CC3c Maximum Flood Extent

REV	DATE	BY	DESCRIPTION	CHK	APP
002	17/07/2025	EH	Final Maps	IF	RW
001	23/06/2025	EH	Issued Draft Version 001	IF	RW

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PROJECT:
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Appendix B

TITLE:
Linton Drain
Maximum Flood Extents
All Flood Events

DRAWN:	CHECKED:	APPROVED:
EH	IF	RW
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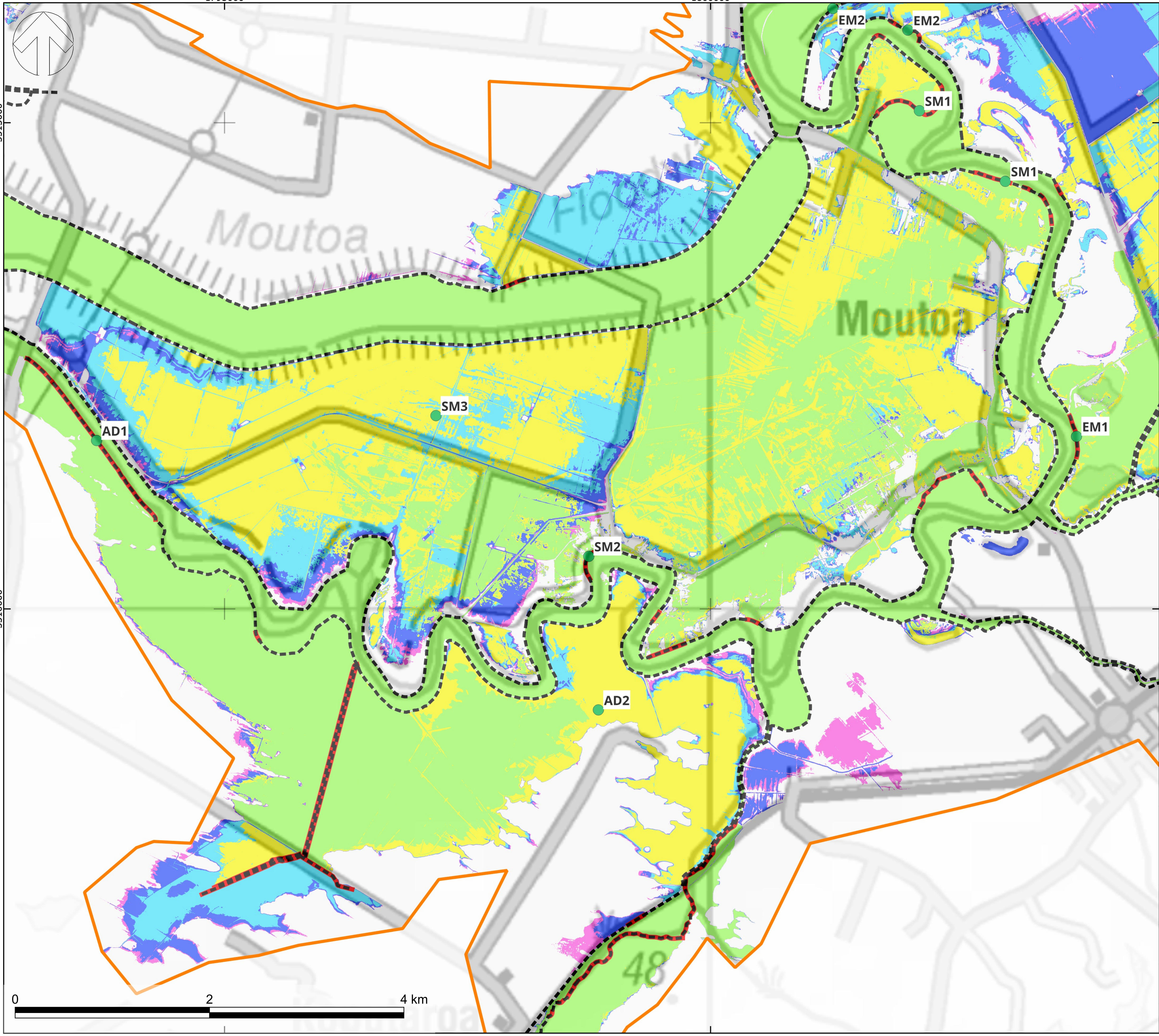
DRAWING No: 1-E0118.00-DRW-1007
REV: 001



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Key:
- Model Outline
- Horizons Stopbanks
- Flood Observation Locations
- Main Stopbank Overtopping Locations - 200yrCC3c
- 50-year CC0c Maximum Flood Extent
- 100-year CC0c Maximum Flood Extent
- 200-year CC0c Maximum Flood Extent
- 100-year CC3c Maximum Flood Extent
- 200-year CC3c Maximum Flood Extent

REV	DATE	BY	DESCRIPTION	CHK	APP
002	17/07/2025	EH	Final Maps	IF	RW
001	23/06/2025	EH	Issued Draft Version 001	IF	RW

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Lower Manawatu Model
Appendix B

TITLE:
Southern Moutoa Floodplain
Maximum Flood Extents
All Flood Events

DRAWN:	CHECKED:	APPROVED:
EH	IF	RW
PROJECT No: 1-E0118.00	SCALE @A3: 1: 37500	DATE: 23/06/2025

DRAWING No: 1-E0118.00-DRW-1008 | REV: 001

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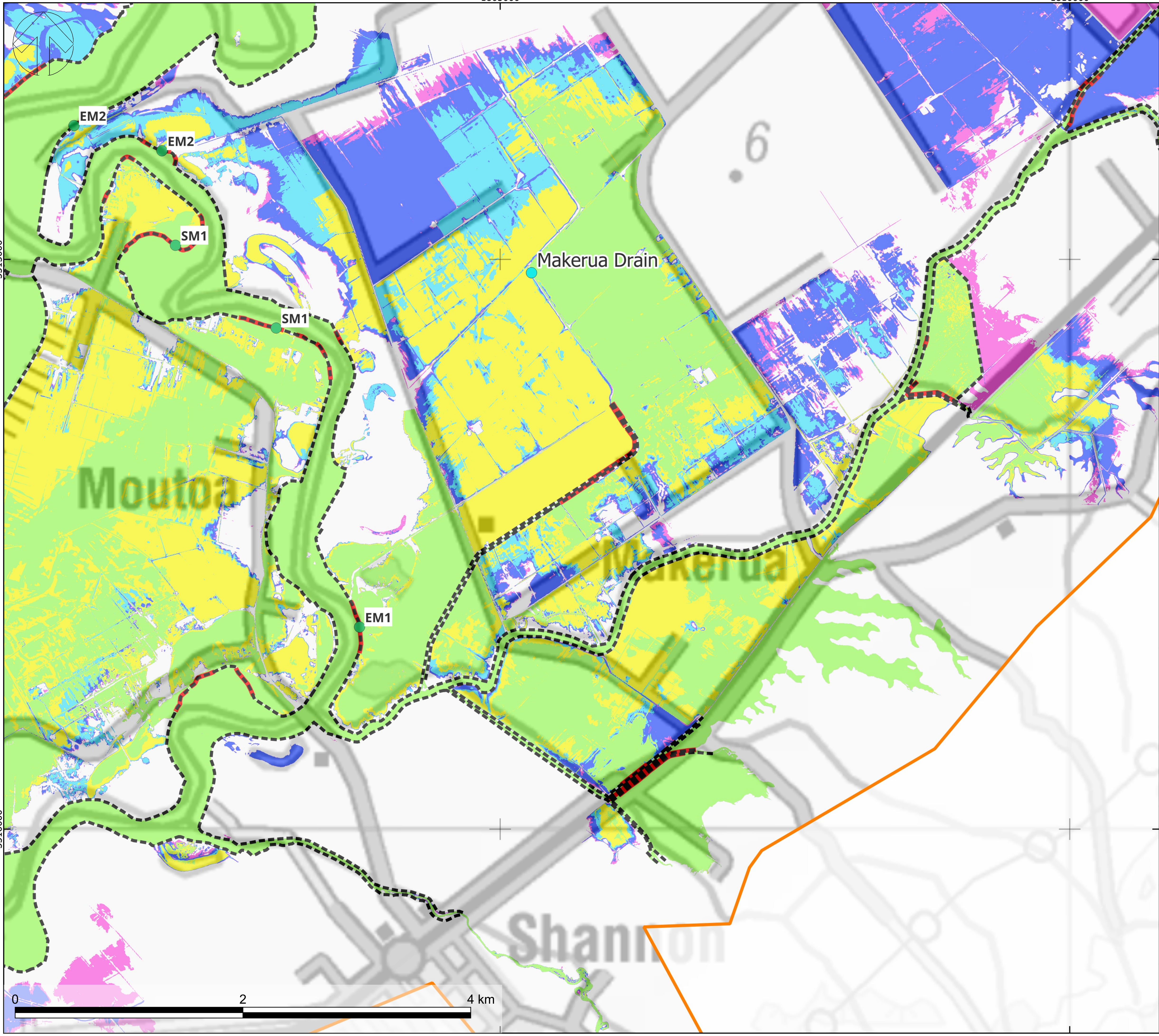

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Key:
- Model Outline
- Horizons Stopbanks
- Watercourse Upstream Inflows
- Flood Observation Locations
- Main Stopbank Overtopping Locations - 200yrCC3c
- 50-year CC0c Maximum Flood Extent
- 100-year CC0c Maximum Flood Extent
- 200-year CC0c Maximum Flood Extent
- 100-year CC3c Maximum Flood Extent
- 200-year CC3c Maximum Flood Extent

REV	DATE	BY	DESCRIPTION	CHK	APP
002	17/07/2025	EH	Final Maps	IF	RW
001	23/06/2025	EH	Issued Draft Version 001	IF	RW

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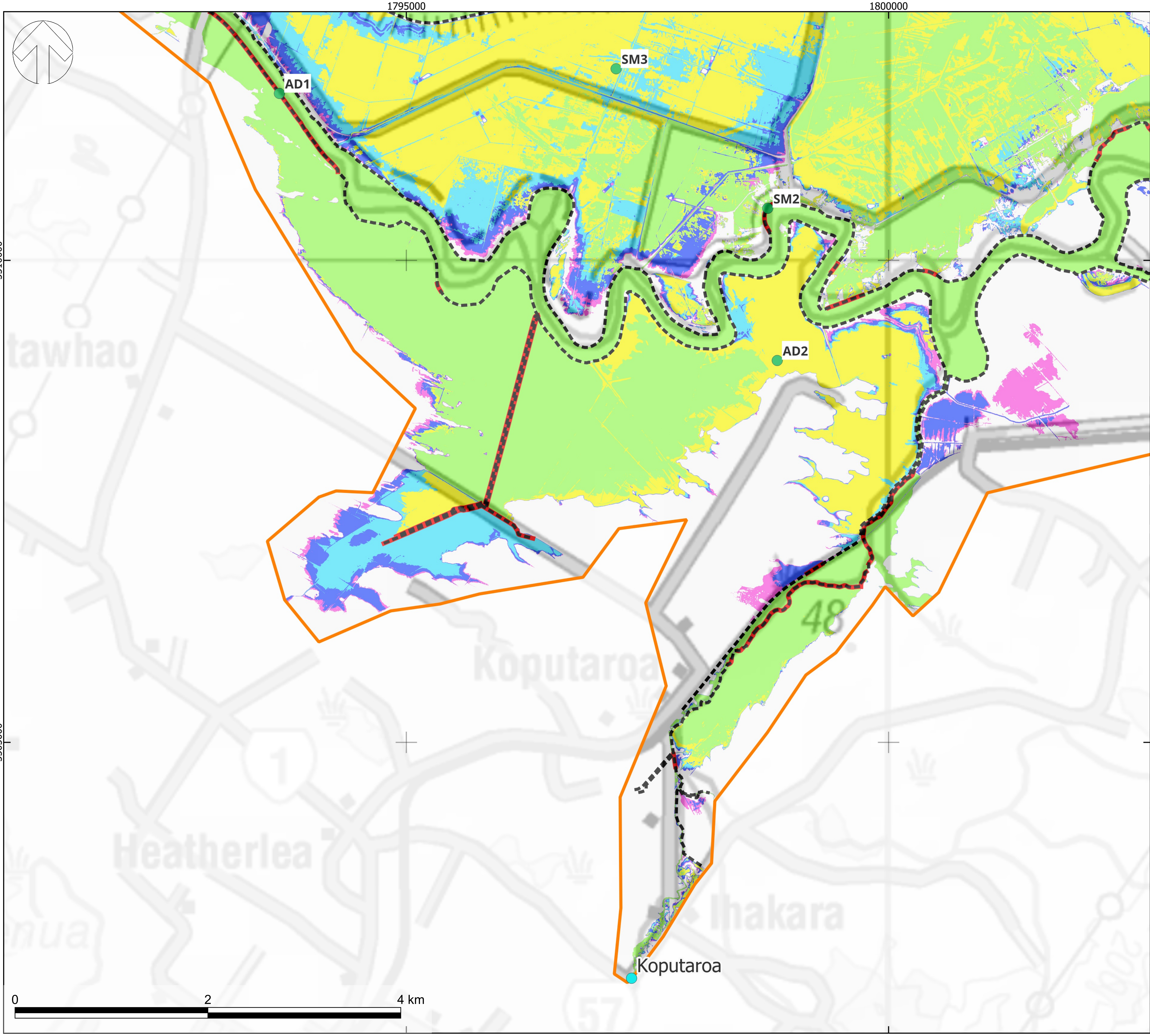
PROJECT: Lower Manawatu Model Appendix B

TITLE: Eastern Moutoa Floodplain Maximum Flood Extents All Flood Events

DRAWN:	CHECKED:	APPROVED:
EH	IF	RW
PROJECT No: 1-E0118.00	SCALE @A3: 1: 32000	DATE: 23/06/2025

DRAWING No: 1-E0118.00-DRW-1009 | REV: 001



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Key:
- Model Outline
- Horizons Stopbanks
- Watercourse Upstream Inflows
- Flood Observation Locations
- Main Stopbank Overtopping Locations - 200yrCC3c
- 50-year CC0c Maximum Flood Extent
- 100-year CC0c Maximum Flood Extent
- 200-year CC0c Maximum Flood Extent
- 100-year CC3c Maximum Flood Extent
- 200-year CC3c Maximum Flood Extent

REV	DATE	BY	DESCRIPTION	CHK	APP
002	17/07/2025	EH	Final Maps	IF	RW
001	23/06/2025	EH	Issued Draft Version 001	IF	RW

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PROJECT:
Lower Manawatu Model
Appendix B

TITLE:
Arantangata Floodplain
Maximum Flood Extents
All Flood Events

DRAWN:	CHECKED:	APPROVED:
EH	IF	RW
PROJECT No: 1-E0118.00	SCALE @A3: 1: 37500	DATE: 23/06/2025

DRAWING No: 1-E0118.00-DRW-1010
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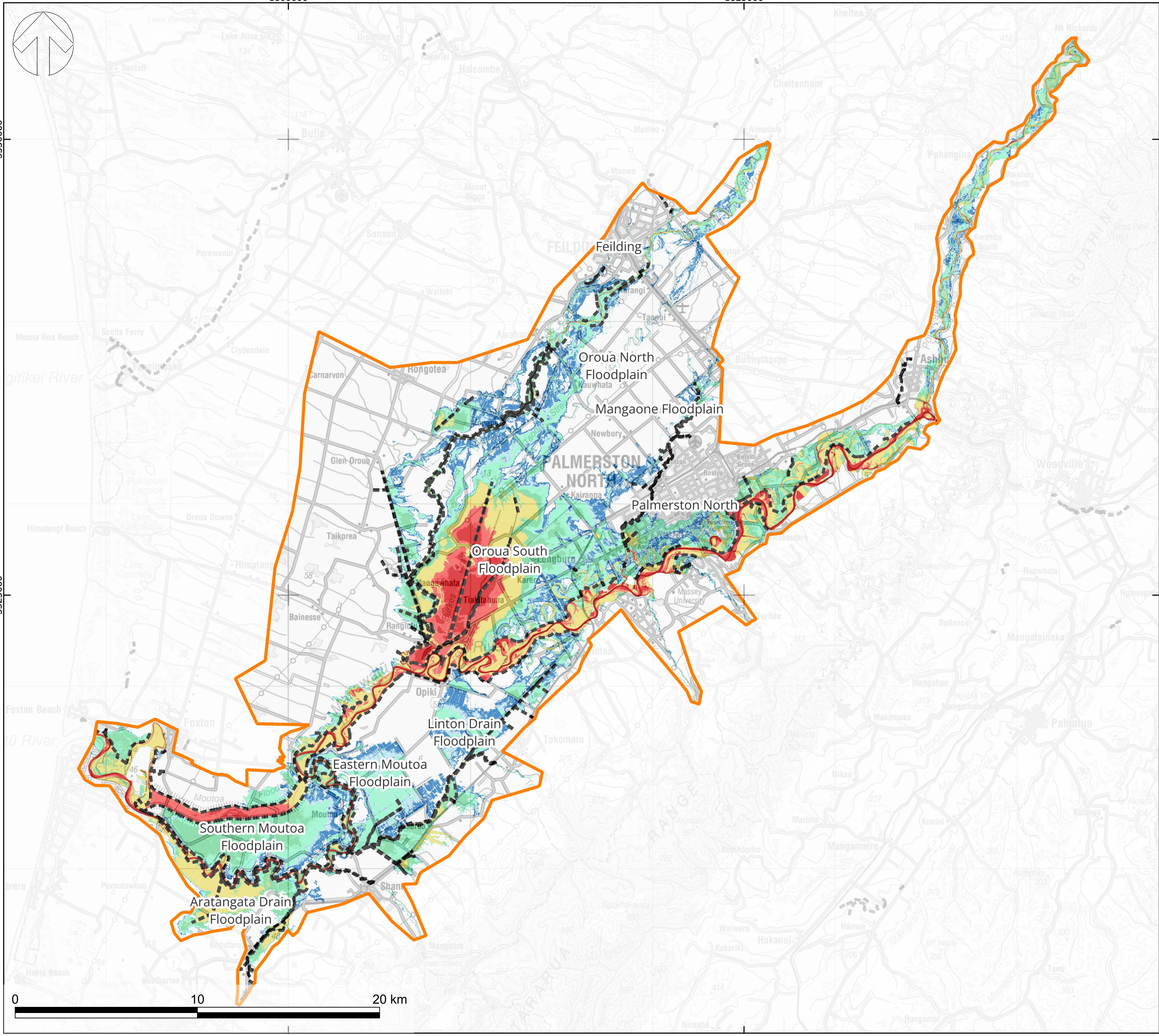

Key:
- Model Outline
- Horizons Stopbanks

Hazard + Maximum Flood Depth (m)
- H1 <= 0.3
- H2 0.3 - 0.5
- H3 0.5 - 1.2
- H4 1.2 - 2.0
- H5 2.0 - 4.0
- H6 4.0 - 5.0
- H6+ > 5.0

REV	DATE	BY	DESCRIPTION	CHK	APP
001	17/07/2025	EH	Issued Draft Version 001	IF	RW

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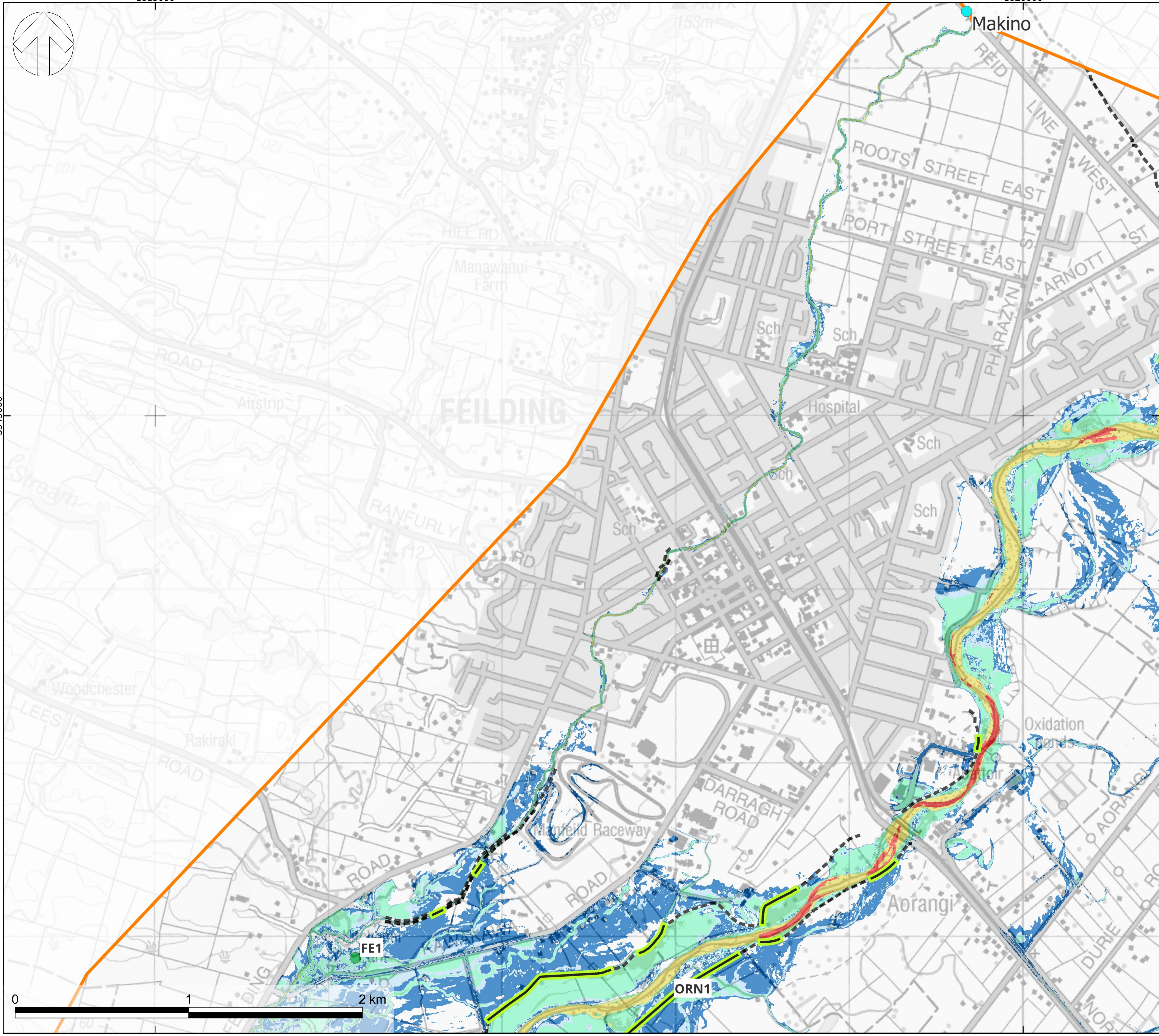
PROJECT: Lower Manawatu Model Appendix B

TITLE: Full Catchment Maximum Flood Depths 200yr plus 3-degree warming

DRAWN:	CHECKED:	APPROVED:
EH	IF	RW
PROJECT No: 1-E0118.00	SCALE @A3: 1: 200000	DATE: 17/07/2025

DRAWING No: 1-E0118.00-DRW-1101 — REV: 001



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Note:
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Key:

- Model Outline
- Horizons Stopbanks
- Watercourse Upstream Inflows
- Flood Observation Locations
- 200yrCC3c Stopbank Overtopping

Hazard + Maximum Flood Depth (m)

- H1 <= 0.3
- H2 0.3 - 0.5
- H3 0.5 - 1.2
- H4 1.2 - 2.0
- H5 2.0 - 4.0
- H6 4.0 - 5.0
- H6+ > 5.0

REV	DATE	BY	DESCRIPTION	CHK	APP
001	17/07/2025	EH	Issued Draft Version 001	IF	RW

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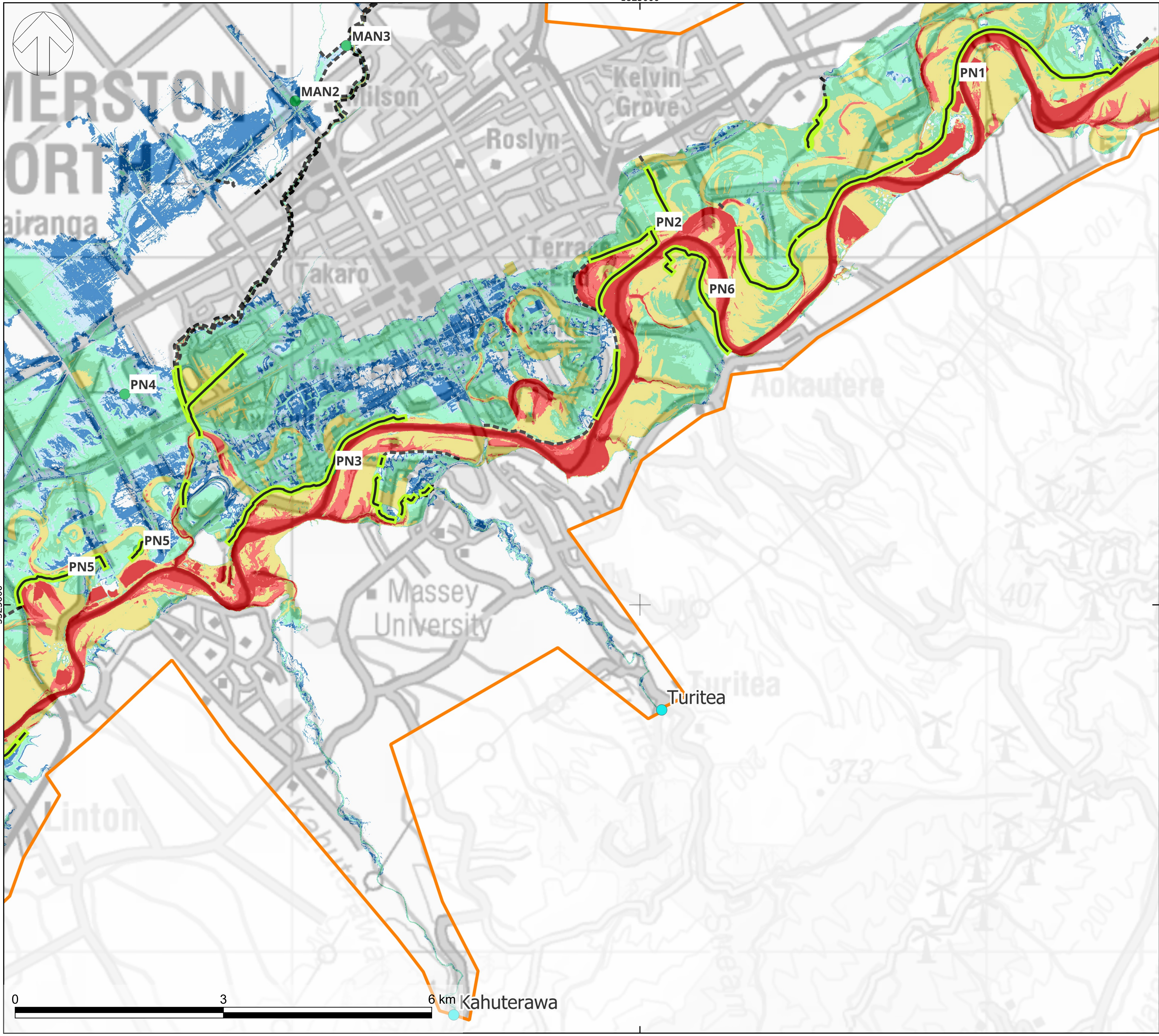
PROJECT: Lower Manawatu Model Appendix B

TITLE: Feilding Maximum Flood Depths 200yr plus 3-degree warming

DRAWN:	CHECKED:	APPROVED:
EH	IF	RW

PROJECT No:	SCALE @A3:	DATE:
1-E0118.00	1: 21000	17/07/2025

DRAWING No:	REV:
1-E0118.00-DRW-1102	001



Key:

- Model Outline
- Horizons Stopbanks
- Watercourse Upstream Inflows
- Flood Observation Locations
- 200yrCC3c Stopbank Overtopping

Hazard + Maximum Flood Depth (m)

- H1 <= 0.3
- H2 0.3 - 0.5
- H3 0.5 - 1.2
- H4 1.2 - 2.0
- H5 2.0 - 4.0
- H6 4.0 - 5.0
- H6+ > 5.0

REV	DATE	BY	DESCRIPTION	CHK	APP
001	17/07/2025	EH	Issued Draft Version 001	IF	RW

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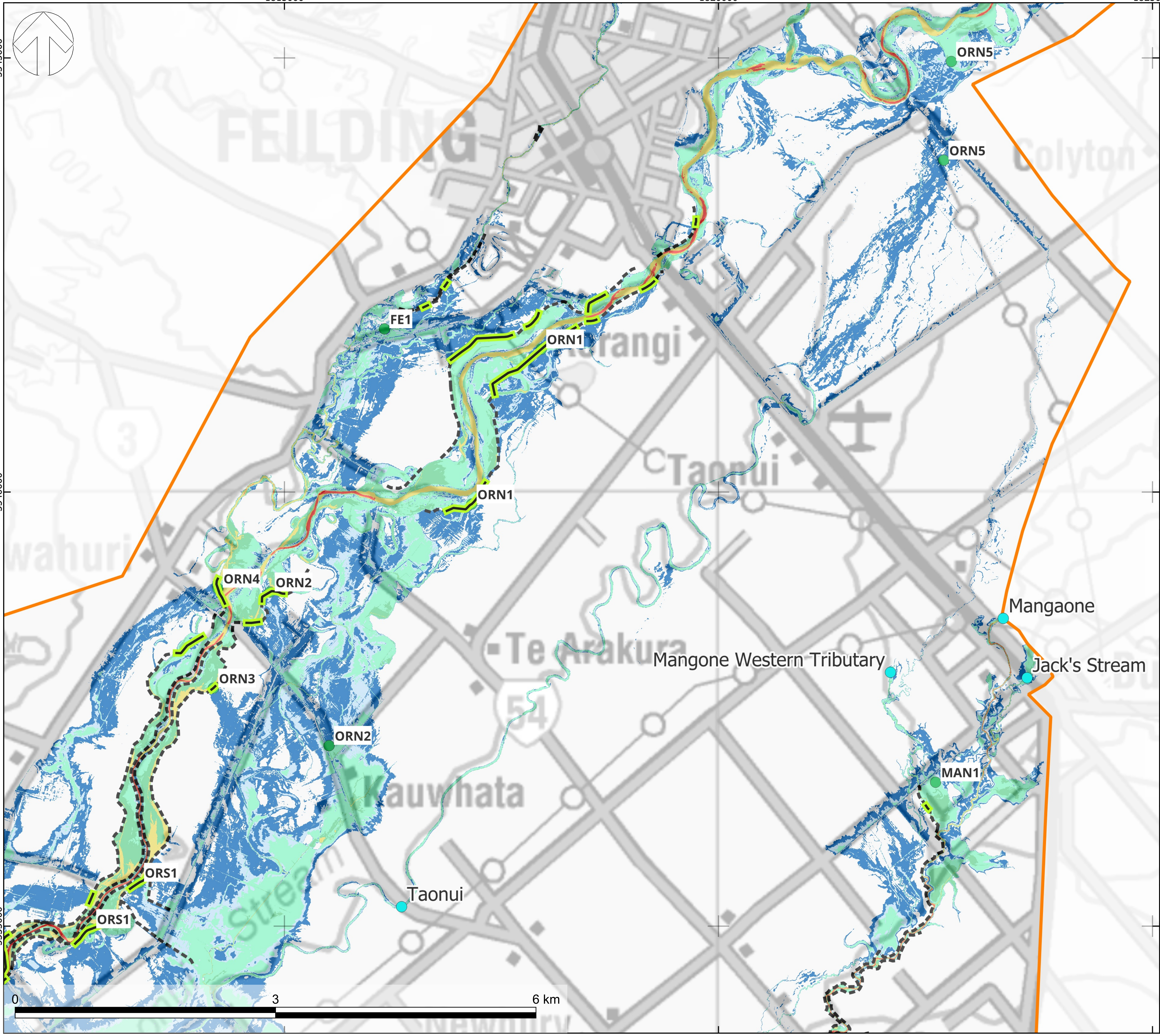
PROJECT:
Lower Manawatu Model
Appendix B

TITLE:
Palmerston North
Maximum Flood Depths
200yr plus 3-degree warming

DRAWN:	CHECKED:	APPROVED:
EH	IF	RW
PROJECT No: 1-E0118.00	SCALE @A3: 1: 52500	DATE: 17/07/2025

DRAWING No: 1-E0118.00-DRW-1103
REV: 001



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Key:
- Model Outline
- Horizons Stopbanks
- Watercourse Upstream Inflows
- Flood Observation Locations
- 200yrCC3c Stopbank Overtopping

Hazard + Maximum Flood Depth (m)
- H1 <= 0.3
- H2 0.3 - 0.5
- H3 0.5 - 1.2
- H4 1.2 - 2.0
- H5 2.0 - 4.0
- H6 4.0 - 5.0
- H6+ > 5.0

REV	DATE	BY	DESCRIPTION	CHK	APP
001	17/07/2025	EH	Issued Draft Version 001	IF	RW

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PROJECT:
Lower Manawatu Model
Appendix B

TITLE:
Oroua North
Maximum Flood Depths
200yr plus 3-degree warming

DRAWN:	CHECKED:	APPROVED:
EH	IF	RW
PROJECT No: 1-E0118.00	SCALE @A3: 1: 42000	DATE: 17/07/2025

DRAWING No: 1-E0118.00-DRW-1104
REV: 001

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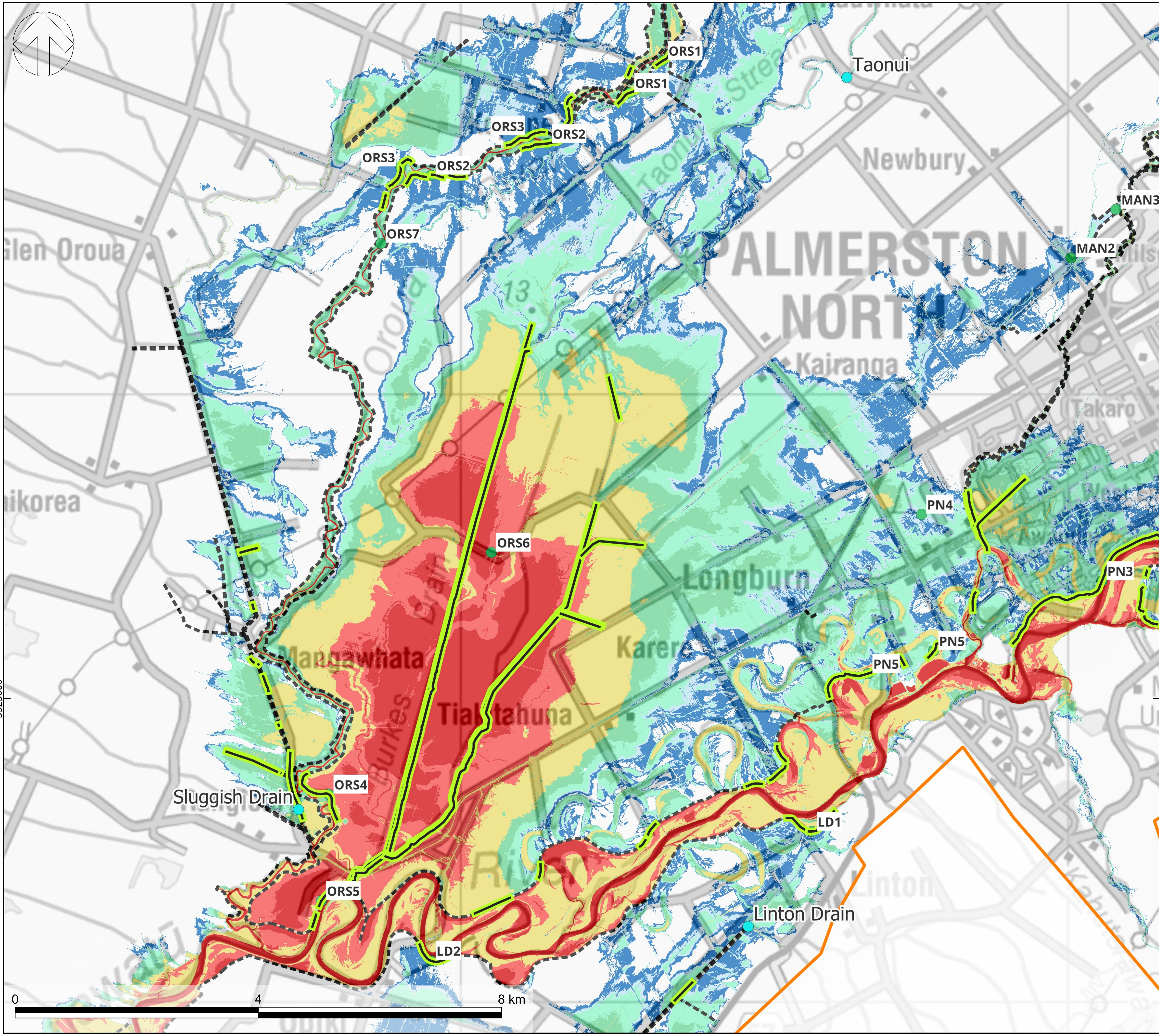

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Key:
- Model Outline
- Horizons Stopbanks
- Watercourse Upstream Inflows
- Flood Observation Locations
- 200yrCC3c Stopbank Overtopping

Hazard + Maximum Flood Depth (m)
- H1 <= 0.3
- H2 0.3 - 0.5
- H3 0.5 - 1.2
- H4 1.2 - 2.0
- H5 2.0 - 4.0
- H6 4.0 - 5.0
- H6+ > 5.0

REV	DATE	BY	DESCRIPTION	CHK	APP
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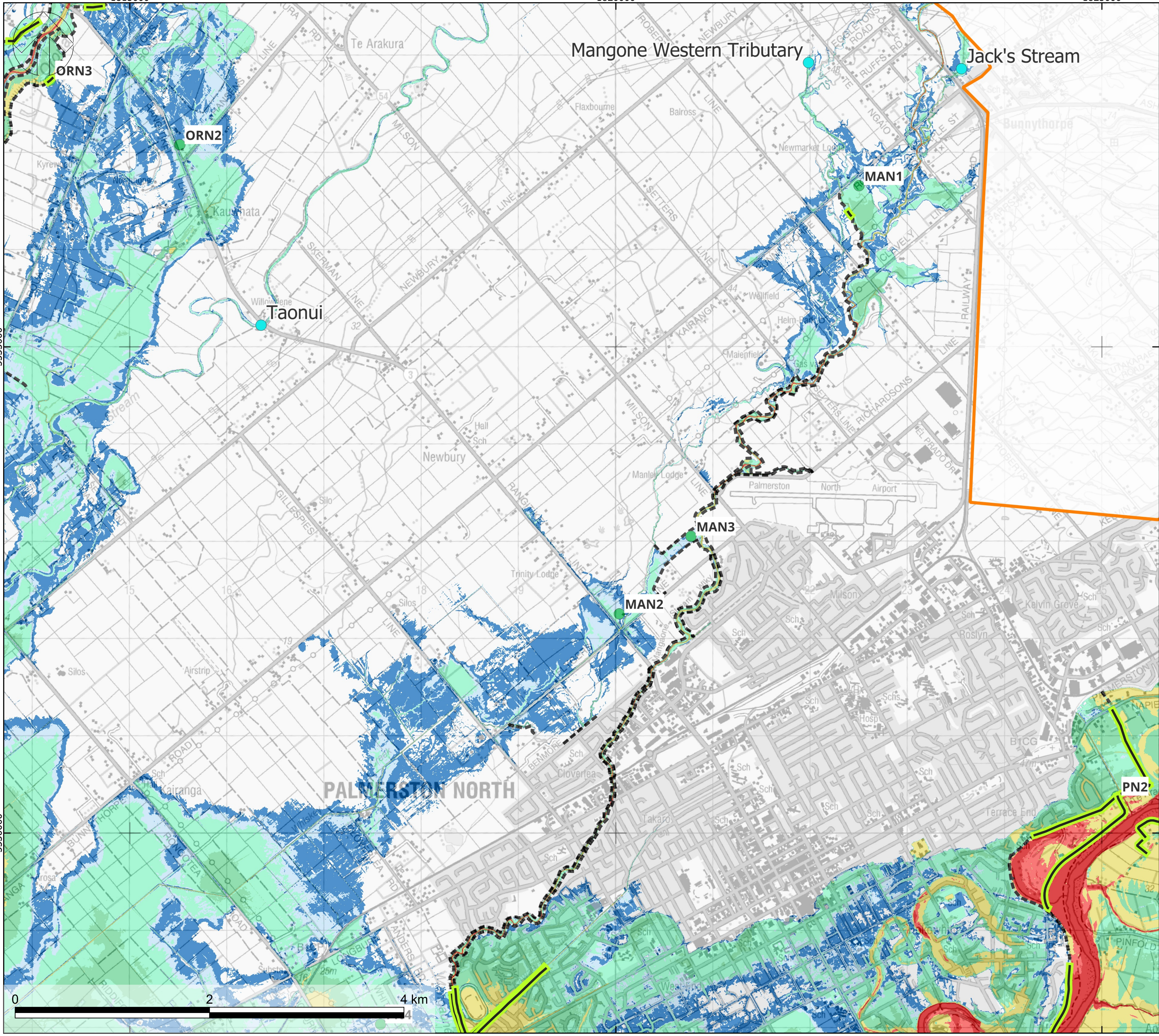
PROJECT:
Lower Manawatu Model
Appendix B

TITLE:
Oroua South
Maximum Flood Depths
200yr plus 3-degree warming

DRAWN:	CHECKED:	APPROVED:
EH	IF	RW
PROJECT No: 1-E0118.00	SCALE @A3: 1: 60000	DATE: 17/07/2025

DRAWING No: 1-E0118.00-DRW-1105
REV: 001



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Key:
- Model Outline
- Horizons Stopbanks
- Watercourse Upstream Inflows
- Flood Observation Locations
- 200yrCC3c Stopbank Overtopping

Hazard + Maximum Flood Depth (m)
- H1 <= 0.3
- H2 0.3 - 0.5
- H3 0.5 - 1.2
- H4 1.2 - 2.0
- H5 2.0 - 4.0
- H6 4.0 - 5.0
- H6+ > 5.0

REV	DATE	BY	DESCRIPTION	CHK	APP
001	17/07/2025	EH	Issued Draft Version 001	IF	RW

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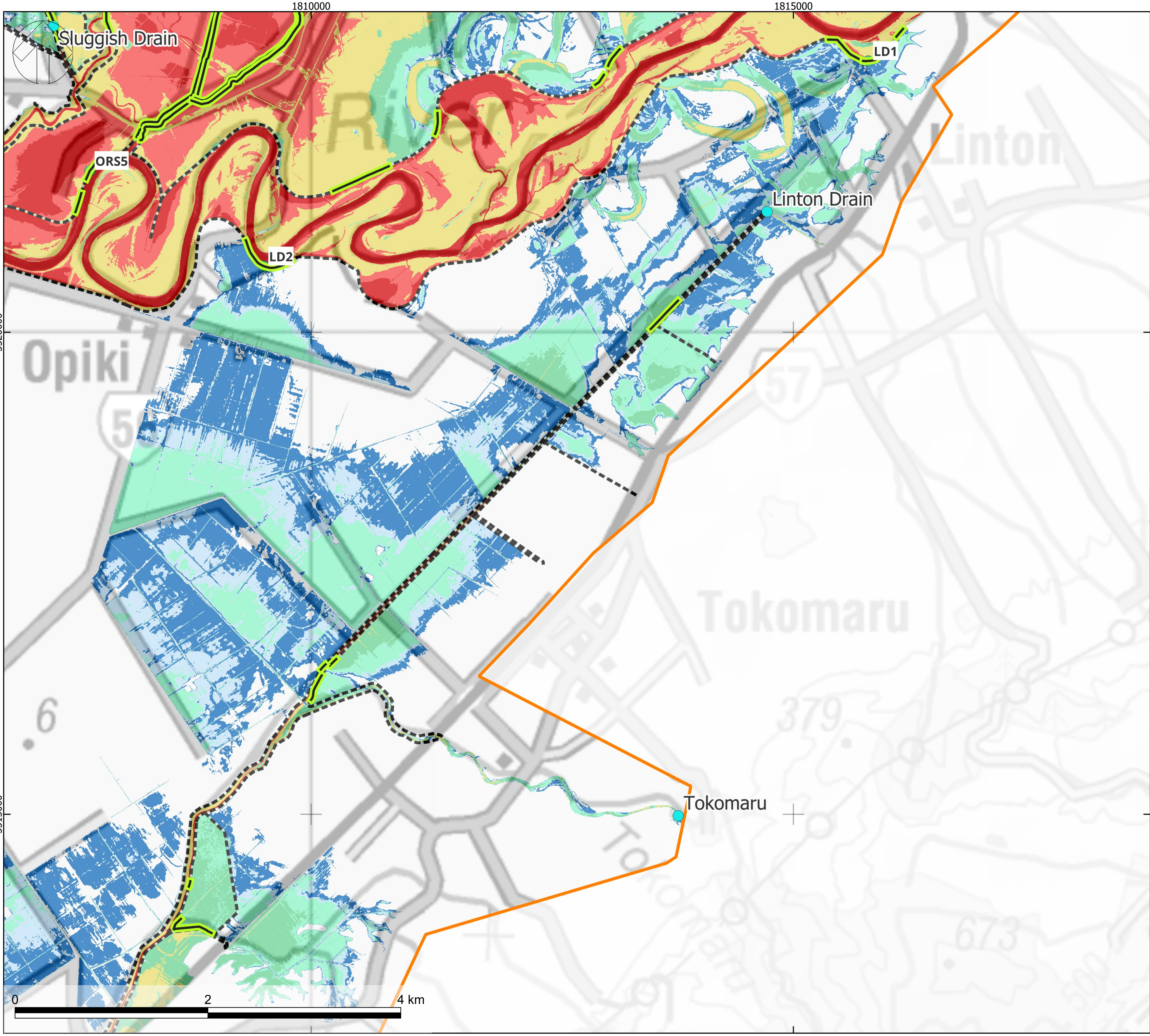
PROJECT:
Lower Manawatu Model
Appendix B

TITLE:
Mangaone
Maximum Flood Depths
200yr plus 3-degree warming

DRAWN:	CHECKED:	APPROVED:
EH	IF	RW
PROJECT No: 1-E0118.00	SCALE @A3: 1: 37500	DATE: 17/07/2025

DRAWING No: 1-E0118.00-DRW-1106
REV: 001



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Key:
- Model Outline
- Horizons Stopbanks
- Watercourse Upstream Inflows
- Flood Observation Locations
- 200yrCC3c Stopbank Overtopping

Hazard + Maximum Flood Depth (m)
- H1 <= 0.3
- H2 0.3 - 0.5
- H3 0.5 - 1.2
- H4 1.2 - 2.0
- H5 2.0 - 4.0
- H6 4.0 - 5.0
- H6+ > 5.0

REV	DATE	BY	DESCRIPTION	CHK	APP
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PROJECT:
Lower Manawatu Model
Appendix B

TITLE:
Linton Drain
Maximum Flood Depths
200yr plus 3-degree warming

DRAWN:	CHECKED:	APPROVED:
EH	IF	RW
PROJECT No: 1-E0118.00	SCALE @A3: 1: 37500	DATE: 17/07/2025

DRAWING No:	REV:
1-E0118.00-DRW-1107	001

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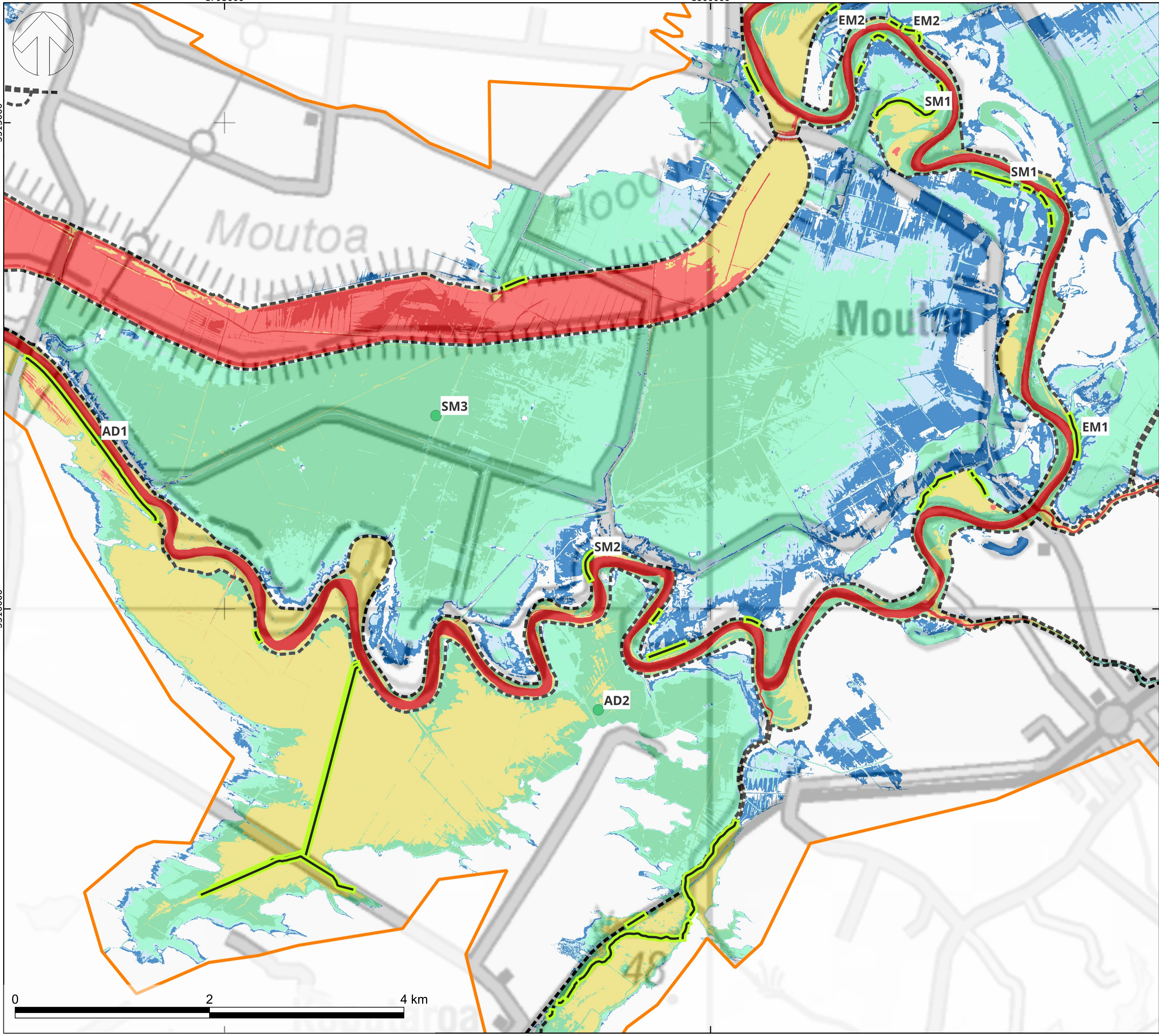

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Key:

- Model Outline
- Horizons Stopbanks
- Flood Observation Locations
- 200yrCC3c Stopbank Overtopping

Hazard + Maximum Flood Depth (m)

- H1 <= 0.3
- H2 0.3 - 0.5
- H3 0.5 - 1.2
- H4 1.2 - 2.0
- H5 2.0 - 4.0
- H6 4.0 - 5.0
- H6+ > 5.0

REV	DATE	BY	DESCRIPTION	CHK	APP
001	17/07/2025	EH	Issued Draft Version 001	IF	RW

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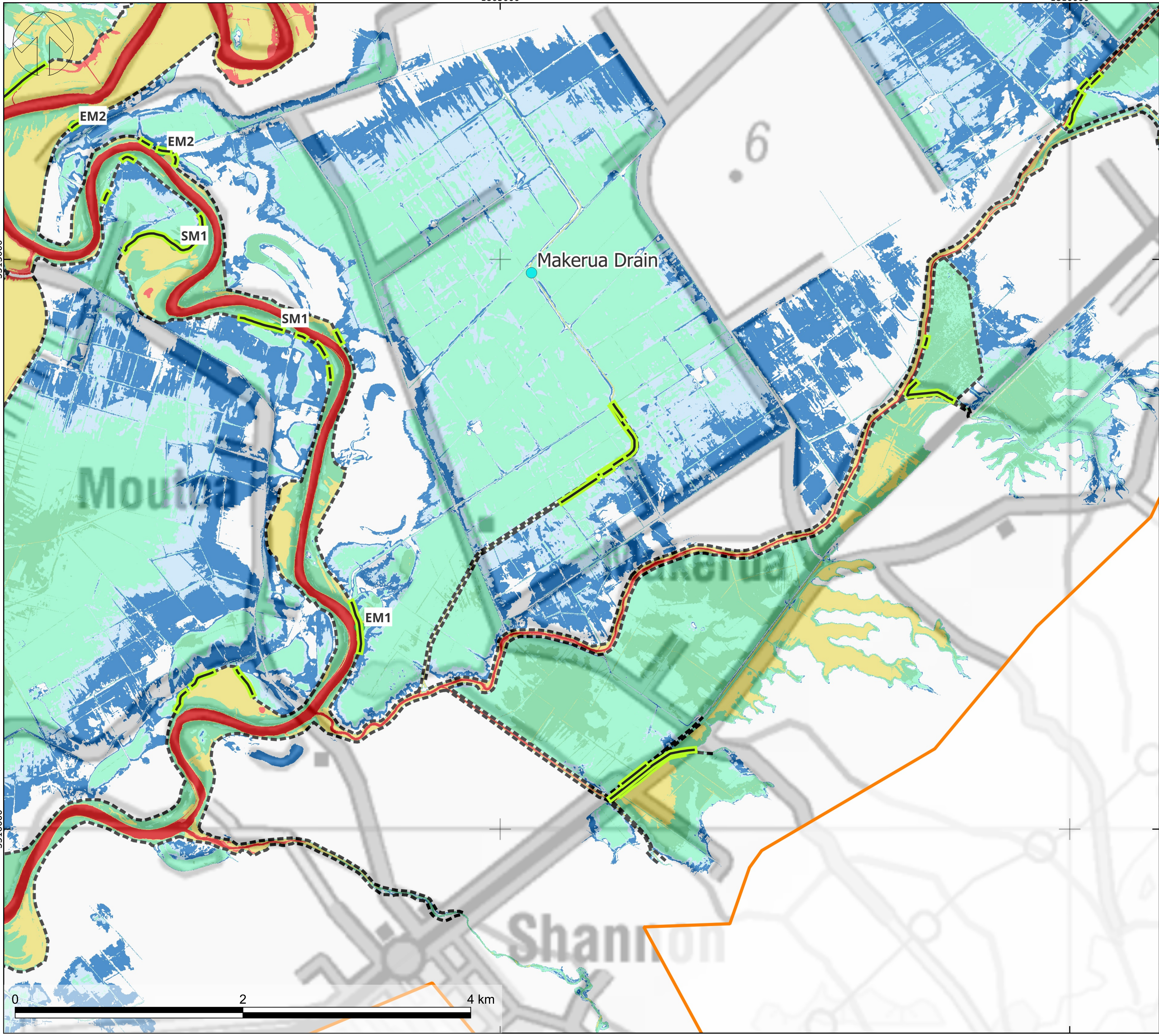
PROJECT: Lower Manawatu Model Appendix B

TITLE: Southern Moutoa Floodplain Maximum Flood Depths 200yr plus 3-degree warming

DRAWN:	CHECKED:	APPROVED:
EH	IF	RW
PROJECT No: 1-E0118.00	SCALE @A3: 1: 37500	DATE: 17/07/2025

DRAWING No:	REV:
1-E0118.00-DRW-1108	001



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Note:
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Key:
- Model Outline
- Horizons Stopbanks
- Watercourse Upstream Inflows
- Flood Observation Locations
- 200yrCC3c Stopbank Overtopping

Hazard + Maximum Flood Depth (m)
- H1 <= 0.3
- H2 0.3 - 0.5
- H3 0.5 - 1.2
- H4 1.2 - 2.0
- H5 2.0 - 4.0
- H6 4.0 - 5.0
- H6+ > 5.0

REV	DATE	BY	DESCRIPTION	CHK	APP
001	17/07/2025	EH	Issued Draft Version 001	IF	RW

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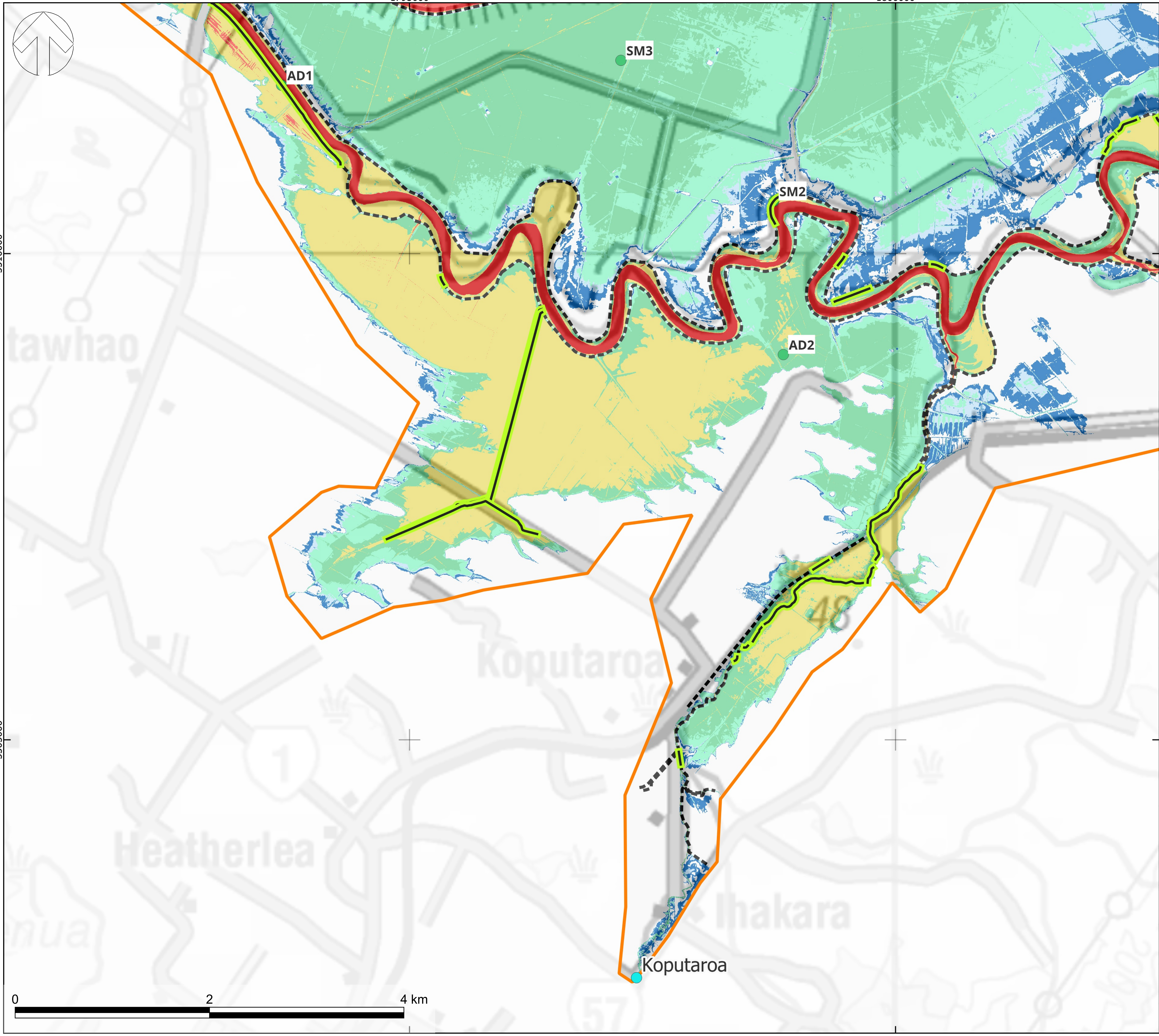
PROJECT: Lower Manawatu Model
Appendix B

TITLE: Eastern Moutoa Floodplain
Maximum Flood Depths
200yr plus 3-degree warming

DRAWN:	CHECKED:	APPROVED:
EH	IF	RW
PROJECT No: 1-E0118.00	SCALE @A3: 1: 32000	DATE: 17/07/2025

DRAWING No: 1-E0118.00-DRW-1109 | REV: 001



Key:
- Model Outline
- Horizons Stopbanks
- Watercourse Upstream Inflows
- Flood Observation Locations
- 200yrCC3c Stopbank Overtopping

Hazard + Maximum Flood Depth (m)
- H1 <= 0.3
- H2 0.3 - 0.5
- H3 0.5 - 1.2
- H4 1.2 - 2.0
- H5 2.0 - 4.0
- H6 4.0 - 5.0
- H6+ > 5.0

REV	DATE	BY	DESCRIPTION	CHK	APP
001	17/07/2025	EH	Issued Draft Version 001	IF	RW

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CLIENT:
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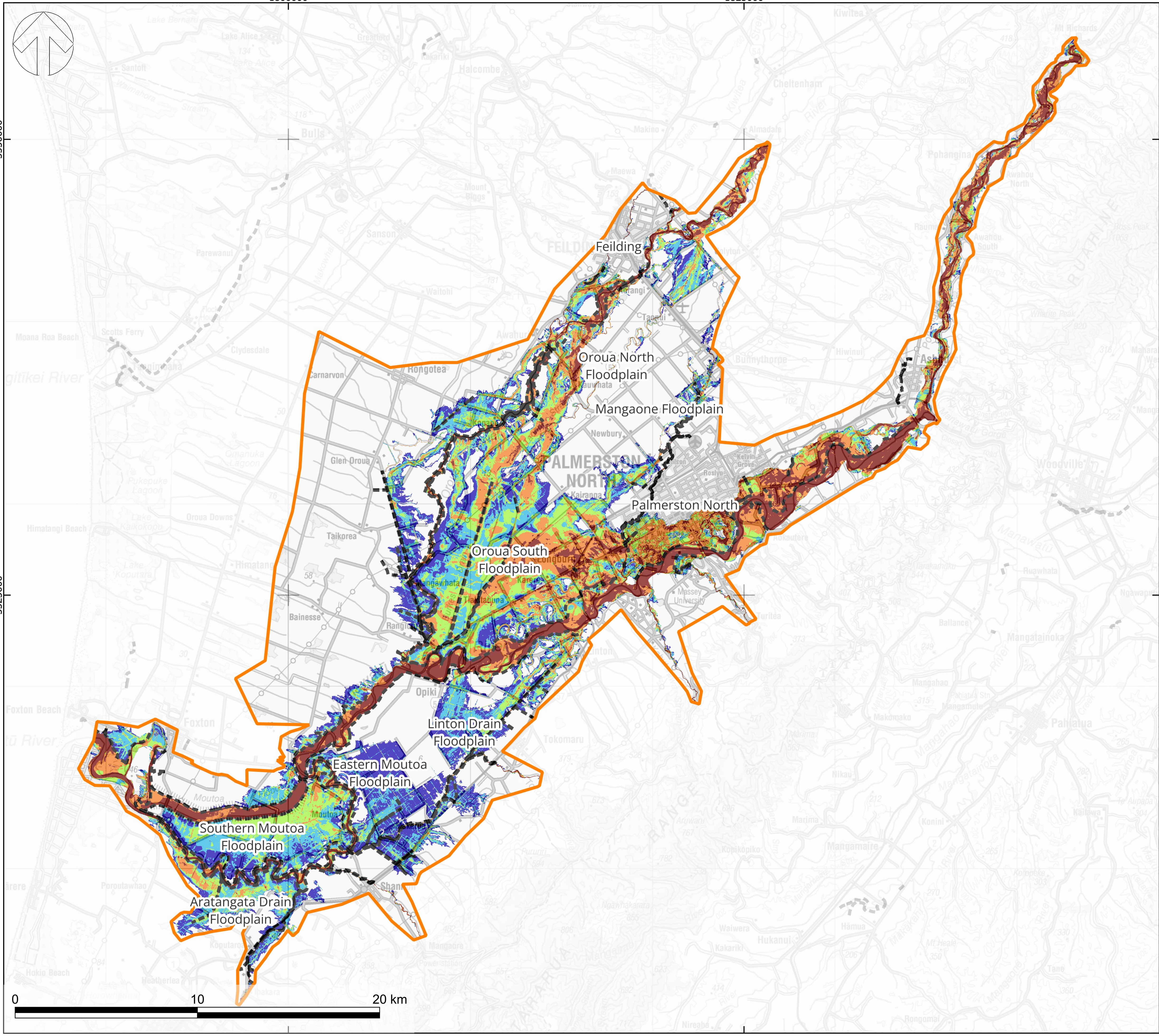
PROJECT:
Lower Manawatu Model
Appendix B

TITLE:
Arantangata Floodplain
Maximum Flood Depths
200yr plus 3-degree warming

DRAWN:	CHECKED:	APPROVED:
EH	IF	RW
PROJECT No: 1-E0118.00	SCALE @A3: 1: 37500	DATE: 17/07/2025

DRAWING No: 1-E0118.00-DRW-1110
REV: 001



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Key:

- Model Outline
- Horizons Stopbanks

Maximum Velocities (m/s)

- <= 0.1
- 0.1 - 0.2
- 0.2 - 0.4
- 0.4 - 0.7
- > 0.7

REV	DATE	BY	DESCRIPTION	CHK	APP
001	17/07/2025	EH	Issued Draft Version 001	IF	RW

DRAWING STATUS: AUTHORISED AND ACCEPTED

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PROJECT: Lower Manawatu Model
Appendix B

TITLE: Full Catchment
Maximum Velocities
200yr plus 3-degree warming

DRAWN:	CHECKED:	APPROVED:
EH	IF	RW
PROJECT No: 1-E0118.00	SCALE @A3: 1: 200000	DATE: 17/07/2025

DRAWING No: 1-E0118.00-DRW-1201 — REV: 001

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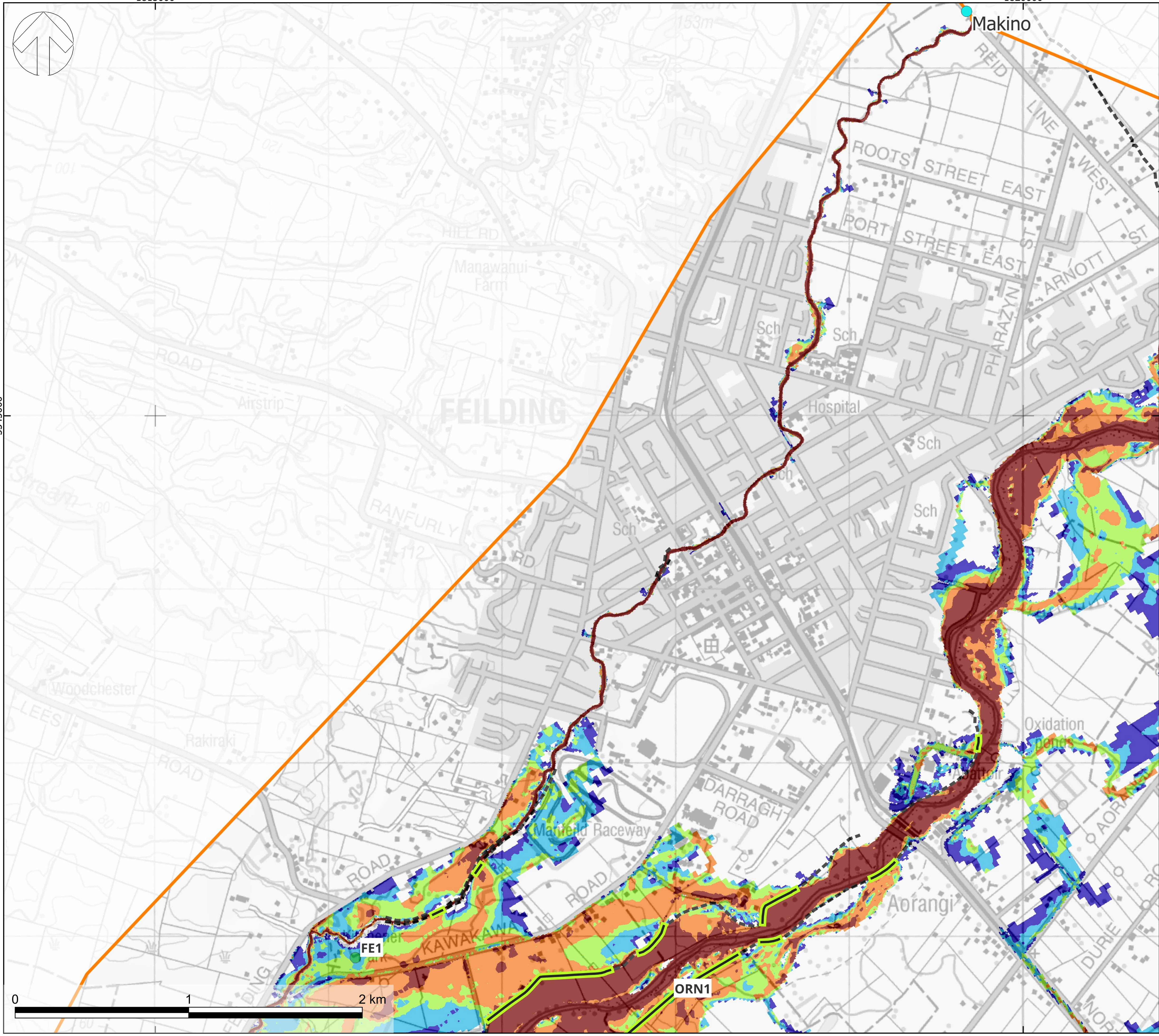

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Key:
- Model Outline
- Horizons Stopbanks
- Watercourse Upstream Inflows
- Flood Observation Locations
- 200yrCC3c Stopbank Overtopping

Maximum Velocities (m/s)
- <= 0.1
- 0.1 - 0.2
- 0.2 - 0.4
- 0.4 - 0.7
- > 0.7

REV	DATE	BY	DESCRIPTION	CHK	APP
001	17/07/2025	EH	Issued Draft Version 001	IF	RW

DRAWING STATUS:
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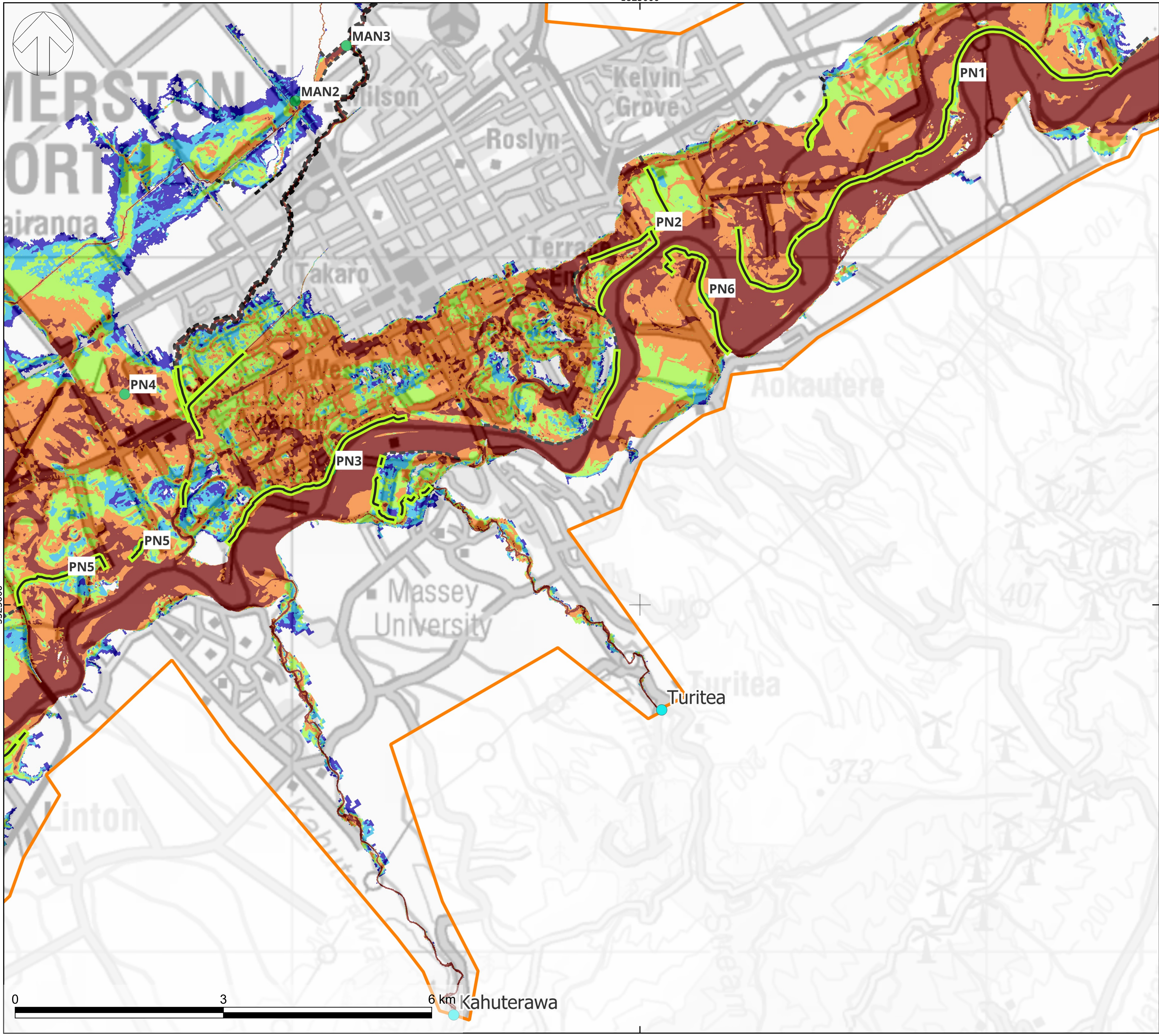
PROJECT:
Lower Manawatu Model
Appendix B

TITLE:
Feilding
Maximum Velocities
200yr plus 3-degree warming

DRAWN:	CHECKED:	APPROVED:
EH	IF	RW
PROJECT No: 1-E0118.00	SCALE @A3: 1: 21000	DATE: 17/07/2025

DRAWING No: 1-E0118.00-DRW-1202
REV: 001



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Key:
- Model Outline
- Horizons Stopbanks
- Watercourse Upstream Inflows
- Flood Observation Locations
- 200yrCC3c Stopbank Overtopping

Maximum Velocities (m/s)
- <= 0.1
- 0.1 - 0.2
- 0.2 - 0.4
- 0.4 - 0.7
- > 0.7

REV	DATE	BY	DESCRIPTION	CHK	APP
001	17/07/2025	EH	Issued Draft Version 001	IF	RW

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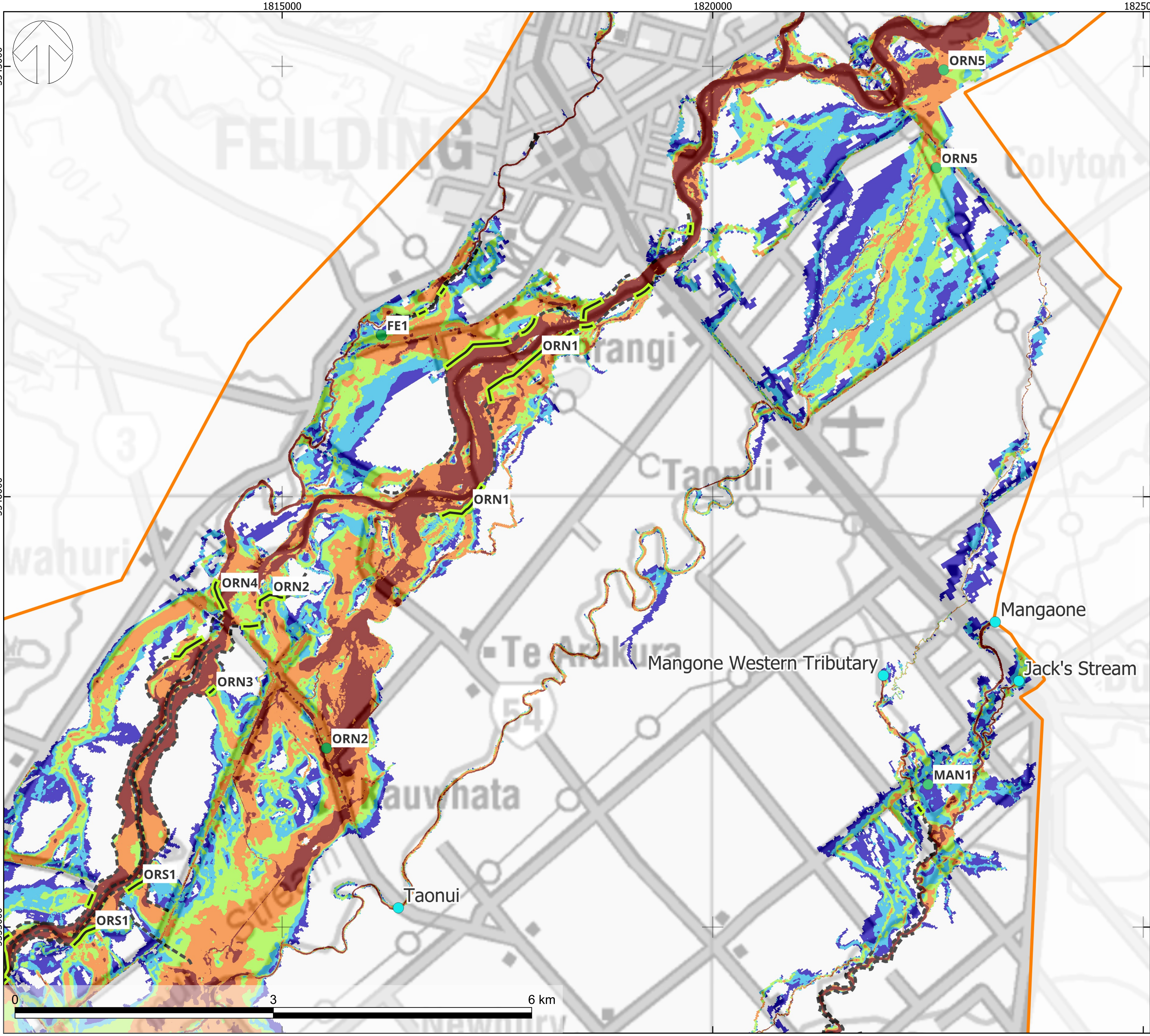
PROJECT: Lower Manawatu Model Appendix B

TITLE: Palmerston North Maximum Velocities 200yr plus 3-degree warming

DRAWN:	CHECKED:	APPROVED:
EH	IF	RW
PROJECT No: 1-E0118.00	SCALE @A3: 1: 52500	DATE: 17/07/2025

DRAWING No: 1-E0118.00-DRW-1203 | REV: 001



Key:
- Model Outline
- Horizons Stopbanks
- Watercourse Upstream Inflows
- Flood Observation Locations
- 200yrCC3c Stopbank Overtopping

Maximum Velocities (m/s)
- <= 0.1
- 0.1 - 0.2
- 0.2 - 0.4
- 0.4 - 0.7
- > 0.7

REV	DATE	BY	DESCRIPTION	CHK	APP
001	17/07/2025	EH	Issued Draft Version 001	IF	RW

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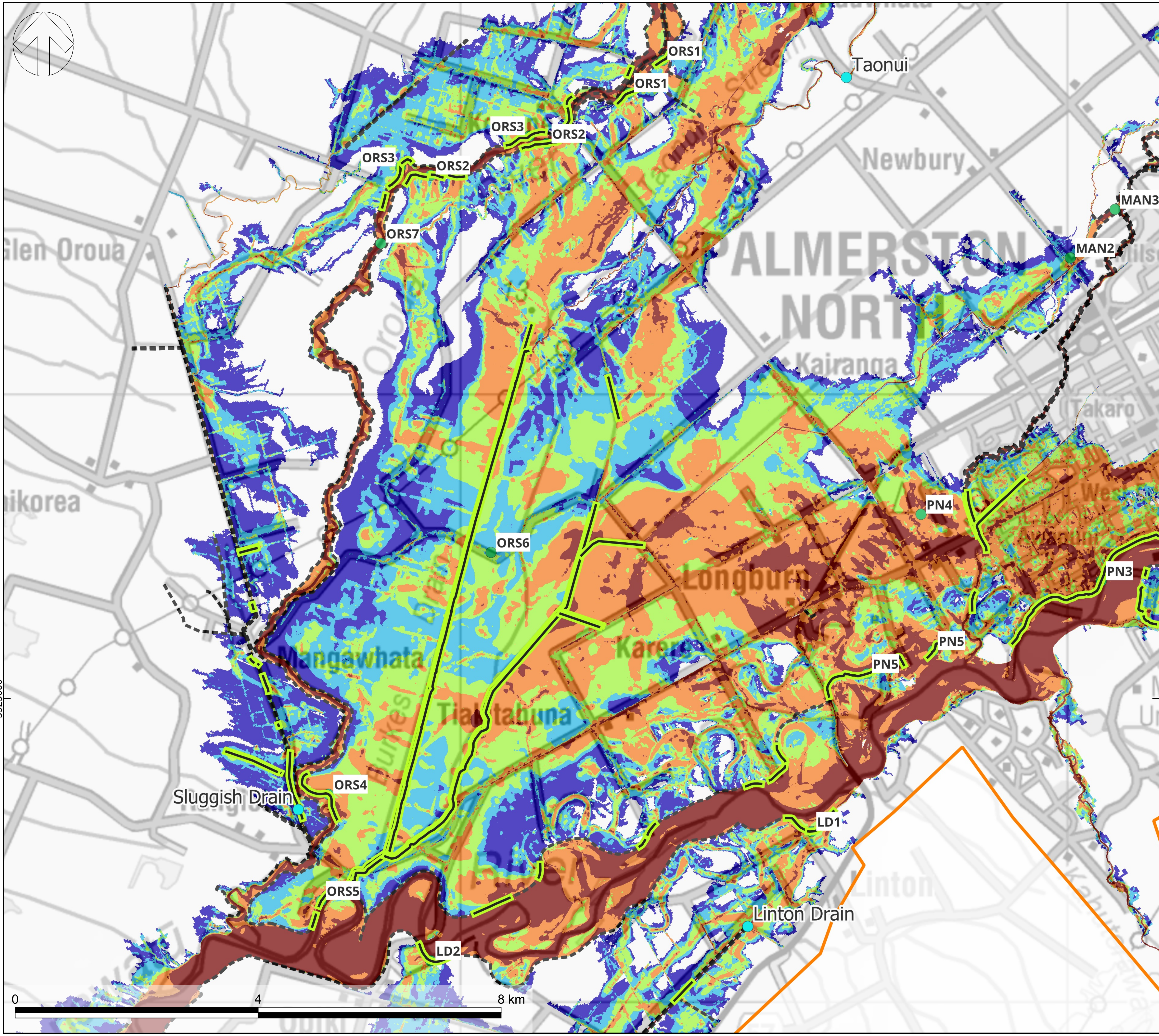
PROJECT: Lower Manawatu Model
Appendix B

TITLE: Oroua North
Maximum Velocities
200yr plus 3-degree warming

DRAWN:	CHECKED:	APPROVED:
EH	IF	RW
PROJECT No: 1-E0118.00	SCALE @A3: 1: 42000	DATE: 17/07/2025

DRAWING No: 1-E0118.00-DRW-1204 REV: 001



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Key:
- Model Outline
- Horizons Stopbanks
- Watercourse Upstream Inflows
- Flood Observation Locations
- 200yrCC3c Stopbank Overtopping

Maximum Velocities (m/s)
- <= 0.1
- 0.1 - 0.2
- 0.2 - 0.4
- 0.4 - 0.7
- > 0.7

001	17/07/2025	EH	Issued Draft Version 001	IF	RW
REV	DATE	BY	DESCRIPTION	CHK	APP

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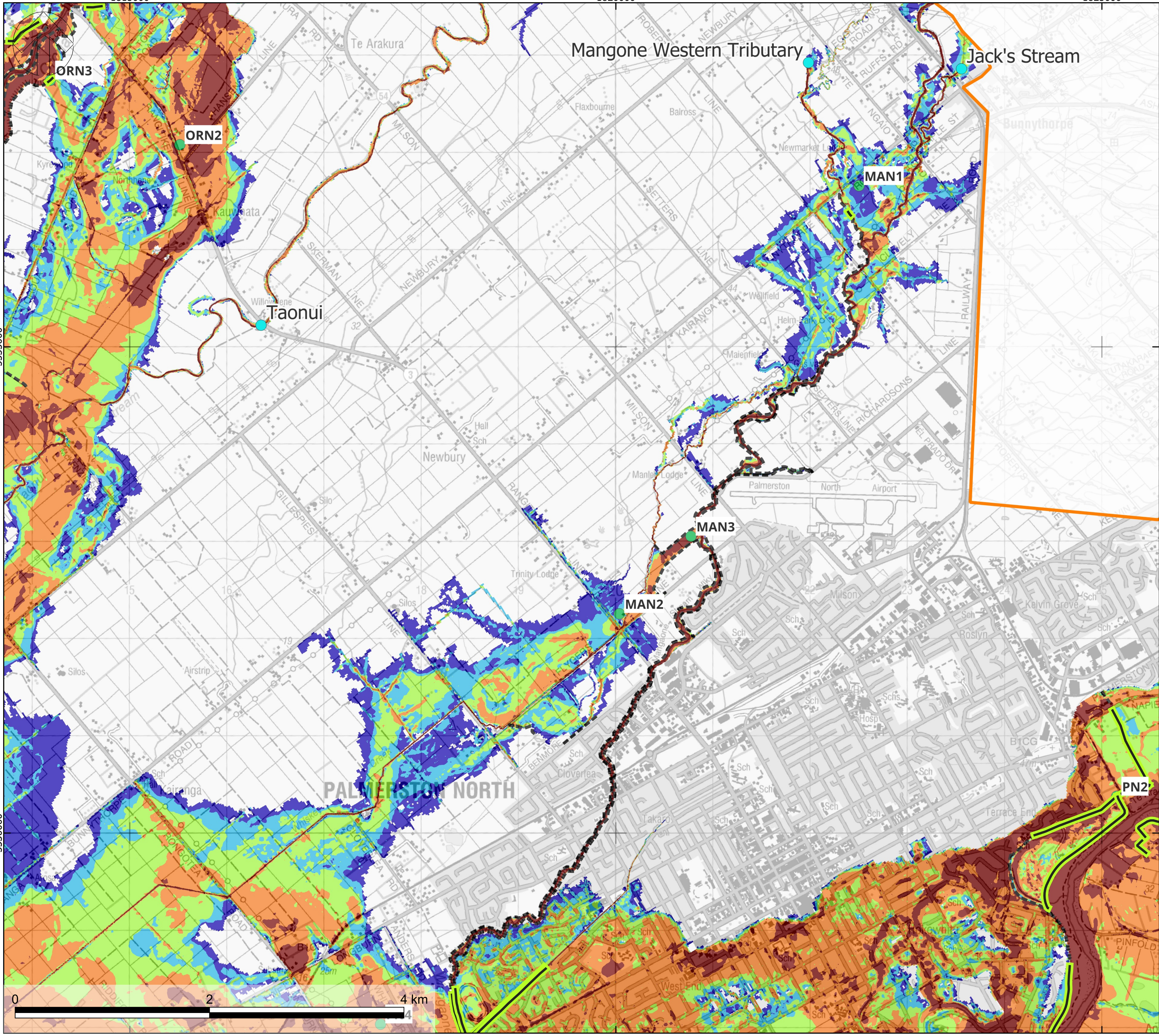
PROJECT:
Lower Manawatu Model
Appendix B

TITLE:
Oroua South
Maximum Velocities
200yr plus 3-degree warming

DRAWN:	CHECKED:	APPROVED:
EH	IF	RW
PROJECT No: 1-E0118.00	SCALE @A3: 1: 60000	DATE: 17/07/2025

DRAWING No:	REV:
1-E0118.00-DRW-1205	001



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Key:
- Model Outline
- Horizons Stopbanks
- Watercourse Upstream Inflows
- Flood Observation Locations
- 200yrCC3c Stopbank Overtopping

Maximum Velocities (m/s)
- <= 0.1
- 0.1 - 0.2
- 0.2 - 0.4
- 0.4 - 0.7
- > 0.7

REV	DATE	BY	DESCRIPTION	CHK	APP
001	17/07/2025	EH	Issued Draft Version 001	IF	RW

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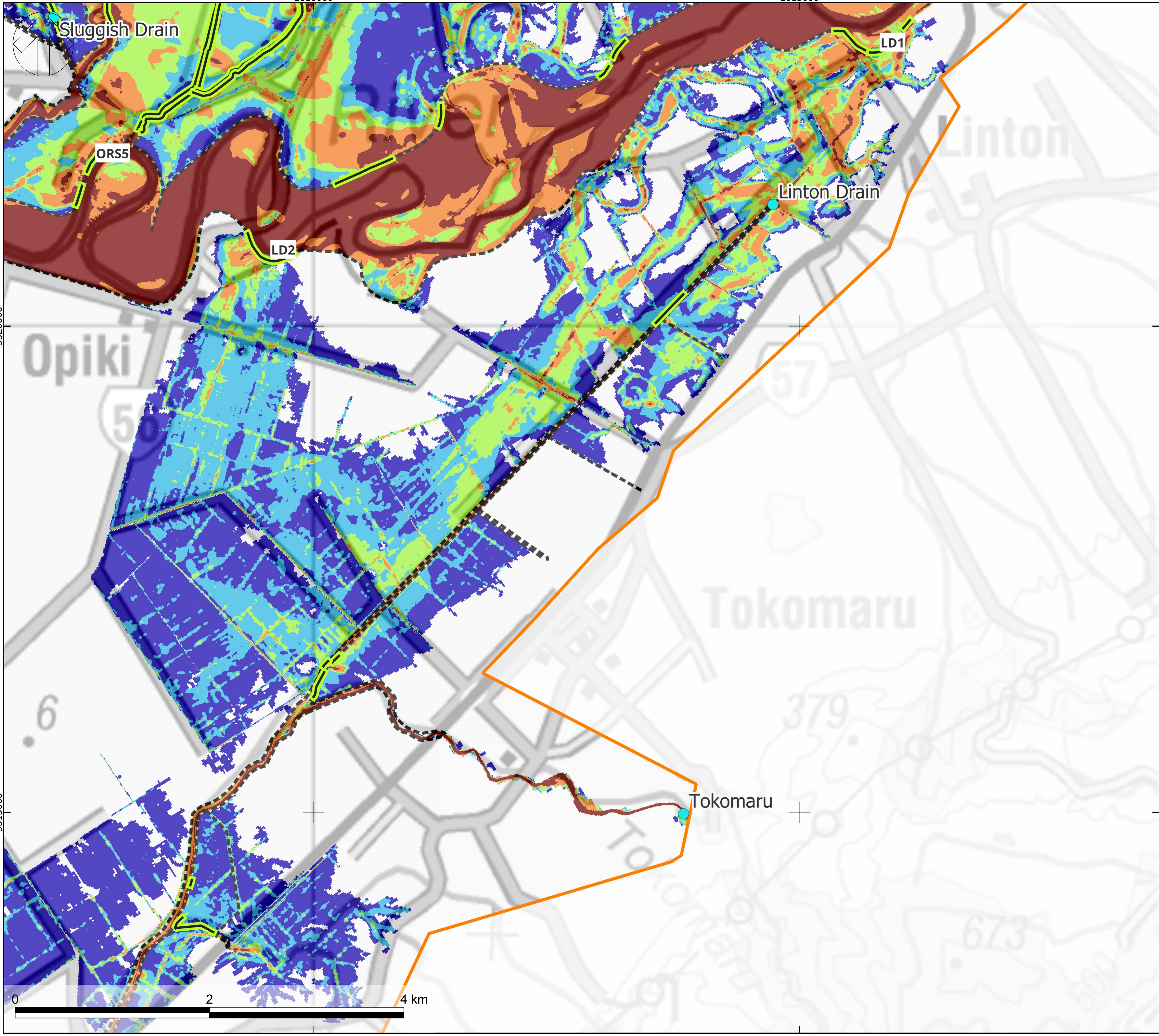
PROJECT: Lower Manawatu Model Appendix B

TITLE: Mangaone Maximum Velocities 200yr plus 3-degree warming

DRAWN:	CHECKED:	APPROVED:
EH	IF	RW
PROJECT No: 1-E0118.00	SCALE @A3: 1: 37500	DATE: 17/07/2025

DRAWING No: 1-E0118.00-DRW-1206 | REV: 001



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Figures not to be used nor distributed without accompanying model build report 'MOUTOA GATES – MODEL BUILD REPORT TO SUPPORT 2025 OPERATIONAL UPGRADES'

Note:
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Key:
- Model Outline
- Horizons Stopbanks
- Watercourse Upstream Inflows
- Flood Observation Locations
- 200yrCC3c Stopbank Overtopping

Maximum Velocities (m/s)
- <= 0.1
- 0.1 - 0.2
- 0.2 - 0.4
- 0.4 - 0.7
- > 0.7

REV	DATE	BY	DESCRIPTION	CHK	APP
001	17/07/2025	EH	Issued Draft Version 001	IF	RW

DRAWING STATUS: AUTHORISED AND ACCEPTED

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wsp.com

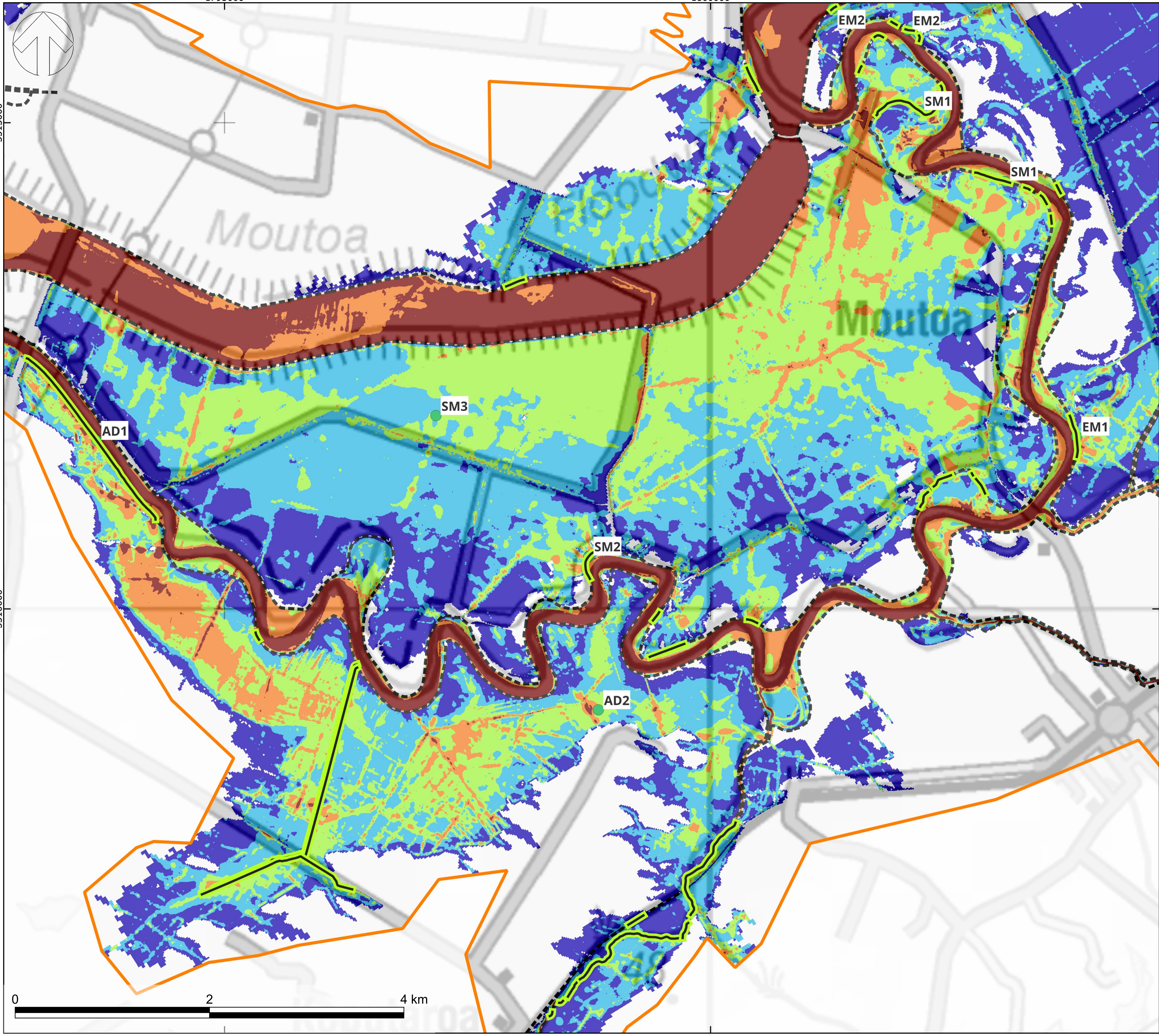
CLIENT: horizons REGIONAL COUNCIL

PROJECT: Lower Manawatu Model
Appendix B

TITLE: Linton Drain
Maximum Velocities
200yr plus 3-degree warming

DRAWN:	CHECKED:	APPROVED:
EH	IF	RW
PROJECT No: 1-E0118.00	SCALE @A3: 1: 37500	DATE: 17/07/2025

DRAWING No: 1-E0118.00-DRW-1207
REV: 001



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Key:
- Model Outline
- Horizons Stopbanks
- Flood Observation Locations
- 200yrCC3c Stopbank Overtopping

Maximum Velocities (m/s)
- <= 0.1
- 0.1 - 0.2
- 0.2 - 0.4
- 0.4 - 0.7
- > 0.7

REV	DATE	BY	DESCRIPTION	CHK	APP
001	17/07/2025	EH	Issued Draft Version 001	IF	RW

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CLIENT:
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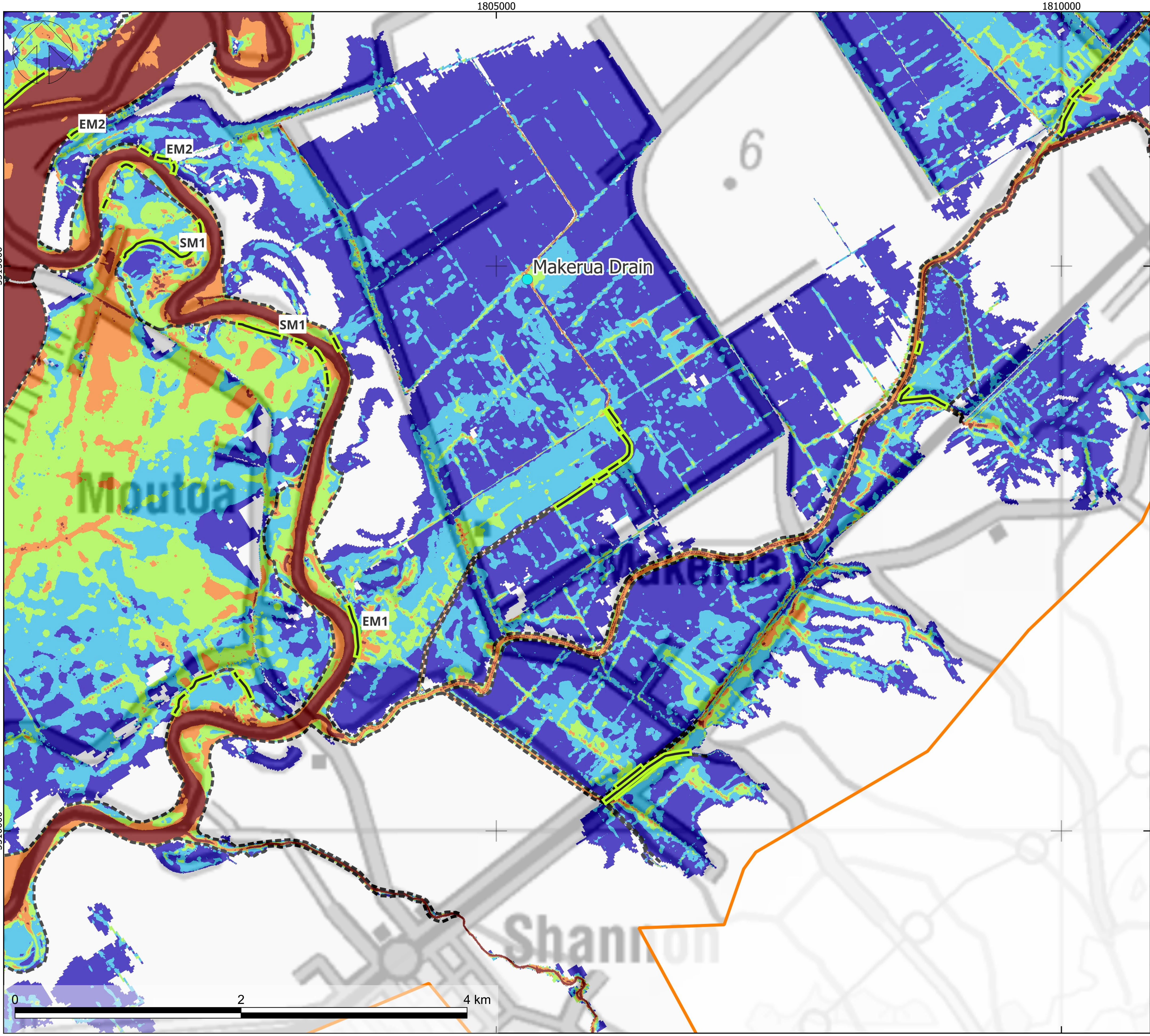
PROJECT:
Lower Manawatu Model
Appendix B

TITLE:
Southern Moutoa Floodplain
Maximum Velocities
200yr plus 3-degree warming

DRAWN:	CHECKED:	APPROVED:
EH	IF	RW
PROJECT No: 1-E0118.00	SCALE @A3: 1: 37500	DATE: 17/07/2025

DRAWING No: 1-E0118.00-DRW-1208 REV: 001



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Key:
- Model Outline
- Horizons Stopbanks
- Watercourse Upstream Inflows
- Flood Observation Locations
- 200yrCC3c Stopbank Overtopping

Maximum Velocities (m/s)
- <= 0.1
- 0.1 - 0.2
- 0.2 - 0.4
- 0.4 - 0.7
- > 0.7

REV	DATE	BY	DESCRIPTION	CHK	APP
001	17/07/2025	EH	Issued Draft Version 001	IF	RW

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PROJECT:
Lower Manawatu Model
Appendix B

TITLE:
Eastern Moutoa Floodplain
Maximum Velocities
200yr plus 3-degree warming

DRAWN:	CHECKED:	APPROVED:
EH	IF	RW
PROJECT No: 1-E0118.00	SCALE @A3: 1: 32000	DATE: 17/07/2025

DRAWING No: 1-E0118.00-DRW-1209
REV: 001

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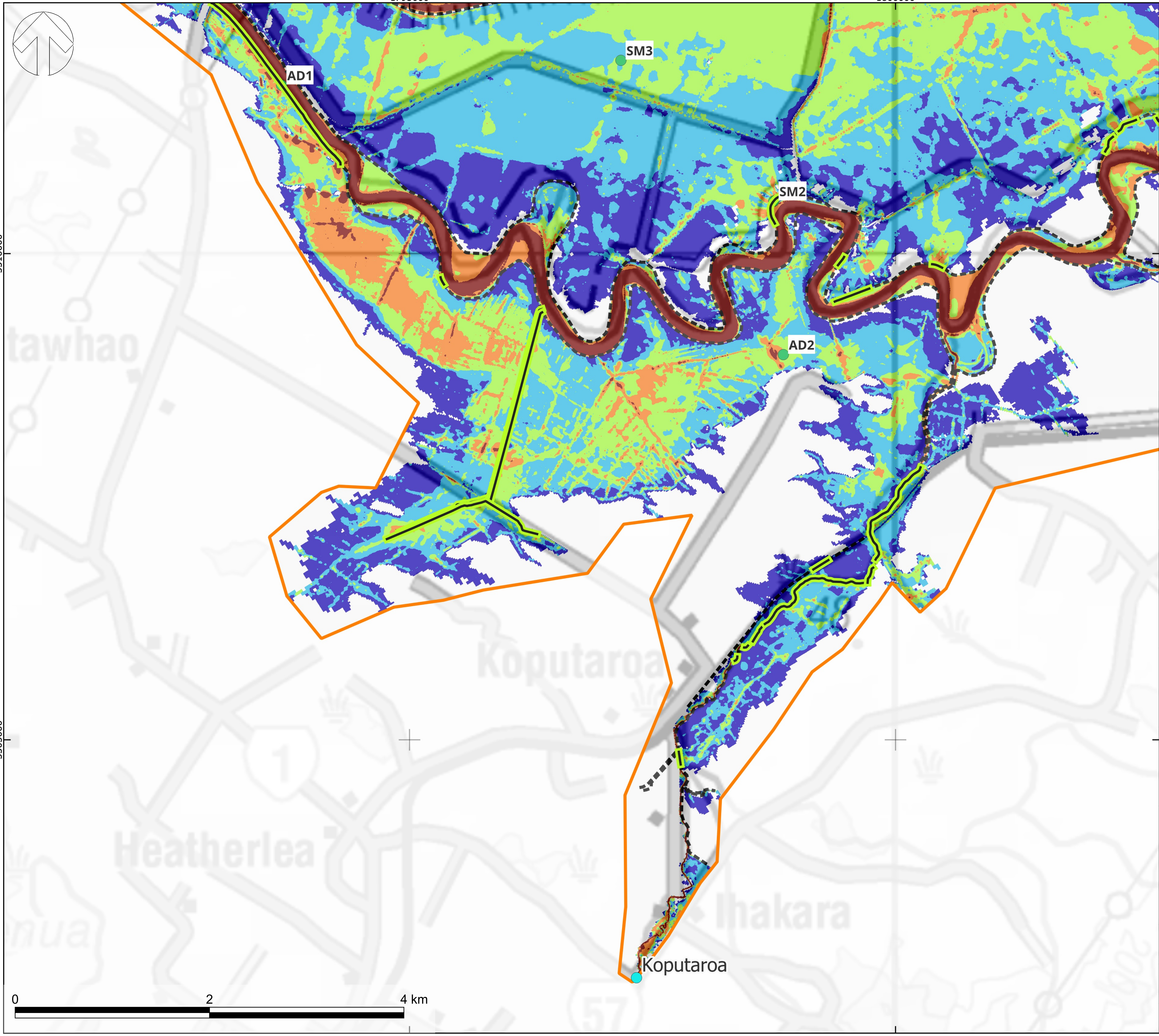

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Key:
- Model Outline
- Horizons Stopbanks
- Watercourse Upstream Inflows
- Flood Observation Locations
- 200yrCC3c Stopbank Overtopping

Maximum Velocities (m/s)
- <= 0.1
- 0.1 - 0.2
- 0.2 - 0.4
- 0.4 - 0.7
- > 0.7

REV	DATE	BY	DESCRIPTION	CHK	APP
001	17/07/2025	EH	Issued Draft Version 001	IF	RW

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PROJECT:
Lower Manawatu Model
Appendix B

TITLE:
Arantangata Floodplain
Maximum Velocities
200yr plus 3-degree warming

DRAWN:	CHECKED:	APPROVED:
EH	IF	RW
PROJECT No: 1-E0118.00	SCALE @A3: 1: 37500	DATE: 17/07/2025

DRAWING No: 1-E0118.00-DRW-1210
REV: 001

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