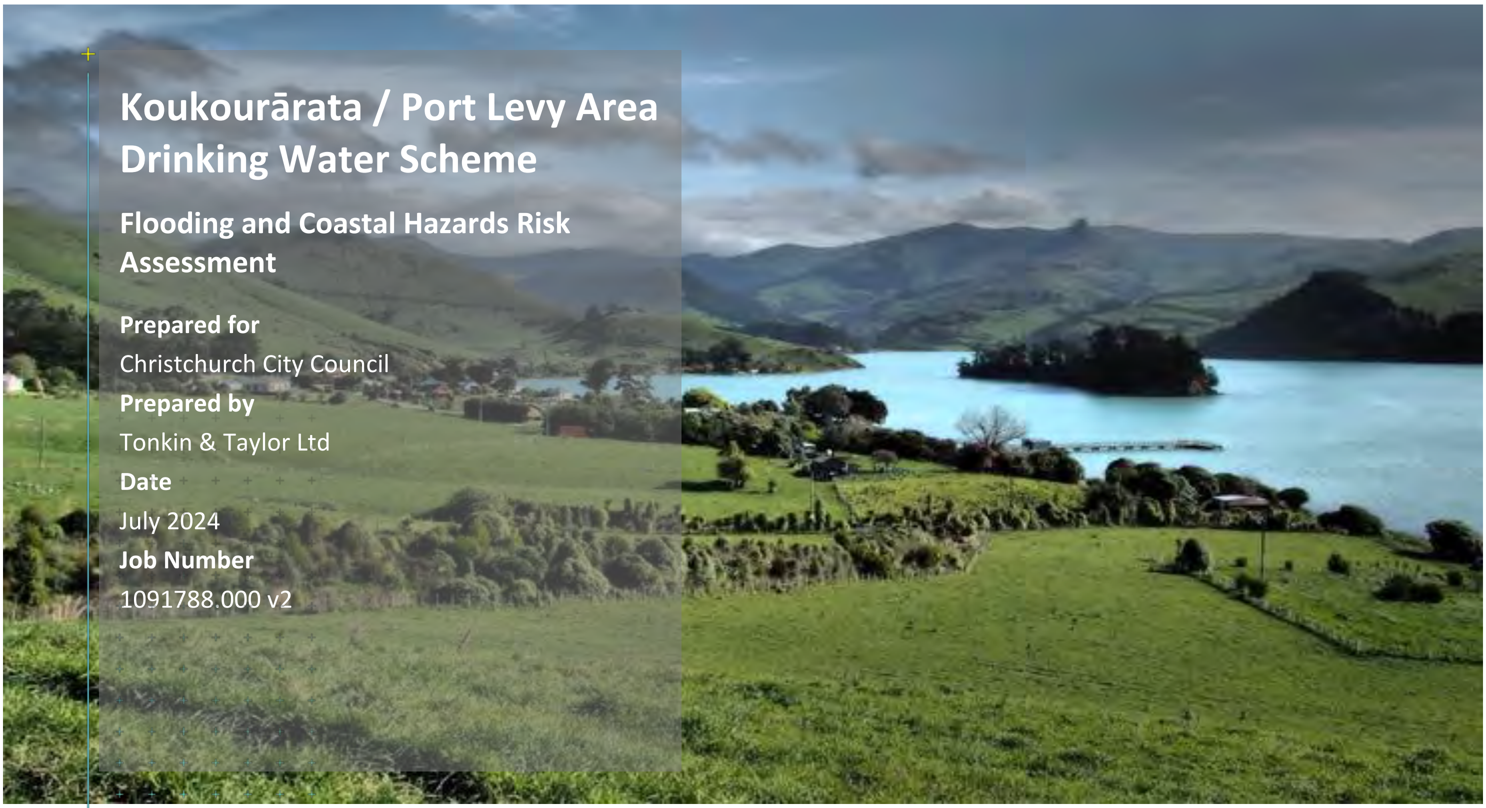
REPORT

Tonkin+Taylor



Koukourārata / Port Levy Area Drinking Water Scheme

Flooding and Coastal Hazards Risk Assessment

Prepared for
Christchurch City Council
Prepared by
Tonkin & Taylor Ltd
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1 Introduction

Tonkin & Taylor Ltd (T+T) was engaged by Christchurch City Council (CCC) to undertake a flood risk and coastal hazards assesment to inform the design and location of the new Koukourārata / Port Levy area drinking water supply scheme.

The assesment includes the Te Kawa, Owhetoro and Koukourārata catchments (hydrology and hydraulic flood model assessments), and the inner coastline adjacent to Port Levy (coastal hazards assessment).

The structure of this summary report is divided into the three individual assessments that form the project scope. Each assesment comprises a high-level description of the methodology and summary of the results. Appended to this report are the technical reports and associated maps for each assesment.

2 Background

CCC established capital project 67456 'WS Koukourārata Drinking Water Scheme' in the 2022 Annual Plan. The purpose of this project is to establish a safe and reliable reticulated drinking water supply scheme for properties around the southeast side of Port Levy inlet including Tūtehuarewa Marae (Figure 2.1).

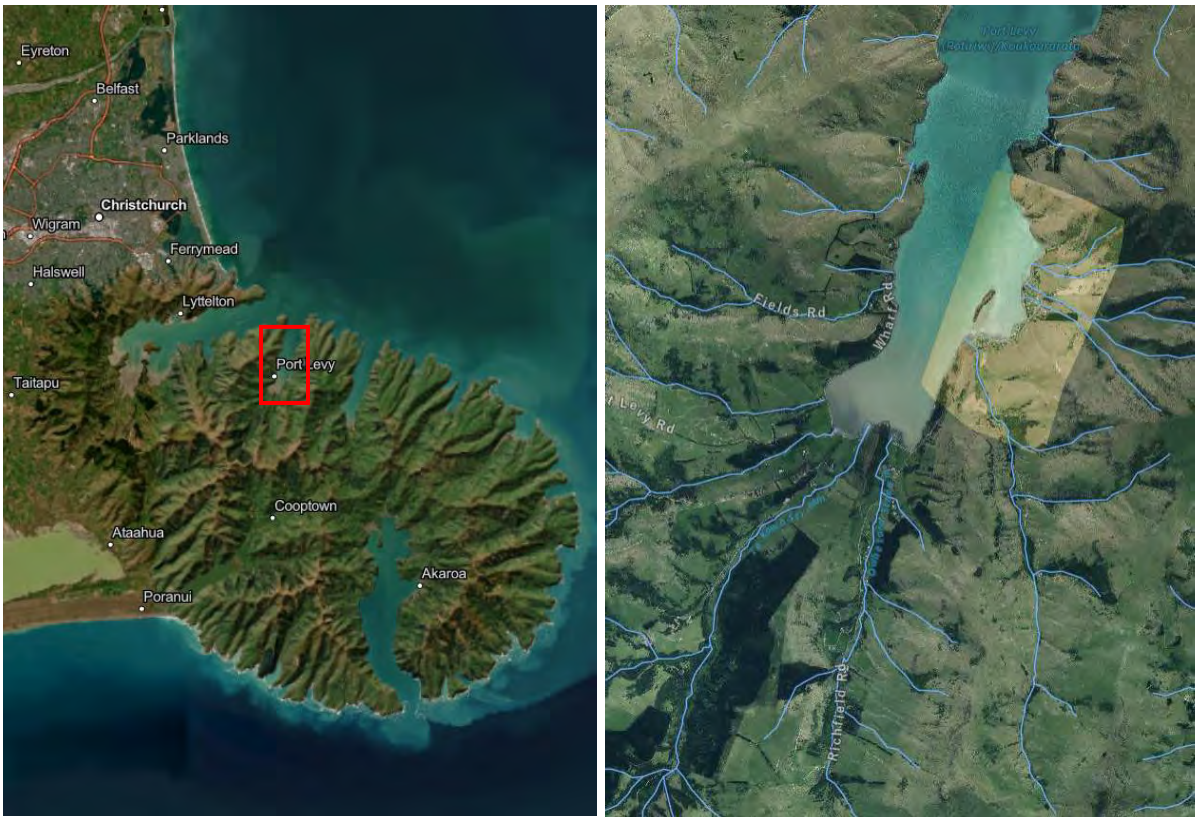

Figure 2.1: Location map to illustrate Port Levy in relation to the broader Banks Peninsular area southeast of Christchurch.

The Port Levy area currently has 45 houses in the target reticulation zone and all of these houses, and the marae are supplied by rainwater tanks supplemented by tanker deliveries. It is expected that there will be ultimately 65 houses in the target reticulation zone. The high-level water supply scheme requirements are as follows:

- Water treatment plant (WTP) capacity is required to accommodate a 24-hour peak capacity of: 65 properties at 1,000 litres per property per day, plus 200 people at the marae at 60 litres per person per day.
- Rural restricted supply connections to all properties excluding the marae, which will be on restricted supply but at a volume that may be greater than 1,000 L per day.
- Minimum treated water storage of three 30,000 L tanks with sufficient storage for 24 hours of demand.
- The WTP site must have area to provide for future expansion (2x 30,000 L tanks). The volume of storage does not need to be designed to accommodate fire flows as Port Levy is a Rural Fire Area where hydrants are not required.
- The WTP site must be situated to provide a minimum of 30 kPa pressure to all properties in the network by gravity feed.

In 2022 Council commissioned investigations into two recently exposed springs (Koukourārata Springs) as a potential water source for the drinking water supply which proved to be not suitable. It was also concluded that due to the highly variable nature of the volcanic strata on Banks Peninsula there is uncertainty that a deep bore would be successful, or able to supply the required yield and quality of water. The recommended option is a surface water take piped to a central water treatment plant for treatment prior to distribution to the community and the Marae.

Council undertook preliminary flow and water quality monitoring on Koukourārata, Owhetoro and Te Kawa streams. Koukourārata stream has been ruled out as a potential water source as it has insufficient flows. Council has now installed continuous flow monitoring stations at Owhetoro and Te Kawa streams and is also undertaking monthly water quality sampling to obtain a better understanding of seasonal flows and water quality.

Due to factors such as accessibility, land use and catchment characteristics, the location of the raw water intake(s) has yet to be confirmed and may need to be located further up in the valley(s) to ensure a resilient supply. Hydrological characteristics along the entire reach for each catchment is therefore required to support the hydraulic flood model.

3 Objective

The objective of this project is to provide CCC with information relating to flood risks and coastal hazards to inform the design and location of the new Koukourārata drinking water supply scheme. This includes the preferred locations for the raw water intake(s), the WTP, reticulation infrastructure, and firefighting storage tanks. Findings from this project will also help set finished floor levels and site levels to ensure future resilience against flooding and sea-level rise.

This is the basis for the work undertaken by T+T and presented in this report.

4 Scope of works

To meet the objective T+T completed the following scope of work:

- **Complete a hydrology assesment** to estimate suitable rainfall-runoff parameters required as input into a hydraulic flood model that was developed to estimate flood levels in the Te Kawa, Owhetoro and Koukourārata catchments.
- **Complete a hydraulic flood model** to estimate flood levels in the Te Kawa, Owhetoro and Koukourārata catchments. Specifically, the model was used to predict the maximum water depths and flood hazard within the three catchments for several different magnitude rainfall events.

- **Complete a coastal hazard assessment** is to identify the magnitude and spatial extent of coastal erosion, coastal inundation and elevated groundwater levels within Port Levy.
- **Undertake consultation** with the CCC Coastal Adaptation Team, ECan and Koukourārata Marae to incorporate information and observations about actual flooding events in the past.

Figure 4.1 illustrates the indicative catchment outlines for the three catchments and the general extent of the coastal assessment that form the scope of works. The general location for the WTP is at the intersection of Port Levy Pigeon Bay Road, and Pa Road.

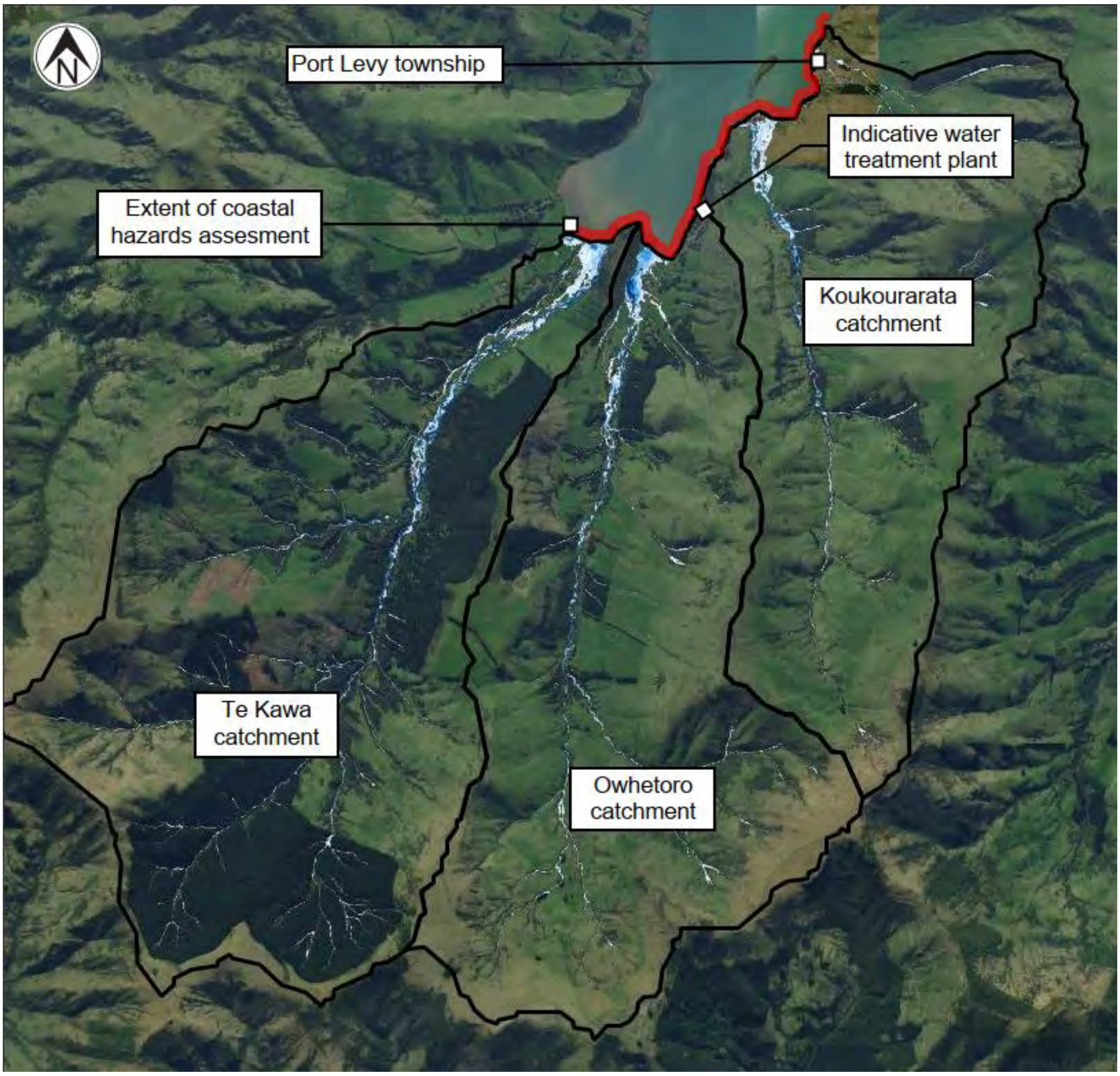

Figure 4.1: Aerial image of the project extent to illustrate three catchments that inform the hydraulic flood model, and general location of the coastal hazards assessment in relation to Port Levy township.

5 Hydrology assessment

*This section provides an overview of the hydrology assesment (to inform the hydraulic flood model) by describing the simplified methodology and key results. The complete technical report can be found in **Appendix A.***

5.1 Methodology

5.1.1 Purpose

A hydrology assessment was undertaken to estimate suitable rainfall-runoff parameters required as input into a hydraulic flood model that was developed to estimate flood levels in the Te Kawa, Owhetoro and Koukourārata catchments. The rainfall-runoff parameters estimated included:

- **Initial abstraction (IA):** Soil parameter that accounts for all losses prior to runoff and consists mainly of interception, infiltration, evaporation, and surface depression storage.
- **Constant Loss (CL):** Soil parameter that defines the rate at which precipitation will be infiltrated into the soil layer after the initial abstraction volume has been satisfied.
- **Design rainfall hyetographs:** Representation of the distribution of design rainfall intensity over time.

5.1.2 Hydrology review

A desktop review of available rainfall station and streamflow gauge data for the Banks Peninsula was undertaken. A map showing the gauged catchments and location of streamflow gauges and rainfall stations is shown in Figure 5.1.

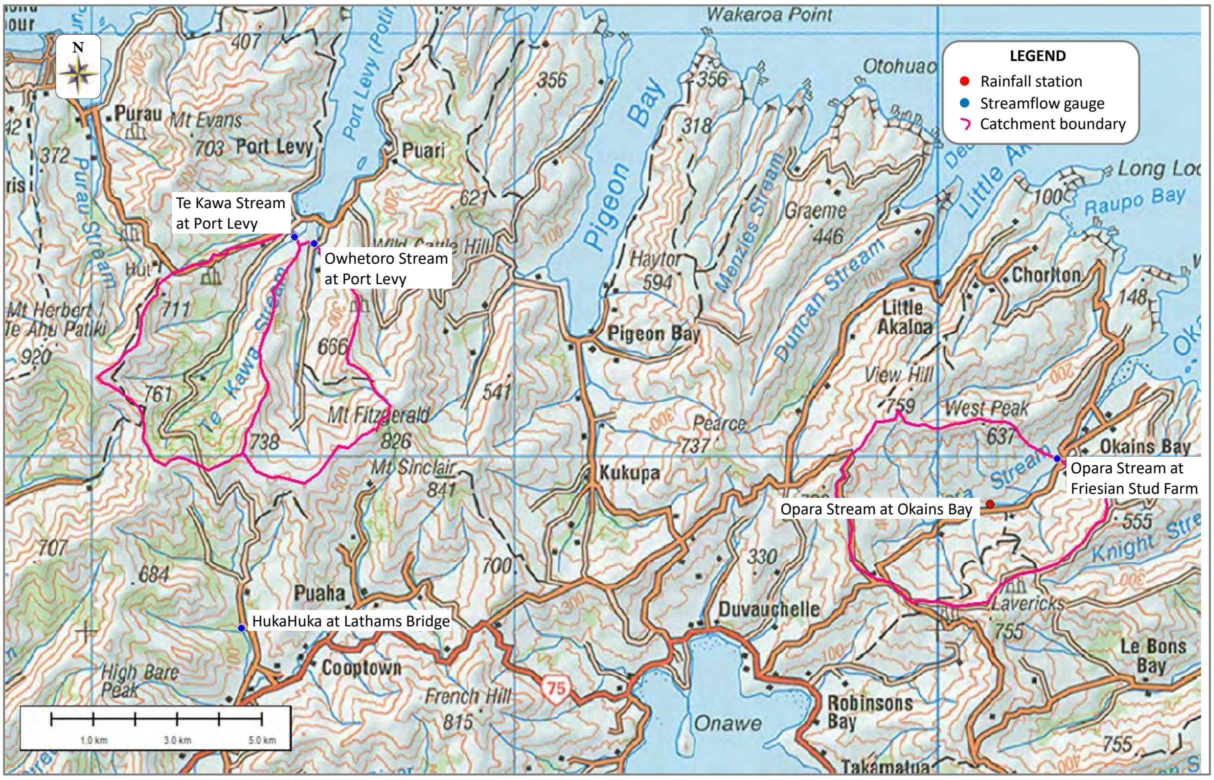

Figure 5.1: Location of catchments, streamflow gauges and rainfall stations.

Hydrometeorological data in the Banks Peninsula area is limited. There are no rainfall stations in the project catchments and the streamflow gauges in the Te Kawa and Owhetoro streams only began in March 2023. The Opara catchment has a streamflow gauge at Friesian Stud Farm that started recording in March 1998. There is a rainfall station near the centre of the Opara catchment with a record from September 2019.

5.1.3 Rainfall-runoff model calibration

IA and CL soil parameters were estimated by developing and calibrating a rainfall-runoff model. The rainfall-runoff calibration model was developed in HEC-HMS software to estimate the catchment flow during several historical rainfall events based on an assumed IA and CL input.

The Opara Stream was used to calibrate the HEC-HMS model because there is no sufficient data for the three project catchments, and it has similar geographical and physical characterises to the project catchments. Three historical rainfall events (May 2021, July 2022 & July 2023) were run through the model and the modelled flows compared to Opara gauge flows at Friesian Stud Farm. IA and CL parameters were then adjusted in the model until a suitable match between modelled and gauge flows was found.

Based on the model calibration results, the following IA and CL parameters were recommended for Te Kawa, Owhetoro and Koukourārata catchments:

- Initial abstraction = 0 mm.
- Constant Loss = 1.5 mm/hr.

An initial loss of 0 mm assumes that the catchment antecedent conditions prior to the event occurring are wet. This will result in more flooding compared to dry antecedent conditions and is considered conservative for the purposes of hydraulic flood modelling.

5.1.4 Design rainfall

Design rainfall depths for the 5-year, 10-year, 20-year, 50-year, 100-year and 250-year Average Return Interval (ARI) events over a range of durations were sourced for the project catchments from the NIWA HIRDS V4[1].

No climate change allowance was made for the rainfall depths as agreed with CCC in the Statement of Work. The rainfall adopted for the model is considered “present day” climate.

Aerial reduction factors (ARF) were applied to the HIRDS rainfall depths to account for the lower probability that a predicted rainfall depth will occur across an entire catchment.

The HIRDS rainfall depths were transformed into rainfall hyetographs using a modified HIRDS temporal distribution. A temporal storm provides a more realistic representation of rainfall compared to an alternative approach such as a nested storm. The HIRDS temporal distribution was modified based on work undertaken by Council which slightly reduces the peak to create a smooth ascending and descending limb transition.

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[1] National Institute of Water & Atmospheric Research, High Intensity Rainfall Design System.

6 Hydraulic flood model

*This section provides an overview of the flooding assesment by describing the simplified methodology and key results. The complete technical report including flood maps can be found in **Appendix B.***

6.1 Methodology

6.1.1 Purpose

A hydraulic flood model was developed to estimate flood levels in the Te Kawa, Owhetoro and Koukourārata catchments. Specifically, the model was used to predict the maximum water depths and flood hazard within the three catchments for several different magnitude rainfall events. The hydraulic model extent includes the Te Kawa, Owhetoro and Koukourārata catchments as shown in Figure 6.1**.**

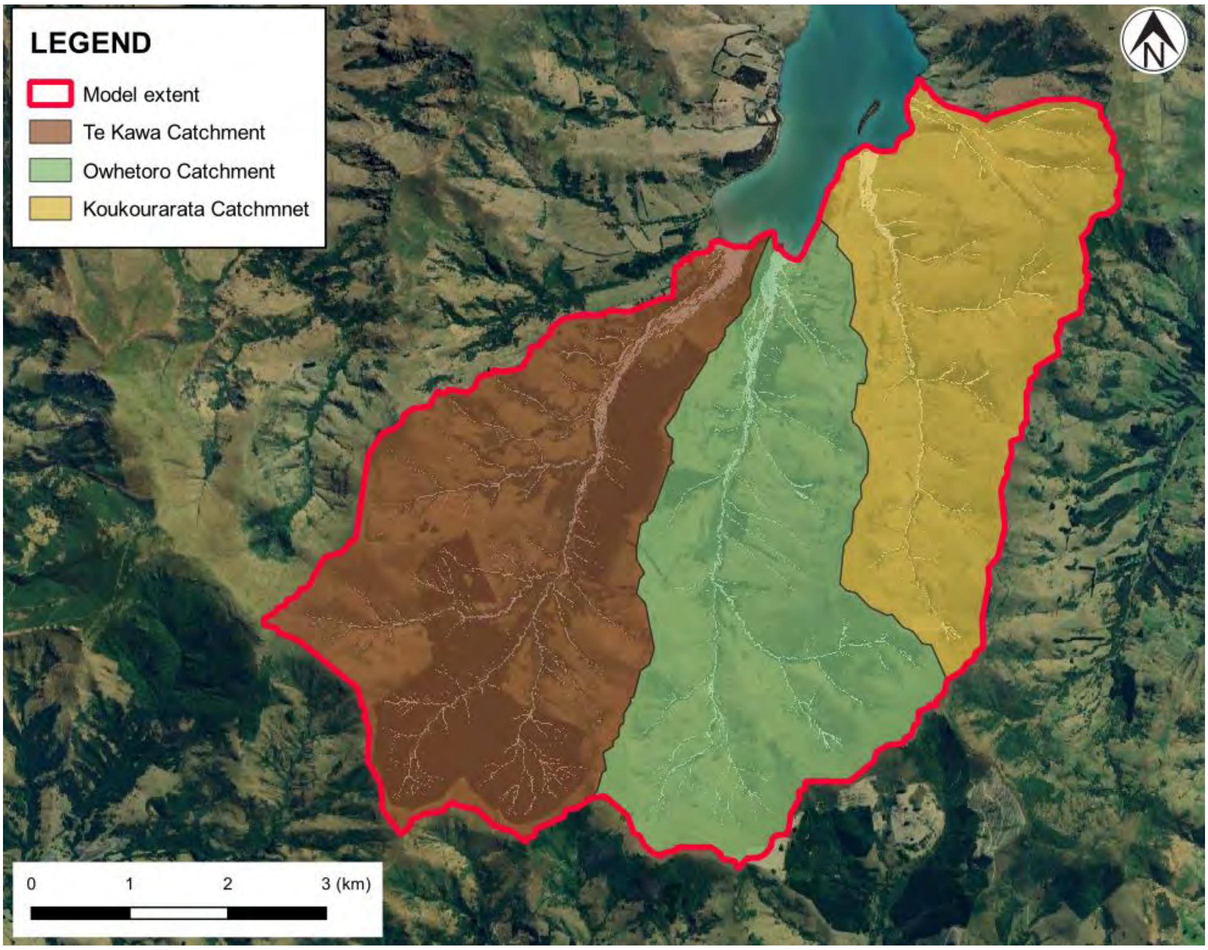

Figure 6.1: Hydraulic model extent and catchments.

6.1.2 Inputs and assumptions

The model was developed in TUFLOW software. TUFLOW is a 2-dimensional hydraulic modelling software that predicts water surface flow across a defined extent based on inputs such as ground terrain levels, rainfall and soil parameters. Ground terrain levels within the hydraulic model were established using a gridded bare earth Digital Elevation Model captured between 2018 and 2019.

Design rainfall hyetographs for the 5-year, 10-year, 20-year, 50-year, 100-year and 250-year ARI events were applied to the model using a rain-on-grid approach. With this approach, rainfall hyetographs are spatially distributed across the entire model extent. This negates the need for other inflows to be inputted into the model.

A downstream tide boundary was implemented in the hydraulic model as a static water level at 1.8 m (NZVD2016 datum) assuming 10-year ARI present day climate conditions. Soil infiltration was represented in the hydraulic model using the Initial Loss (IA) and Constant Loss (CL) approach with an IA of 0 mm and CL of 1.5 mm/hr (described in Section 5.1.3).

6.1.3 Validation

A hydraulic model validation exercise was undertaken to assess the suitability of the adopted inputs and assumptions. NIWA maintain streamflow gauges on both the Owhetoro and Te Kawa Streams (located approximately 500 m upstream from the coast). Recorded flow data is available for these gauges from March 2023 to December 2023. Over this period, two relatively moderate flood events occurred within the catchments, both in July 2023.

There are no available rainfall stations within the Owhetoro and Te Kawa catchments which provided rainfall data for the July events. Rainfall station data from other surrounding catchments within Banks Peninsula are available with the nearest and most similar geographically being a station located near Diamond Harbour.

The hydraulic model was run with the recorded Diamond Harbour station inputted as a rainfall boundary for the July events. The modelled flow in the Owhetoro and Te Kawa catchments were then compared to the gauge flows. Overall, the modelled flows show a reasonable correlation to the gauge flows. It is important to consider the high degree of uncertainty associated with the rainfall data that may have fallen within the Owhetoro and Te Kawa catchments during the July events.

6.2 Results

Maximum modelled water depth and flood hazard maps are provided in for the following events:

- 5-year ARI rainfall with 10-year ARI tide.
- 10-year ARI rainfall with 10-year ARI tide.
- 20-year ARI rainfall with 10-year ARI tide.
- 50-year ARI rainfall with 10-year ARI tide.
- 250-year ARI rainfall with 10-year ARI tide.
- 20-year ARI rainfall with 100-year ARI tide.

Flood depths less than 0.1 m have been removed from flood maps as this is the threshold depth above which flooding has been considered with confidence as “real” and not potentially an artefact of inaccuracies in the DEM. Flood hazard maps adopt the hazard criteria from Smith et al. (2014)[2].

Flood depth and hazard maps (Appendix B1 to B16) are represented as “peak of peak” maximum modelled flood depth and hazard for each of the simulated ARI events. “Peak of peak” outputs are the enveloped maximums reached at any one cell in the model extent across the modelled rainfall durations. The “peak of peak” overlays does not come from any single event simulation but are compiled from all event simulations.

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[2] Smith, G.P., Davey, E.K. and Cox, R.J. (2014), Flood Hazard UNSW Australia Water Research Laboratory Technical Report 2014/07 30 September 2014.

7 Coastal hazards assessment

This section provides an overview of the coastal hazards assessment by describing the simplified methodology and key results. The complete technical report including the coastal setting, coastal erosion, coastal inundation and rising groundwater maps can be found in Appendix C.

7.1 Coastal erosion

7.1.1 Methodology

Coastal erosion is the loss of sediment, resulting in the shoreline position shifting landward. Majority of the Porty Levy shoreline is characterised by weakly consolidated banks and consolidated basalt cliffs. These shoreline types are not able to rebuild following periods of erosion and are subject to a one-way process of retreat. For the bank shorelines, the Areas Susceptible to Coastal Erosion (ASCE) have been defined based on the components presented in Equation 1 and Figure 7.1.

$$Future\ ASCE_{Bank} = (LT\ x\ T)\ x\ SL + SS \tag{6-1}$$

Where:

LT = Long-term retreat (regression rate), (m/year).

T = Timeframe over which erosion occurs (years).

SL = Factor for the potential increase in future long-term retreat due to sea level rise effects.

SS = Slope stability allowance. This is the horizontal distance from the base of the eroded bank toe to the crest at a stable angle of repose (m).

Equation 1: Areas Susceptible to Coastal Erosion (ASCE).

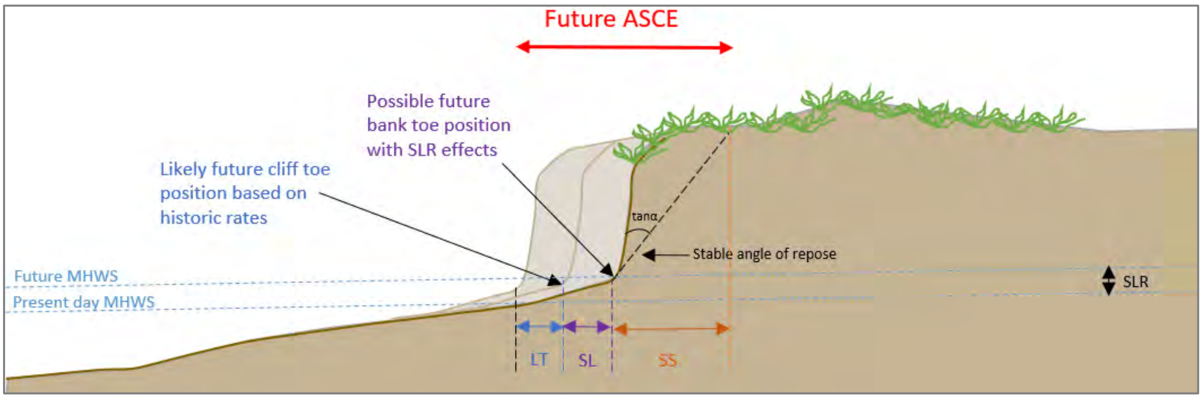

Figure 7.1: Conceptual model of components contributing to the coastal erosion hazard.

The resulting ASCE have been calculated probabilistically and offset from the 2021 bank toe. The probabilistic approach combines parameter bounds for each contributing erosion component to determine a probabilistic forecast of potential erosion distance over a selected timeframe.

For the sections of shoreline characterised by high, basalt cliffs, the cliff Area Susceptible to Coastal Erosion (ASCE) defined in by T+T (2021) has been adopted. The basalt cliffs typically show very minimal toe erosion and the hazard along the slopes tends to be dominated by general slope instability hazard across the upper slope (refer to T+T, 2021). A full description of the erosion hazard methodology is presented in Section 3 of Appendix C.

7.1.2 Results

The range of resulting ASCE distances for the Port Levy shoreline are presented in Table 7.1. $P_{50\%}$ means there is 50% chance of an erosion distance being exceeded within that timeframe and can be considered a likely scenario. $P_{5\%}$ means there is a 5% change of an erosion distance being exceeded within that timeframe and can be considered a very unlikely or potential scenario. The resulting ASCE for 2080 SSP5-8.5 $P_{5\%}$ and 2130 SSP5-8.5+ $P_{5\%}$ have been mapped in Appendix C.10.

The assessment indicates that current erosion rates along the Port Levy shoreline are typically low, however the weakly consolidated banks do show undercutting in some locations and once the bank material is eroded away by the sea it is unable to rebuild. As the sea level rises, there is expected to be increased wind-wave energy reaching the shoreline due increased water depths which will increase the rates of erosion. The results show that by 2130 there is potential for -12 to -34 m of erosion from the present-day shoreline. The future erosion will likely impact the access roads around Port Levy including, Pa Road, Fernlea Point Road and Wharf Road, as well as some residential properties which are on the current coastal edge.

A sensitivity analysis for the high VLM rates provided by GNS (2023) has also been undertaken. The higher VLM rate provided by GNS (2023) (-6.6mm/year) increases the relative sea level rise by 0.5 m out to 2130 under the SSP5-8.5+ scenario. This increase in sea level rise is anticipated to only increase the erosion distances by no greater than 1 m over the 2130 timeframe. Given the small difference in erosion rates, this scenario has not been mapped.

Table 7.1: Summary of future ASCE distances (m from 2021 bank toe)

Timeframe	Sea level rise scenario	Probability of Exceedance	
		$P_{50\%}$	$P_{5\%}$
2080	SSP5-8.5	-5 to -21	-7 to -31
2130	SSP5-8.5H+	-8 to -24	-12 to -34

7.2 Coastal inundation

7.2.1 Methodology

Coastal inundation includes flooding of normally dry land due to high coastal water levels (static inundation) and the periodic impact of wave runup as waves break along the shore (dynamic inundation). Coastal inundation levels for Port Levy are based on the following combinations:

$$Extreme\ static\ water\ level = ST + SU + SLR \qquad (6\text{-}2)$$

$$Extreme\ dynamic\ water\ level = ST + RU + SLR \qquad (6\text{-}3)$$

Where:

ST = Storm tide level defined by the combination of astronomical tide, storm surge and mean sea level fluctuations.

SU = Wave set-up caused by wave breaking and onshore directed momentum flux across the surf zone.

RU = Wave run-up being the maximum potential vertical level reached by individual waves above the storm tide level (note this component implicitly includes wave set-up). Run-up extent has not been mapped within this assessment.

SLR = Sea level rise over the defined planning timeframes.

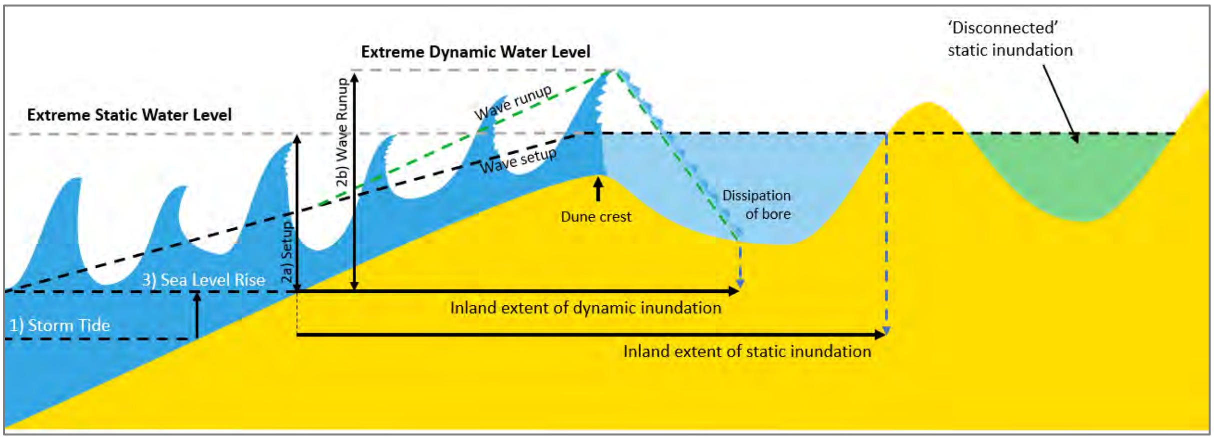

Figure 7.2: Conceptual model the of components contributing to coastal inundation hazard.

7.2.2 Results

The present-day and future extreme static and dynamic water levels for Port Levy are presented in Table 7.2. The inundation extent and depth associated with 100-year ARI static water levels for 2080 SSP5-8.5 and 2130 SSP5-8.5+ have been mapped based on a bathtub approach using the 2021 LiDAR. Appendix C.12 and Appendix C.13 shows the static inundation extent and depths for the 2080 and 2130 scenarios, respectively.

The low-lying coastal areas in Port Levy, in particular along Wharf Road and Fernlea Point Road, are the most susceptible to static coastal inundation. The assessment indicates that by 2130 the 100-year ARI static water level could extend up to 250 m landward of present-day MHWS.

The extent of dynamic inundation is highly variable and dependant on the nearshore and backshore topography. As waves run up the shoreface they reach a maximum potential height at the coastal edge before decreasing with distance inland due to friction and energy loss. The reduction in run-up height with distance from the coastal edge can be assessed at a site-specific scale however it is generally restricted to 15 to 30 m from the coastal edge. Due to the alongshore variability in topography, the extent of wave run-up (i.e. dynamic inundation) has not been mapped within this assessment. There is also high uncertainty in the future extent of the wave run-up effects as the sea level rises.

A sensitivity analysis for the high VLM rates provided by GNS (2023) has also been undertaken. The comparison between the 2130 inundation extents for the NZ SeaRise VLM rate (-1.7 mm/year) and the GNS (2023) VLM rate (-6.6 mm/year) is shown in Appendix C.14. The comparison shows that based on the topography there is only minor difference in the inundation extent for the different VLM scenarios. The high VLM rate provided by the recent GNS (2023) study increases the static inundation extent up by up to 50 m landward across the low coastal areas near Fernlea Road.

Table 7.2: Summary of present-day and future 10-year and 100-year ARI static water levels

Timeframe	Sea level rise scenario	Relative sea level rise (m)	Extreme static water level (m NZVD16)[1]		Extreme dynamic water level (m NZVD16)[2]	
			10-year ARI	100-year ARI	10-year ARI	100-year ARI
Present-day	N/A	0	1.8	2.1	3.0	3.6
2080	SSP8.5	0.59	2.4	2.6	3.6	4.1
2130	SSP8.5+	1.75	3.5	3.8	4.7	5.3
2130	SSP8.5+	2.27[3]	4.1	4.4	5.3	5.9

1 Storm tide level + wave setup + sea level rise.

2 Storm tide level + wave runup (implicitly includes wave setup) + sea level rise.

3 Sensitivity scenario based on GNS (2023) VLM rate of -6.6 mm/year.

7.3 Rising groundwater

7.3.1 Methodology

Low-lying coastal margins generally have a relationship between groundwater level and sea level. Areas where the land level is only slightly above high tide level (or below it) are more likely to experience flooding or wet ground caused by high groundwater, and sea level rise could cause groundwater to become higher in these areas.

The screening assessment completed by T+T (2021) assumed that for land which is low-lying (below 5 m RL) and close to the coast (within 5 km) the 85th percentile groundwater level is approximately equal to the MHWS high tide level. A rise in sea level is assumed to cause an equal rise in groundwater level along the coastal margin (it is acknowledged that the sea level influence on groundwater level will dissipate with distance further inland from the coast). By comparing this groundwater level to the land level, a modelled depth to the 85th percentile groundwater level has been derived. This is illustrated conceptually in Figure 7.3.

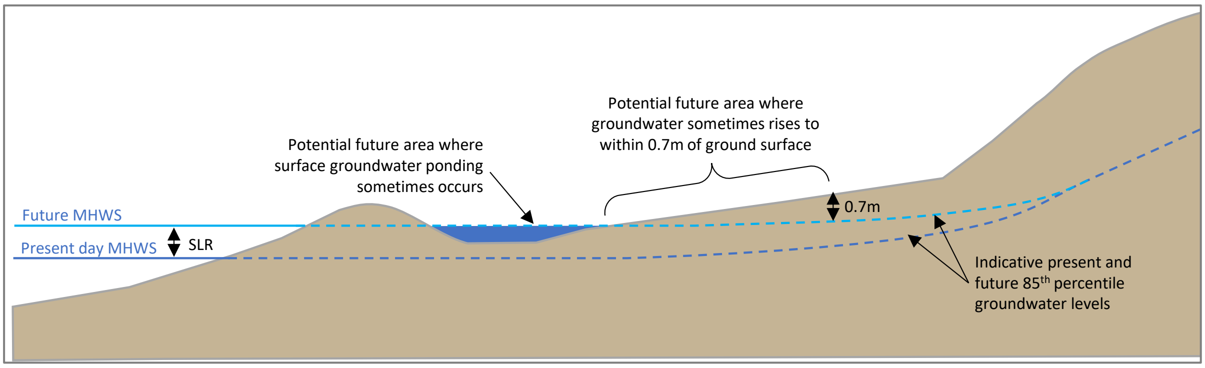

Figure 7.3: Conceptual model for indicative present-day and future groundwater levels for low-lying areas close to the coast within Port Levy.

Using 2021 LiDAR data and the sea level rise scenarios outlined in Table 7.3, mapping has been completed to identify the potential areas where future groundwater may be within 70 cm or above ground level. The following two categories have been mapped:

1. Projected groundwater levels sometimes rise up to or above the ground surface (e.g., surface ponding or increased land drainage demands).

2 Projected groundwater levels sometimes rise to within 0.7 m of the ground surface (e.g., wet/soft ground underfoot or affecting buildings and infrastructure).

Table 7.3: Scenarios and levels used to map potential ground water susceptibility near the coastal margin

Timeframe	Sea level rise scenario	Sea level rise (m)	85th percentile groundwater level up to or above ground surface (m NZVD16)	85th percentile groundwater level within 70cm of ground surface (m NZVD16)
Present-day	N/A	0	0.84	1.5
2080	SSP5-8.5	0.59	1.43	2.1
2130	SSP5-8.5+	1.75	2.59	3.3

7.3.2 Results

The groundwater hazard maps for 2080 and 2130 are presented in Appendix C.16-17 respectively. The groundwater assessment shows a similar hazard extent as the coastal inundation hazard. The low-lying areas around Wharf Road, Fernlea Point Road and Pa Road are likely to be susceptible to elevated groundwater levels in the future as the sea level rises.

8 Summary

A flood risk and coastal hazards assesment has been carried out to inform the design and location of the new Koukourārata / Port Levy area drinking water supply scheme. This included the Te Kawa, Owhetoro and Koukourārata catchments as well as the inner coastline adjacent to the Port Levy township.

Suitable rainfall-runoff parameters were estimated and calibrated using HEC-HMS software under the hydrology assesment to inform the hydraulic flood model for each catchment. Ground terrain levels, rainfall and soil parameters were used to generate maximum modelled water depth and flood hazard maps for six events using TUFLOW software. The hydraulic model was validated against the Diamond Harbour weather station and showed a reasonable correlation to the gauge flows.

The coastal hazards assessment included erosion, inundation and groundwater based on the most recent data from Ministry for the Environment and GNS Science. Current erosion rates along the Port Levy shoreline are typically low, however the weakly consolidated banks do show undercutting in some locations. The results show that by 2130 there is potential for -13 to -35 m of erosion from the present-day shoreline.

The coastal inundation assessment found that the low-lying land along Wharf Road and Fernlea Point Road are the most susceptible to static coastal inundation. The assessment indicates that by 2130 the 100-year average return interval static water level could extend up to 250 m landward of present-day mean high water springs.

Groundwater hazard maps were generated to illustrate that the low-lying areas around Wharf Road, Fernlea Point Road and Pa Road are likely to be susceptible to elevated groundwater levels in the future as the sea level rises.

9 Clarifications and limitations

- The purpose this report is to provide the method and results from the three individual assessments, as opposed to providing an interpretation of model results.

- The flooding assessment focuses mainly on flood flows and does not include assessing base flow (flow duration curves).
- The security of water supply from contributing streams is not included in this scope.
- The flood depth and hazard maps provided represent a present day climate scenario and are not climate change adjusted.
- Limitations for the hydraulic model developed for this assessment is provided in Section 7 of Appendix B.

10 Applicability

This report has been prepared for the exclusive use of our client Christchurch City Council, with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose, or by any person other than our client, without our prior written agreement.

Tonkin & Taylor Ltd
Environmental and Engineering Consultants

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Project Director

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Appendix A Hydrology assesment memo

Memo

To: Brad Tiller

Job No: 1091788.0000

From: John Hansford

Date: 13 December 2023

cc: Richard Brunton

Subject: Port Levy Flooding and Coastal Risk Assessment
Hydrological analysis

1 Introduction

Rainfall-runoff model parameters are required as input to a hydraulic flood model that will be used to assess flood levels in the Te Kawa, Owhetoro and Koukourārata catchments.

A desktop review of available rainfall and stream flow data for the Banks Peninsula has been undertaken. A map showing the gauged catchments and location of streamflow gauges and rainfall stations is shown in Figure 1.1.

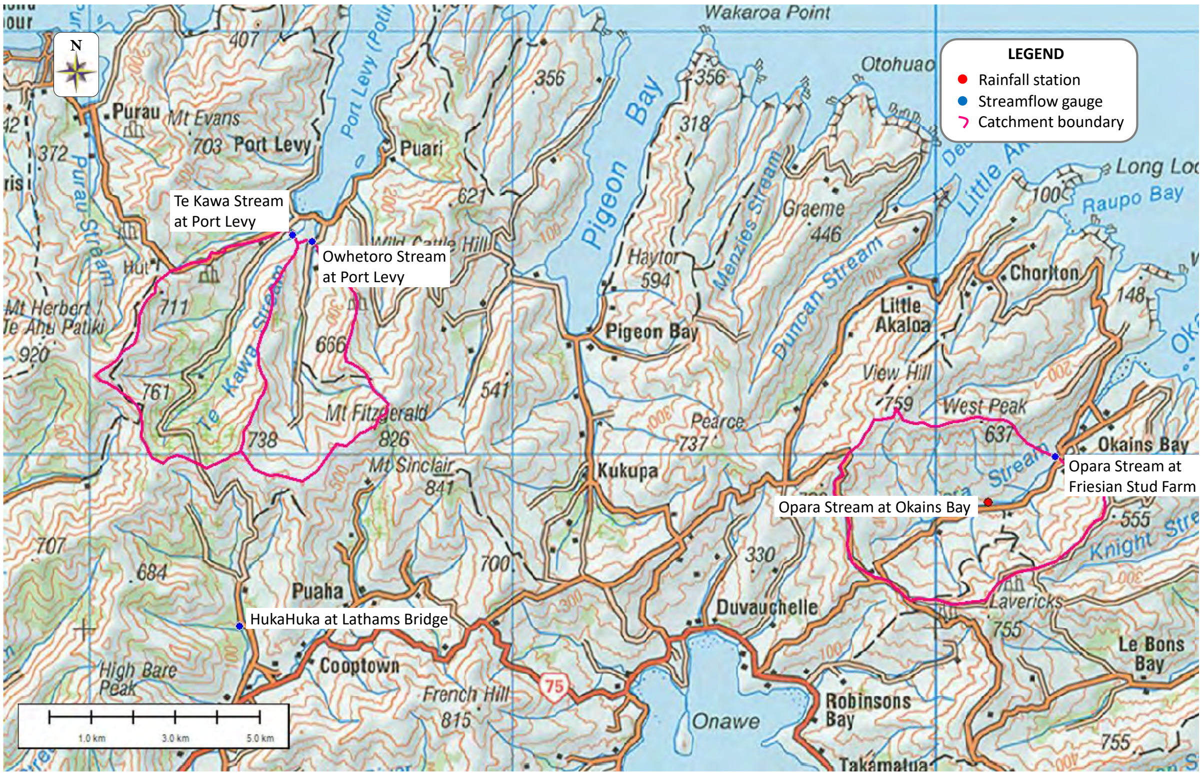

Figure 1.1: Location of catchments, streamflow gauges and rainfall stations used in this study.

Hydrometeorological data in the Banks Peninsula area is limited. There are no rainfall stations in the project catchments and the streamflow gauges in the Te Kawa and Owhetoro streams only began in March 2023. The Opara Catchment has a streamflow gauge at Friesian Stud Farm that started recording in March 1998. There is a rainfall station in near the centroid the catchment with a record from September 2019.

The following sections present:

- Data available for the hydrological analysis;
- Catchment characteristics;
- Rainfall-runoff model calibration to determine suitable parameters for input to a rain-on-grid hydraulic model;
- Design rainfall with and without allowance for climate change for a range of average recurrence interval (ARI) and storm durations; and
- Generation of hyetographs required for the hydraulic flood model.

2 Data

Rainfall data for the from 26 September 2019 to 18 August 2023 was obtained from NIWA for rainfall station 337001 Opara Stream at Okains Bay. From 3 March 2021 to 29 May 2021 and then from 22 October 2021 to 27 December 2021 there is no data.

None of the other streamflow gauges on the Banks Peninsular have suitably located rainfall stations that could provide catchment rainfall.

Environment Canterbury (ECan) have provided recorded streamflow data for the Opara Stream at Friesian Stud Farm from 25 March 1998 to 26 July 2023.

New Zealand River Flood Statistics (NZRFS) provides frequency analysis results based on a 16 year period, which is considered too short for confidence in the frequency distribution, particularly for less frequent events.

HIRDS[1] rainfall data were downloaded for locations near the centroids of the Opara, Te Kawa, Owhetoro and Koukourārata catchments. The rainfall depth data is included as Appendix A1 and in a spreadsheet together with the HIRDS temporal distributions[2] for 1, 2, 3, 6, 12, 24, 48 and 72 hour storms (the 2 hour and 3 hour temporal distributions were interpolated between the 1 hour and 6 hour cumulative rainfall functions. The 'East of SI' region was used for the temporal distributions.

3 Frequency analysis

Twenty-six annual maxima were extracted from the streamflow record provided by ECan for the Opara Stream at Friesian Stud Farm and input to our frequency analysis software. The best fitting frequency distributions are shown together with the data in Figure 3.1.

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[1] https://hirds.niwa.co.nz/

[2] Distributions from NIWA 'High Intensity Rainfall Design System Version 4', technical report dated August 2018.

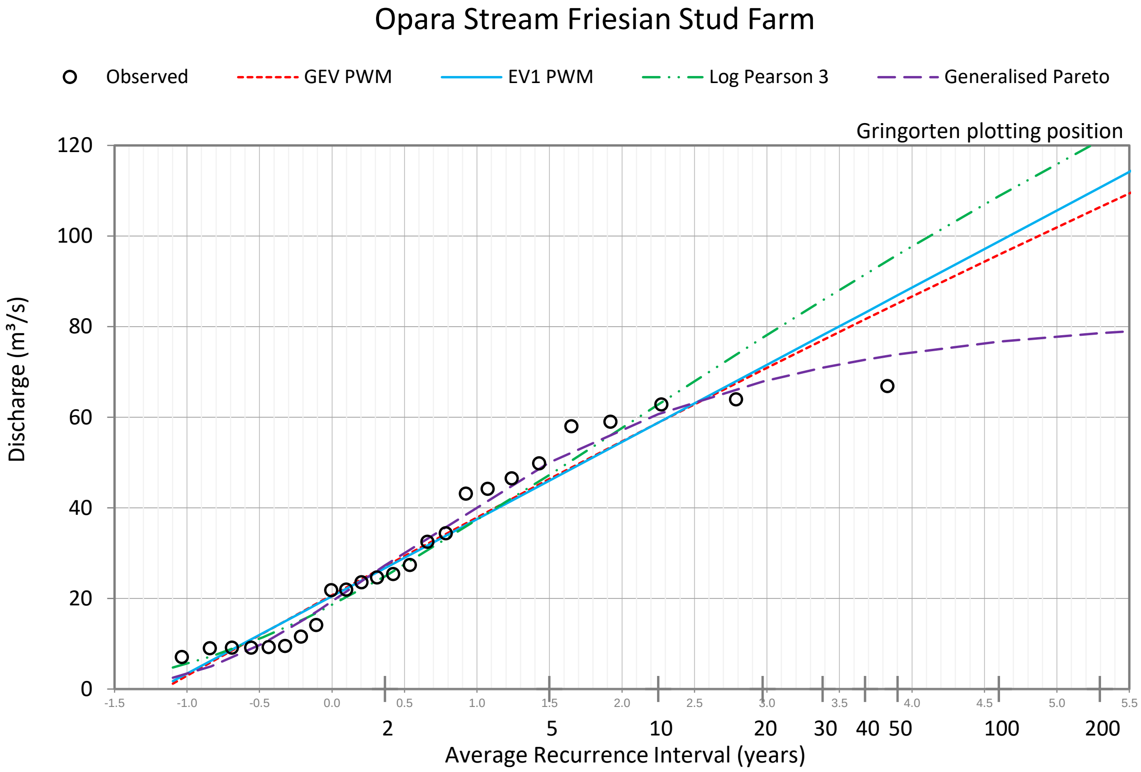


Figure 3.1: Opara Stream at Friesian Stud Farm: frequency analysis results.

Figure 3.1 shows that the three highest recorded annual flood peaks have a very similar discharge, which causes the Generalised Pareto distribution to be strongly concave down and statistically the best fit to the data. Statistically, the Log Pearson 3 (LP3) distribution is the next best fit to the data followed by the General Extreme Value (GEV) and Extreme Value Type 1 (EV1) distributions. For the frequency calibration, the simulated flood peaks were compared to the LP3, GEV, EV1 and the NZRFS distributions.

4 Rainfall-runoff model

HEC-HMS with the initial loss (Ia) and constant loss (CL) parameters and Clark Unit Hydrograph was selected for this study. The model was set up and calibrated to determine suitable Ia and CL values for input to a rain-on-grid model for the Te Kawa, Owhetoro and Koukourārata catchments. The model will also be used to generate lumped catchment design hydrographs at locations selected by the flood modeller.

4.1 Model calibration

Streamflow and rainfall data for the Opara Stream was used to calibrate the HEC-HMS model because there is no sufficient data for the three project catchments.

4.1.1 Catchment characteristics

The streamflow gauge at Friesian Stud Farm in the Opara Stream has a catchment area of 21 km^2. The equal area slope along the longest watercourse is 4.3% and the time of concentration (Tc), estimated using the United States Bureau of Reclamation formula, is 1.25 hours. The Landcare Research soil permeability map classifies approximately 35% of the catchment as moderate over slow permeability with the rest moderate permeability, suggesting infiltration rate in the range 1 to

4 mm/hr. From the Google Earth imagery, the catchment is predominantly grass used for grazing and recreation.

4.1.2 Event based calibration

Three of the recorded larger flood events, with rainfall data recorded at the Okains Bay rainfall station, were selected for calibrating the model. The model parameters and simulated and observed flows are shown in Figure 4.1 to Figure 4.3. The plots all show reasonable simulation of the observed events. The differences are attributed to how well the observed rainfall represents rainfall on the catchment. The Ia parameter represents antecedent conditions and was set to zero because all the events had appreciable rainfall prior to the calibration event.

The model parameters for the three events are summarised in Table 4.1.

Table 4.1: Summary of event based HEC-HMS parameters

Event	CL (mm/hr)	Tc (hrs)	R (hrs)
May 2021	2	1	2
July 2022	1	0.8	1.2
July 2023	1.5	1	2

Observed peak discharge 37 m^3/s Simulated peak discharge 36 m^3/s

Ia	0
CL	2
Tc	1
R	2

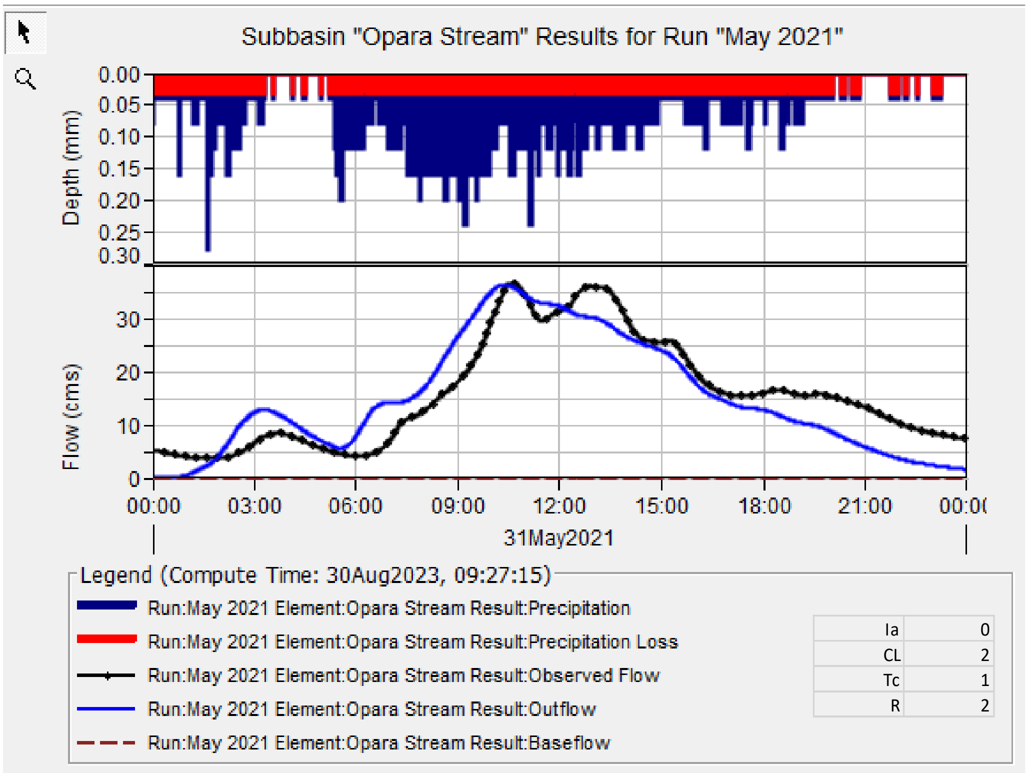


Figure 4.1: Opara Stream at Friesian Stud Farm: 31 May 2021.

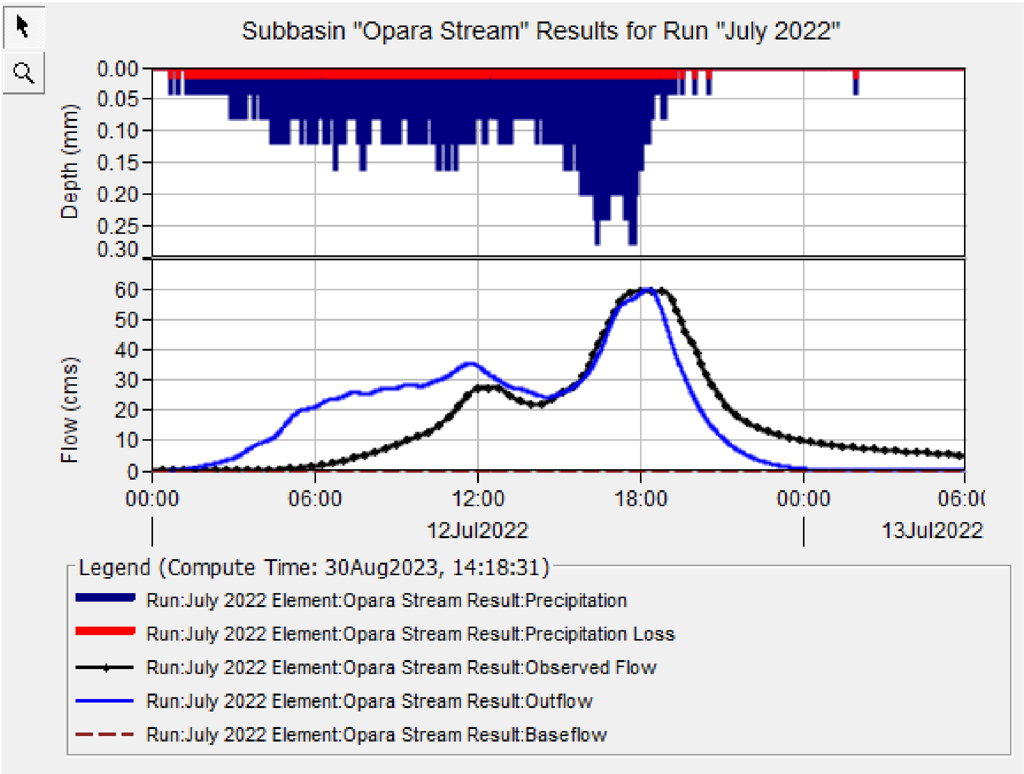
<table>
<tr><td colspan="3">Observed peak discharge 59 m^3/s Simulated peak discharge 60 m^3/s</td></tr>
<tr><td>Ia</td><td>0</td><td rowspan="4"> </td></tr>
<tr><td>CL</td><td>1</td></tr>
<tr><td>Tc</td><td>0.8</td></tr>
<tr><td>R</td><td>1.2</td></tr>
</table>

Figure 4.2: Opara Stream at Friesian Stud Farm: 12 July 2022.

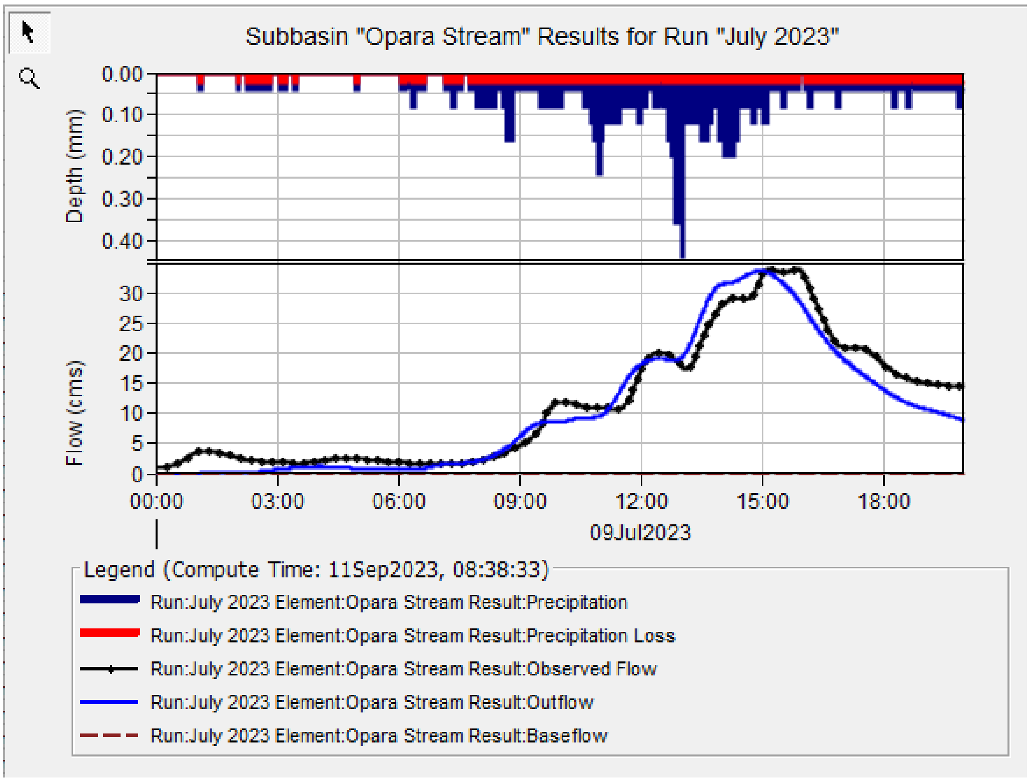
<table>
<tr><td colspan="3">Observed peak discharge 34 m^3/s Simulated peak discharge 34 m^3/s</td></tr>
<tr><td>Ia</td><td>0</td><td rowspan="4"> </td></tr>
<tr><td>CL</td><td>1.5</td></tr>
<tr><td>Tc</td><td>1</td></tr>
<tr><td>R</td><td>2</td></tr>
</table>

Figure 4.3: Opara Stream at Friesian Stud Farm: 9 July 2023.

4.1.3 Flood frequency calibration

The assumption for the flood frequency calibration is that the ARI of rainfall is the same as the ARI of the resulting flood, which is essentially what we do determining floods from design rainfall.

Flood hydrographs were generated from rainfall for ARI of 5, 10, 20, 50, 100 and 250 years and storm durations of 1, 2, 3, 6, 12 and 24 hours. The largest simulated flood peak for each ARI were compared to the frequency analysis results.

Simulations were carried using the model parameters from the event-based calibrations. Plots showing the comparison between the simulated distribution and the frequency analysis results are shown in Figure 4.4 to Figure 4.6.

The plots comparing the frequency distribution simulated using the model parameters determined for the May 2021 and July 2023 events correlate well with the LP3 distribution as shown in Figure 4.4 and Figure 4.6 but Figure 4.5 shows that the simulated frequency distribution using the July 2022 parameters is much higher than the LP3 distribution.

Ia	0
CL	2
Tc	1
R	2

Figure 4.4: Comparison of simulated and frequency analysis (May 2021 parameters).

Based on the calibration results Ia = 0 mm, CL = 1.5 mm/hr, Tc = 1 hour (80% of USBR estimate) and R = 2 hours (double Tc) were adopted for the Opara Stream catchment. CL = 1.5 mm/hr was selected as a conservative estimate for determining flood discharge rather than 2 mm/hr that fits the frequency analysis plots slightly better for less frequent events.

Ia	0
CL	1
Tc	0.8
R	1.2

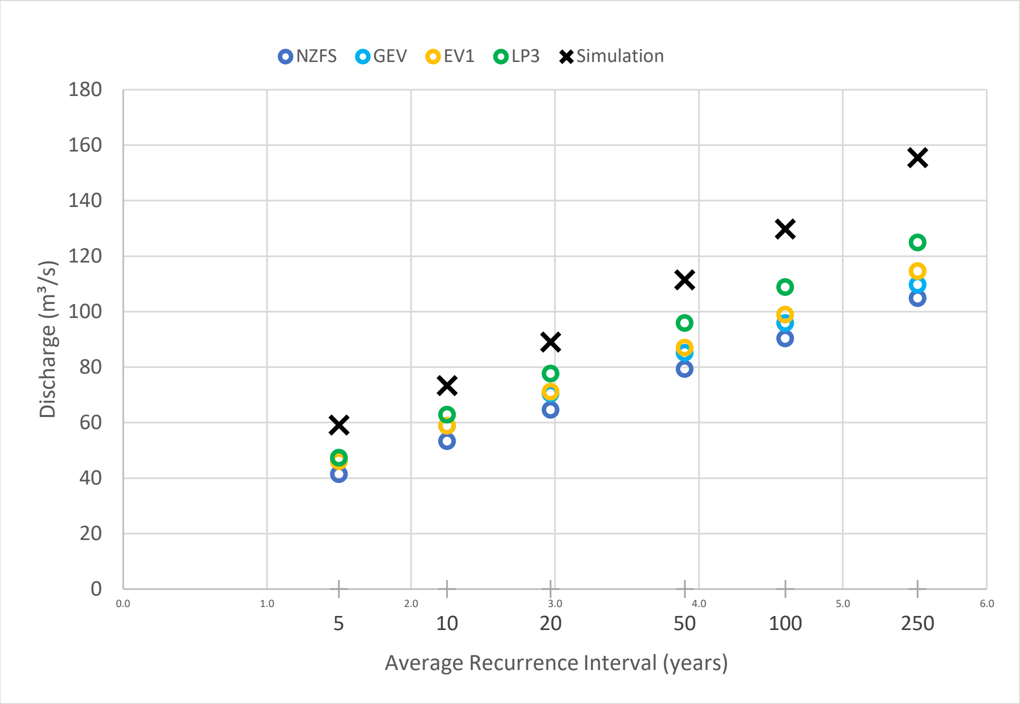


Figure 4.5: Comparison of simulated and frequency analysis (July 2022 parameters).

Ia	0
CL	1.5
Tc	1
R	2

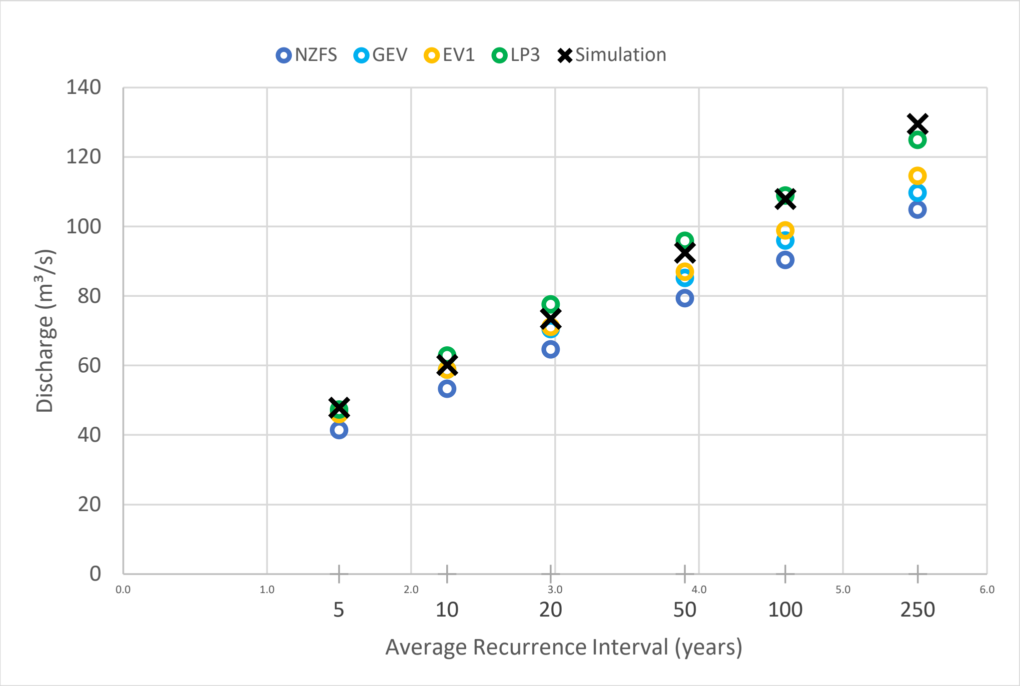


Figure 4.6: Comparison of simulated and frequency analysis (July 2023 parameters).

5 Model parameters for project catchments

The Landcare Research soil permeability and land use in the project catchments are shown in Figure 5.1 and Figure 5.2.

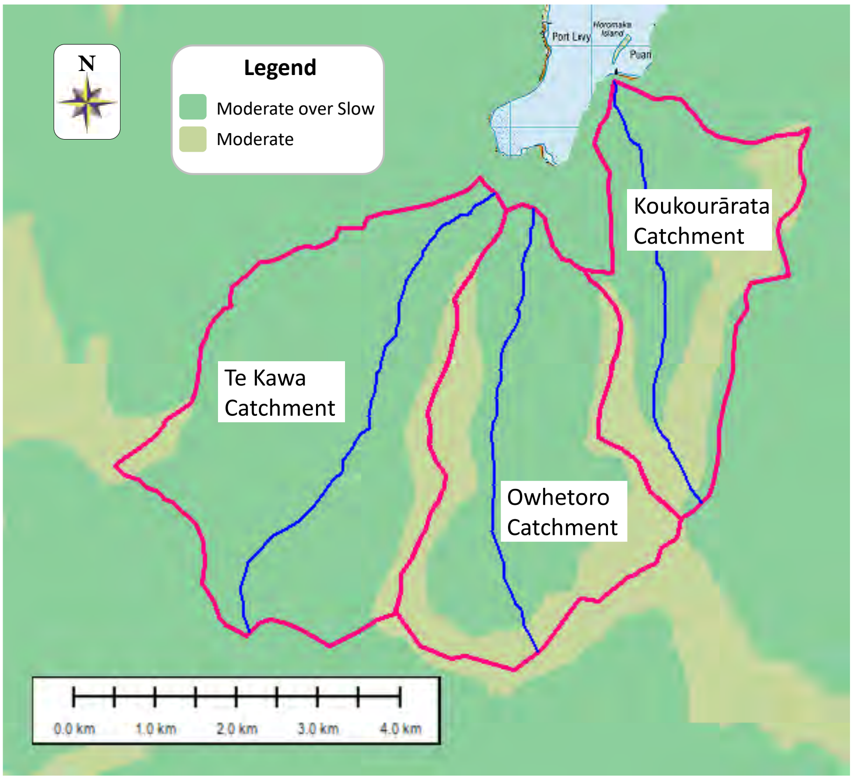


Figure 5.1: Landcare Research Permeability Map.

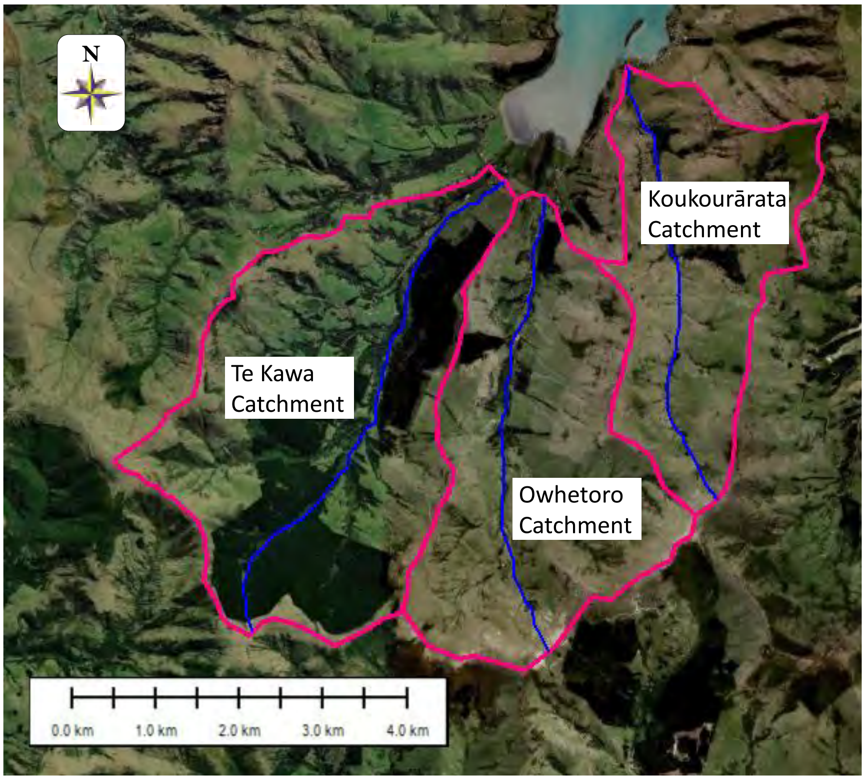


Figure 5.2: Land use.

Based on the land use and soil permeabilities, CL for the Owhetoro and Koukourārata catchments is expected to be similar to CL determined for the Opara Catchment and a CL of 1.5 is appropriate. The Te Kawa Catchment will have lower CL due to the lower soil permeability but runoff from this catchment will also be reduced due to the forest cover (approximately 50%).

A CL of 1.5 mm/hr is considered appropriate for the project catchments with sensitivity analyses using a CL of 1 mm/hr.

6 Recommendations

Based on the calibration results Ia = 0 mm, CL = 1.5 mm/hr, Tc = 1 hour (80% of the USBR estimate) and R = 2 hours (double Tc) were found to result in the best approximation of peak flows for the Opara Stream catchment.

CL of 1.5 mm/hr is recommended for the project catchments.

Appendix A1: HIRDS rainfall data (Historic)

- **Opara Catchment**
- **Te Kawa Catchment**
- **Owhetoro Catchment**
- **Koukourārata Catchment**

Opara catchment : Historical Data : Aerial reduction for 21 km² catchment

ARI	Storm duration (hours)								
	1	**2**	**3**	**6**	**12**	**24**	**48**	**72**	**96**
5	14.0	22.4	29.4	46.4	71.8	107.9	155.5	187.8	212.0
10	17.2	27.4	36.0	56.6	87.5	131.0	188.1	226.7	255.6
20	20.7	32.9	43.1	67.8	104.4	155.8	222.8	268.0	301.6
50	25.8	41.0	53.6	83.9	128.6	191.2	272.2	326.4	366.7
100	30.1	47.6	62.2	97.0	148.3	219.7	311.7	373.1	418.5
250	36.1	57.0	74.2	115.4	175.7	259.0	365.8	436.6	488.7

Te Kawa Catchment : Historical Data : Aerial reduction for 15 km² catchment

ARI	Storm duration (hours)								
	1	**2**	**3**	**6**	**12**	**24**	**48**	**72**	**96**
5	14.8	23.3	31.8	47.1	72.0	106.8	151.9	182.1	204.5
10	18.2	28.5	37.0	57.5	87.6	129.5	183.4	219.5	246.1
20	21.9	34.2	44.4	68.7	104.4	153.8	217.1	259.2	290.2
50	27.3	42.6	55.1	85.0	128.6	188.6	265.1	315.7	352.8
100	31.8	49.5	64.0	98.4	148.3	216.8	303.7	360.9	402.7
250	38.2	59.2	76.4	117.1	175.8	255.9	356.8	422.8	470.9

Owhetoro Catchment : Historical Data : Aerial reduction for 11.5 km² catchment

ARI	Storm duration (hours)								
	1	**2**	**3**	**6**	**12**	**24**	**48**	**72**	**96**
5	15.1	23.6	30.7	47.8	73.2	108.7	155.0	186.2	209.5
10	18.6	29.0	37.5	58.3	89.0	131.8	187.3	224.6	252.3
20	22.3	34.8	45.0	69.7	106.1	156.6	221.8	265.4	297.7
50	27.9	43.3	59.1	86.3	130.8	192.2	270.9	323.3	361.9
100	32.5	50.4	64.9	99.8	150.9	221.0	310.4	369.7	413.2
250	39.1	60.4	77.6	118.9	178.9	260.8	364.8	433.2	483.3

Koukourarata Catchment : Historical Data : Aerial reduction for 8.5 km² catchment

ARI	Storm duration (hours)								
	1	**2**	**3**	**6**	**12**	**24**	**48**	**72**	**96**
5	14.5	22.8	30.8	46.2	70.4	103.9	146.5	174.5	194.9
10	17.8	27.9	36.3	56.4	85.7	125.9	176.9	210.2	234.5
20	21.4	33.5	43.5	67.4	102.0	149.5	209.2	248.1	276.3
50	26.7	41.7	54.0	83.3	125.6	183.1	255.1	301.7	335.3
100	31.1	48.4	62.6	96.3	144.7	210.2	291.8	344.4	382.2
250	37.3	57.9	74.8	114.4	171.2	247.6	342.1	402.6	445.9

Appendix B Hydraulic flood model build report

B1 Present day climate 5-year ARI rainfall + 10-year tide flood map

B2 Present day climate 10-year ARI rainfall + 10-year tide flood map

B3 Present day climate 20-year ARI rainfall + 10-year tide flood map

B4 Present day climate 50-year ARI rainfall + 10-year tide flood map

B5 Present day climate 100-year ARI rainfall + 10-year tide flood map

B6 Present day climate 250-year ARI rainfall + 10-year tide flood map

B7 Present day climate 20-year ARI rainfall + 100-year tide flood map

B8 Present day climate 5-year ARI rainfall + 10-year tide hazard map

B9 Present day climate 10-year ARI rainfall + 10-year tide hazard map

B10 Present day climate 20-year ARI rainfall + 10-year tide hazard map

B11 Present day climate 50-year ARI rainfall + 10-year tide hazard map

B12 Present day climate 100-year ARI rainfall + 10-year tide hazard map

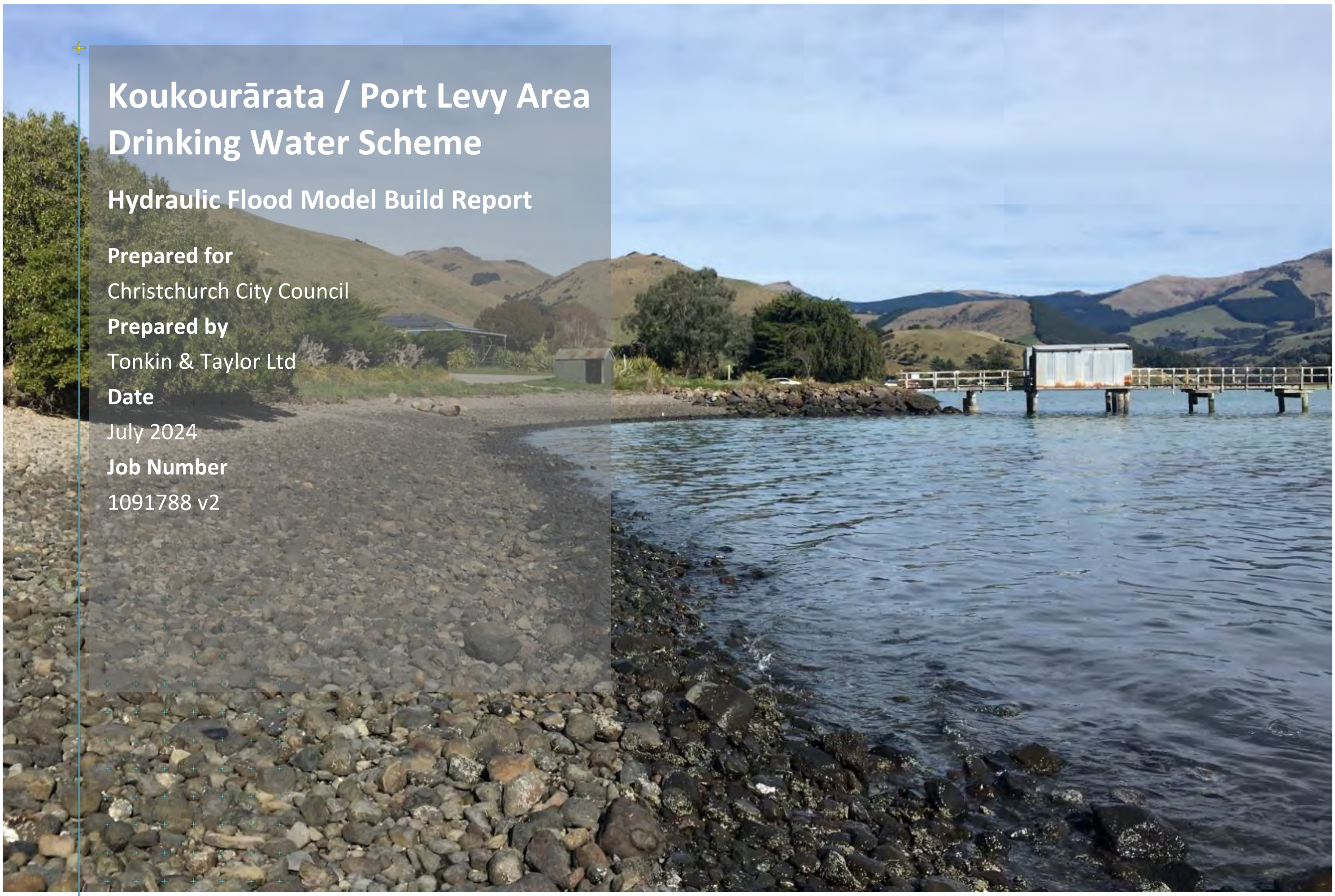
B13 Present day climate 250-year ARI rainfall + 10-year tide hazard map

B14 Present day climate 20-year ARI rainfall + 100-year tide hazard map

B15 100-year ARI rainfall + 10-year tide low roughness difference map

B16 100-year ARI rainfall + 10-year tide high roughness difference map

REPORT



Koukourārata / Port Levy Area Drinking Water Scheme

Hydraulic Flood Model Build Report

Prepared for
Christchurch City Council
Prepared by
Tonkin & Taylor Ltd
Date
July 2024
Job Number
1091788 v2

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Document control

Title: Koukourārata / Port Levy Area Drinking Water Scheme					
Date	**Version**	**Description**	**Prepared by:**	**Reviewed by:**	**Authorised by:**
19/12/2023	1	Draft for client review	E Fairclough	R Brunton	P Cochrane
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Christchurch City Council	1 PDF copy
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Table of contents

1 Introduction

Tonkin & Taylor Ltd (T+T) was engaged by Christchurch City Council (CCC) to undertake a flood risk and coastal hazards assesment to inform the design and location of the new Koukourārata / Port Levy area drinking water supply scheme.

The purpose of this technical report is to provide more detailed methodology and analysis relating to the hydraulic flood model information overviewed in the flooding and coastal hazards risk assessment[1] (herein the 'T+T summary report'). For clarity, appendices referenced in this report can be found in the T+T summary report.

2 Model purpose

The purpose of the hydraulic flood model was to simulate the behaviour of surface water flow during rainfall events within the Te Kawa, Owhetoro and Koukourārata catchments located in Port Levy, Banks Peninsula. Specifically, the model was used to predict the maximum water depths and flood hazard within the three catchments for several different magnitude rainfall events.

3 Model build

3.1 Model software

The model was developed in 2-dimensional TUFLOW HPC software, release version 2023-AC. The model was developed in TUFLOW software. TUFLOW is a 2-dimensional hydraulic modelling software that predicts water surface flow across a defined extent based on inputs such as ground terrain levels, rainfall and soil parameters. The model adopts an adaptive timestep approach.

3.2 Datums

The model adopts the following datums:

- Horizontal: New Zealand Transverse Mercator (NZTM).
- Vertical: NZVD 2016.

3.3 Model extent

The hydraulic model extent is shown in Figure 3.1. The hydraulic model extent was agreed with CCC in the project Statement of Work[2]. There are three primary catchments within the model extent, including:

- Te Kawa: 1,484 ha.
- Owhetoro: 1,269 ha.
- Koukourārata: 1,064 ha.

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[1] Koukourārata / Port Levy Area Drinking Water Scheme, Flooding and Coastal Hazards Assesment, Job No: 1091788.000 v1, dated December 2023.

[2] Koukourārata / Port Levy Area Flooding and Coastal Hazards Risk Assessment', dated 22 August 2023.

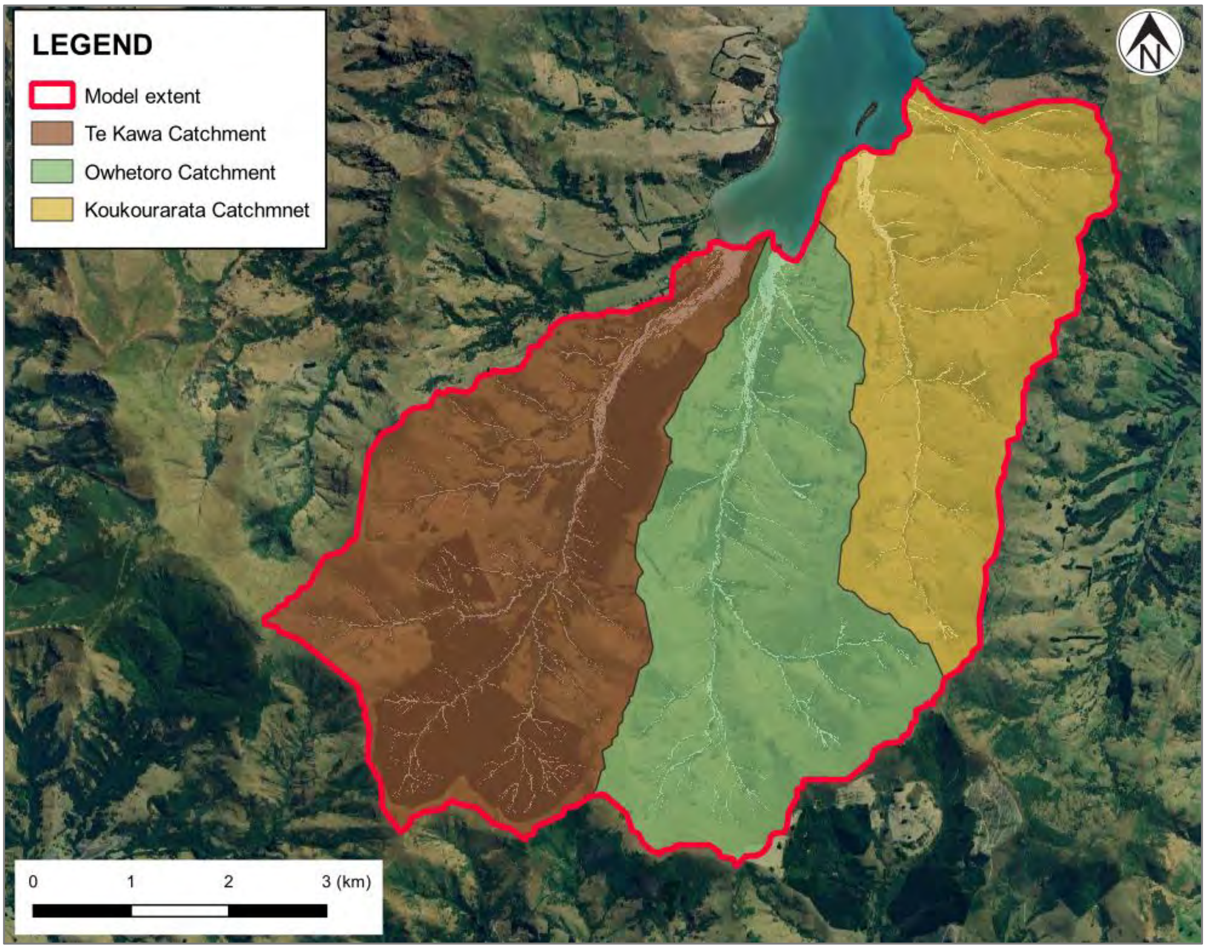

Figure 3.1: Hydraulic model extent and catchments.

3.4 Model topography

The ground levels within the model extent were established using a 1 m x 1 m (1 m^2) gridded bare earth Digital Elevation Model (DEM). The bare earth DEM was sourced from Land Information New Zealand (LINZ) publicly available LiDAR dataset, 2018-2019 LiDAR DEM[3] captured between 2018 and 2019. The DEM is shown in Figure 3.2.

More recent 2020-2022 LiDAR is available for a small area of the model extent. However, due to the lack of coverage, it was not used for the model. Where areas of the 2018-2019 and 2020-2022 LiDAR overlap, the differences in ground levels are minor.

The DEM represents a bare earth terrain with all buildings and above-ground features having been removed. Using this approach, it is sometimes possible that flooding is shown to occur through the area occupied by large buildings. This is because the model does not recognise these as buildings and works only off the DEM. Care should therefore be exercised in the interpretation of results, particularly in areas where there is a high percentage of ground area covered by above-ground features (trees, buildings, etc). Other features, such as major bridge structures are removed from the terrain, such that these are represented as open channels in the model.

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[3] Metadata for the layer can be found at https://data.linz.govt.nz/layer/105027-canterbury-banks-peninsula-lidar-1m-dem-2018-2019/.

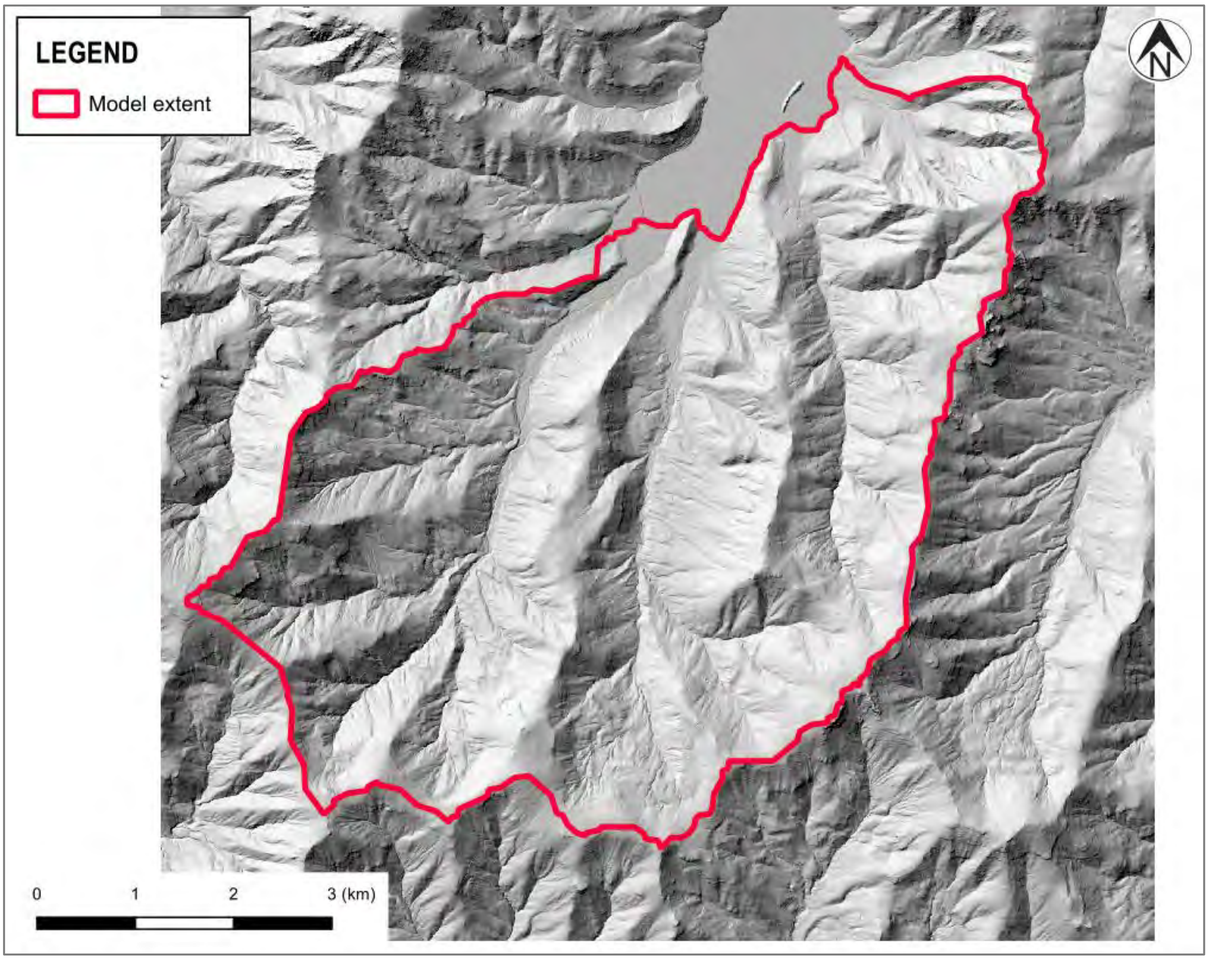

Figure 3.2: 2018-2019 bare earth DEM.

The computational grid cell size within the model is 2 m x 2 m (4 m^2) applied over the entire model extent. In spite of the 2 m x 2 m computational grid cell size, the model applies sub-grid sampling to the computational grid. Sub-grid sampling facilitates improved conveyance and storage within large grid cells by sampling the underlying DEM at its original resolution of 1 m x 1 m.

3.5 Model boundaries

The model has the following boundaries:

1 Rainfall boundary.

2 Downstream tidal boundary.

3 Free flow boundary.

A summary of these boundaries is provided below.

3.5.1 Rainfall boundary:

Rainfall was applied to the model using a rain-on-grid approach. With this approach, rainfall is spatially distributed across the entire model extent.

Rainfall depths for the 5-year, 10-year, 20-year, 50-year, 100-year and 250-year Average Return Interval (ARI) events were sourced from NIWA's High Intensity Rainfall Design System[4] (HIRDS) V4.

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[4] *https://hirds.niwa.co.nz/*, data sourced November 2023.

The HIRDS data extraction point was selected at the mid-point of each catchment so that variation in rainfall associated with elevation was accounted for. No climate change allowance was assumed for the rainfall depths as agreed with CCC in the Statement of Work. The rainfall adopted for the model is considered “present day” climate.

Aerial reduction factors (ARF) were applied to the HIRDS rainfall depths to account for the lower probability that a predicted rainfall depth will occur across an entire catchment. ARF were sourced from the NIWA report ‘*High Intensity rainfall Design System Version 4*’, August 2018. ARF factors vary with ARI, rainfall duration and catchment area. Table 3.1 shows the total rainfall depths adopted for the model (after the application of ARF).

Table 3.1: Total rainfall depths

Scenario/Catchment	Total rainfall depth (mm)					
	1-hour	6-hour	12-hour	24-hour	48-hour	72-hour
5 year present day						
Te Kawa	14.8	47.1	72.0	106.8	151.9	182.1
Owhetoro	15.1	47.8	73.1	108.6	154.9	186.2
Koukourārata	14.5	46.2	70.4	103.9	146.5	174.5
10 year present day						
Te Kawa	18.2	57.5	87.6	129.5	183.5	219.5
Owhetoro	18.5	58.3	88.9	131.7	187.2	224.5
Koukourārata	17.8	56.4	85.7	125.9	176.9	210.2
20 year present day						
Te Kawa	21.9	68.7	104.4	153.8	217.1	259.2
Owhetoro	22.3	69.7	106.2	156.5	221.7	265.3
Koukourārata	21.4	67.4	102.0	149.5	209.2	248.1
50 year present day						
Te Kawa	27.3	85.0	128.6	153.8	265.1	315.6
Owhetoro	27.8	86.3	130.6	192.0	270.8	323.1
Koukourārata	26.7	83.3	125.6	183.1	255.1	301.7
100 year present day						
Te Kawa	31.8	98.4	148.3	216.8	303.7	360.9
Owhetoro	32.4	99.8	150.7	220.8	310.3	369.5
Koukourārata	31.1	96.3	144.7	210.2	291.8	344.4
250 year present day						
Te Kawa	38.2	117.1	175.8	255.9	356.8	422.8
Owhetoro	38.9	118.9	178.7	260.6	364.6	433.0
Koukourārata	37.3	114.4	171.2	247.6	342.1	402.6

The HIRDS rainfall depths were transformed into rainfall hyetographs using a modified HIRDS temporal distribution. The HIRDS distribution for ‘East of South Island’ as defined in the NIWA report ‘*High Intensity rainfall Design System Version 4*’, August 2018 was adopted.

A temporal storm provides a more realistic representation of rainfall compared to an alternative approach such as a nested storm. The HIRDS temporal distribution was modified based on work undertaken by Christchurch City Council (CCC) which slightly reduces the peak to create a smooth ascending and descending limb transition.

Hyetographs were derived for the 5-year, 10-year, 20-year, 50-year, 100-year and 250-year ARI using the HIRDS temporal distribution. Several duration events including 1-hour, 6-hour and 12-hour were tested in the model to identify the critical duration for each catchment (i.e., the event duration which results in the highest water depth).

The model testing found that the 1-hour duration resulted in the highest water depth for all catchments and ARI except for the 5-year and 10-year ARI events, where the 6-hour event was higher in some areas. A 0.5-hour constant intensity event was also tested but predicted a lower water depth compared to the 1-hour duration. It was not necessary to model longer duration events as the critical duration of the catchments was predicted by the model to be 1-hour.

Figure 3.3 show the HIRDS temporal distribution for the 1-hour, 6-hour and 12-hour events. The distributions are normalised so that the figure is independent of ARI.

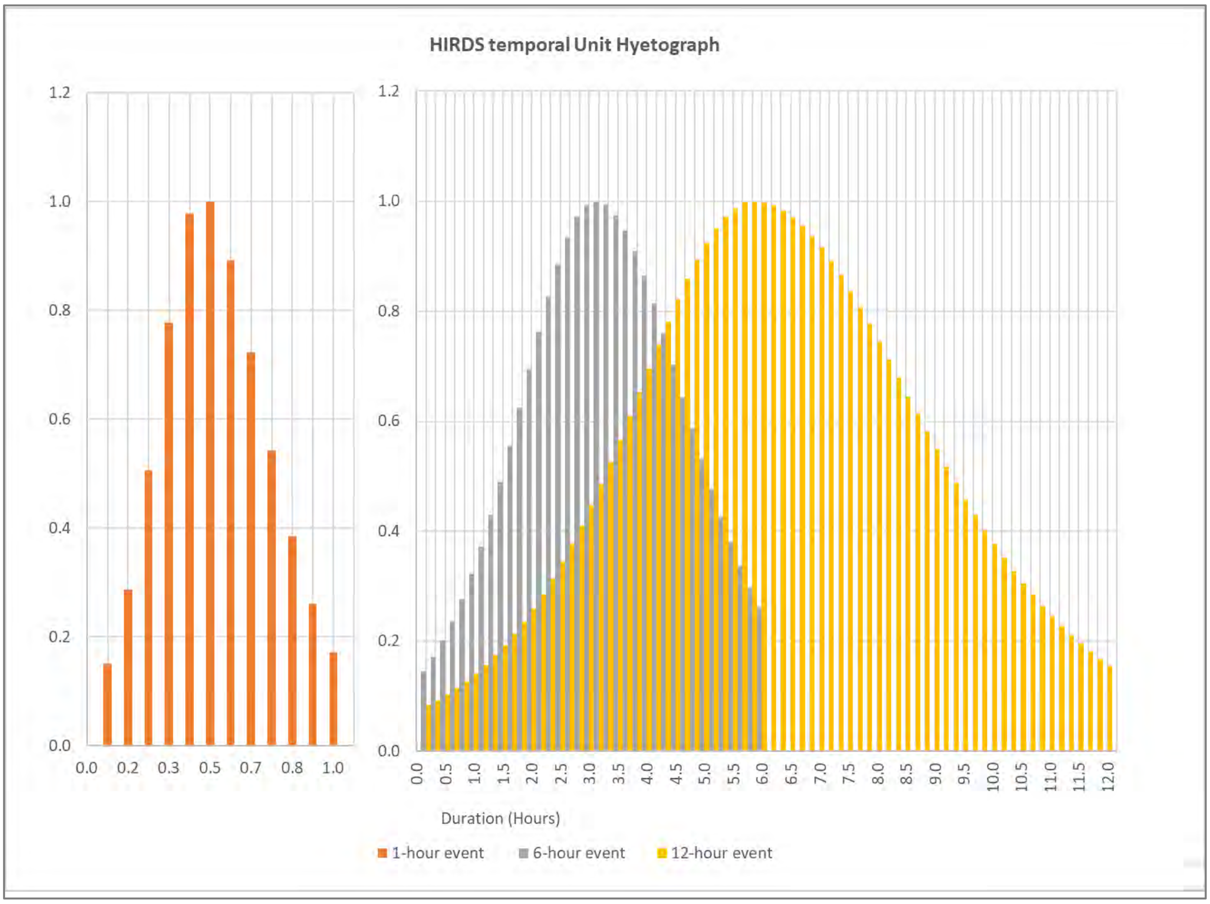


Figure 3.3: HIRDS temporal distribution (normalised).

3.5.2 Downstream tide boundary

The downstream tide boundary was implemented in the model as a static water level at 1.8 m (NZVD2016 datum) assuming 10-year ARI present day climate conditions. Refer to Appendix C of the T+T summary report for further information regarding predicted tide levels.

An additional model running with 100-year ARI tide (2.1 m) and 20-year ARI rainfall was also completed. Other combinations of rainfall and tide ARI conditions are possible which will result in different modelled water depths in the lower areas of the catchment.

3.5.3 Free flow boundary

A free flow boundary was used to allow water to flow out of the model boundary and prevent any "glass wall effect" (i.e., water ponding up at the model boundary) which can result in artificial and inaccurate flood results.

3.6 Surface roughness & soil infiltration

3.6.1 Surface roughness

Hydraulic roughness applied to a model is generally obtained via calibration to observed performance. However, calibration of gridded hydrological models, such as that used in this modelling work, requires significant flood observations to adequately characterise catchment flood performance. For this model, we understand there to be no suitable calibration data available, and as such we have adopted the approach of applying "textbook" roughness to different land cover types.

Surface roughness was represented in the model using a Manning's 'n' approach. Manning's 'n' values were spatially distributed across the model extent based on land use types defined by the Land Cover Database Version 5 (LCDBv5). Manning's 'n' values generally follow the ARR [5](2019) Guideline values.

A separate Manning's 'n' was included for roads (road centreline sourced from LINZ). A separate Manning's 'n' value was included for streams (buffered 5 m from stream centreline sourced from LINZ). Figure 3.4 shows the land use types adopted for the model. Corresponding Manning's 'n' values for each land use type are provided in Table 3.2.

---

[5] Ball J, Babister M, Nathan R, Weeks W, Weinmann E, Retallick M, Testoni I, (Editors) Australian Rainfall and Runoff: A Guide to Flood Estimation, © Commonwealth of Australia (Geoscience Australia), 2019.

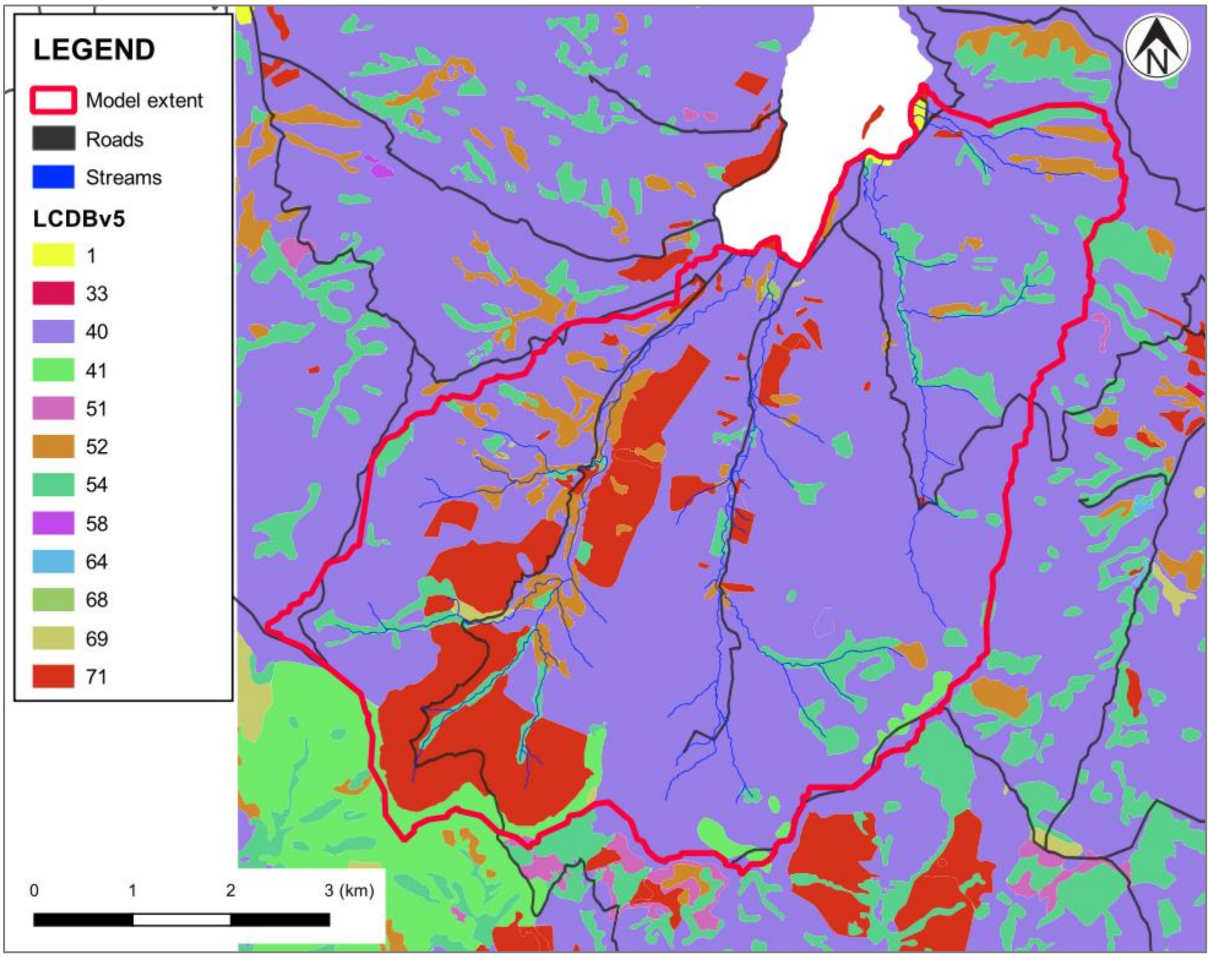


Figure 3.4: Land use types.

Table 3.2: Manning's 'n' values

Land use type ID	Manning's 'n'	Description
1	0.068	Built-up Area (settlement)
33	0.32	Orchard, Vineyard or Other Perennial Crop
40	0.06	High Producing Exotic Grassland
41	0.06	Low Producing Grassland
51	0.4	Gorse and/or Broom
52	0.4	Manuka and/or Kanuka
54	0.4	Broadleaved Indigenous Hardwoods
58	0.4	Matagouri or Grey Scrub
64	0.011	Forest - Harvested
68	0.36	Deciduous Hardwoods
69	0.4	Indigenous Forest
71	0.32	Exotic Forest
88	0.02	Road
21	0.04	River

3.6.2 Soil infiltration

Soil infiltration refers to the process by which water enters and penetrates the soil surface. Soil infiltration allows a portion of the rainfall to enter the soil, thereby reducing the amount of runoff.

Soil infiltration was represented in the model using the initial loss /constant loss approach with an initial loss of 0 mm and constant loss of 1.5 mm/hr. An initial loss of 0 mm assumes that the catchment antecedent conditions prior to the design event occurring are wet. This will result in more flooding compared to dry antecedent conditions. Refer to Appendix A of the T+T summary report for further information regarding the initial loss/constant loss approach.

3.7 Hydraulic structures

There are several hydraulic structures including culverts, stormwater pipes and bridges within the model extent. Data regarding hydraulic structures was obtained from CCC, including:

- Design drawings for the Fernlea bridge (Owhetoro Stream).
- CCC Three Waters Asset Network Map (culverts and pipes).

It was assumed that both Fernlea Point Road bridges on either side of the Fernlea point have identical dimensions and shape due to only a drawing of one of the bridges able to be sourced. Based on imagery, these two bridges appear to have similar geometry. The bridge dimension assumptions are not likely to have a significant effect on water depths as both bridges are overtopped in all modelled events.

The following culverts were included in the model due to their impact on hydraulic properties and outputs of the model:

- Western valley road culverts (Te Kawa Catchment).
- Richfield Road Culvert (Owhetoro Catchment).
- Port Levy Pigeon Bay Road Culverts (Koukourārata Catchment).
- Pa Road Culvert (Koukourārata Catchment).
- Putiki and Purari Road Culverts (Koukourārata Catchment).

Smaller pipes/culverts were not included in the model as the conveyance of these pipes/culverts during flood events has minimal influence on flooding.

4 Model validation

NIWA maintain streamflow gauges on both the Owhetoro and Te Kawa Streams (located approximately 500 m upstream from the coast). Recorded flow data is available for these gauges from March 2023 to December 2023. Over this period, two relatively moderate flood events occurred within the catchments, both in July 2023. The recorded flow from the two streamflow gauges is shown in Figure 4.1.

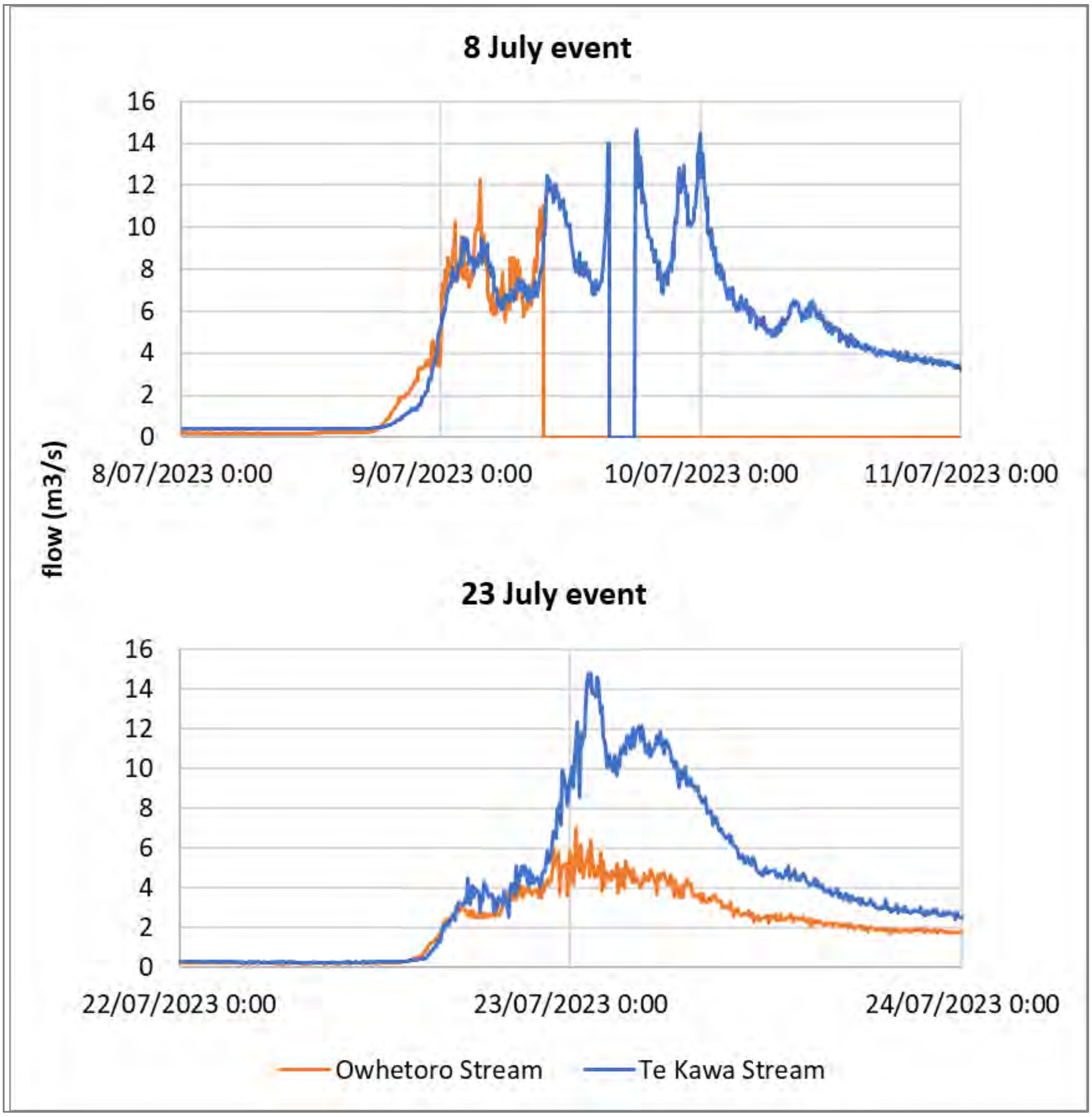


Figure 4.1: Recorded flow data - July events.

Note, the Owhetoro gauge failed part way through the 8 July event. Figure 4.1 indicates that during the 8 July event, flows were relatively similar in both catchments up until the Owhetoro gauge failed. Given the catchments have similar areas and hydrological properties, and assuming rainfall was similar within the two catchments, this is an expected result. During the 23 July event, flow in the Owhetoro was significantly lower than the Te Kawa. This suggests that less rainfall fell within the Owhetoro catchment during the event.

There are no available rainfall stations within the Owhetoro and Te Kawa catchments for the July events. Rainfall station data from other surrounding catchments within Banks Peninsula for the July events are shown in Figure 4.2.

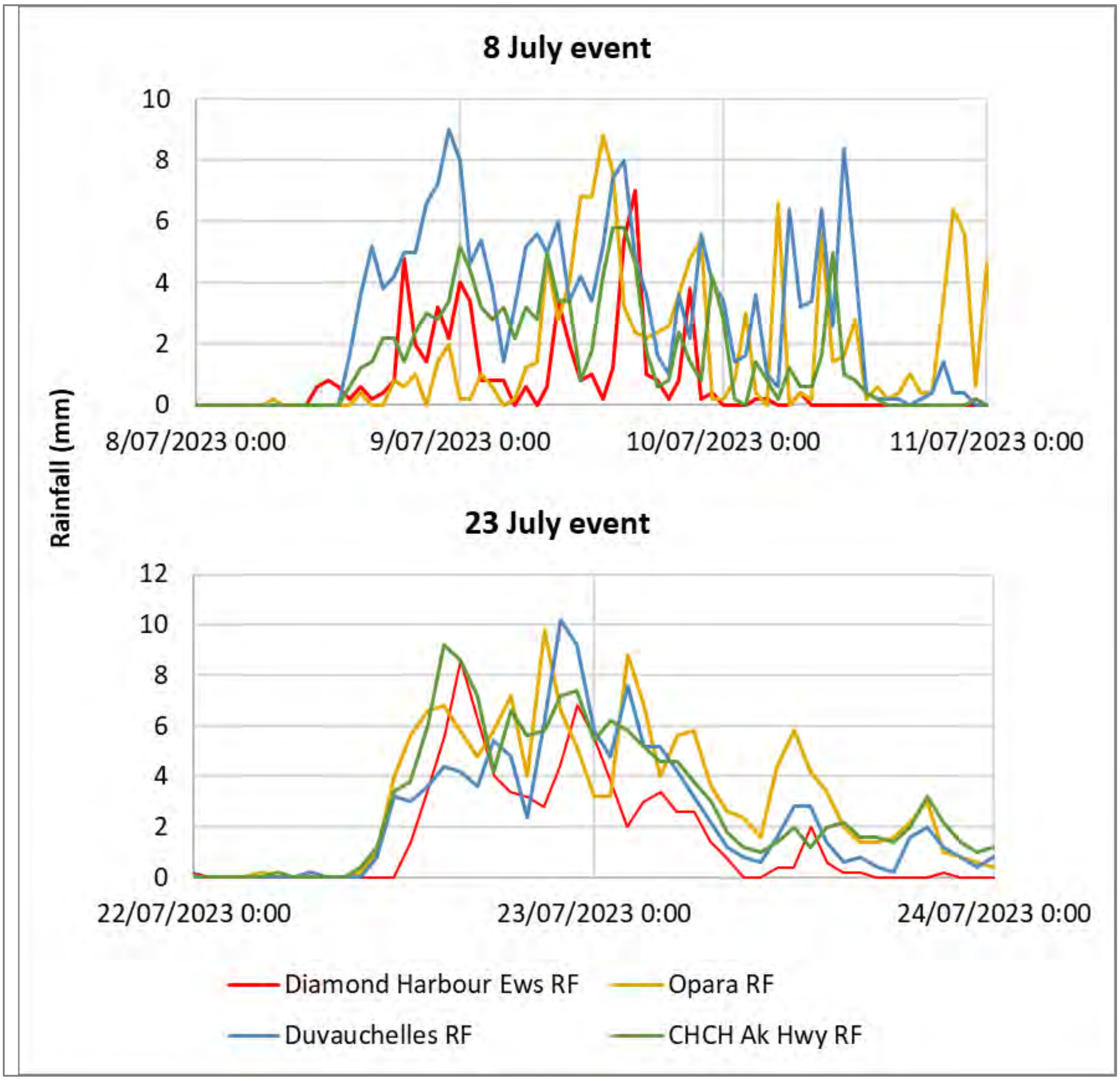


Figure 4.2: Recorded rainfall station data for surrounding catchments.

Based on the HIRDS data in Table 3.1, and the recorded rainfall in Figure 4.2, the ARI of the July events could have been in the order of between a 5-year and 50-year ARI depending on the location. The July events were of relatively long duration and low rainfall intensity. Therefore, it would be expected that a shorter duration storm of similar ARI would cause more flooding than what was observed in the July events.

Figure 4.2 indicates that during the July events, rainfall depths varied significantly across Banks Peninsula. As such, there is a high degree of uncertainty in predicting the rainfall which fell within the Owhetoro and Te Kawa catchments during the events. The nearest Electronic Weather Station (EWS) is Diamond Harbour which also has a similar geographical orientation.

The hydraulic model was run with the recorded Diamond Harbour EWS inputted as a rainfall boundary. Figure 4.3 and Figure 4.4 show the gauge flow compared to the modelled flow in the Owhetoro and Te Kawa Streams for the July events.

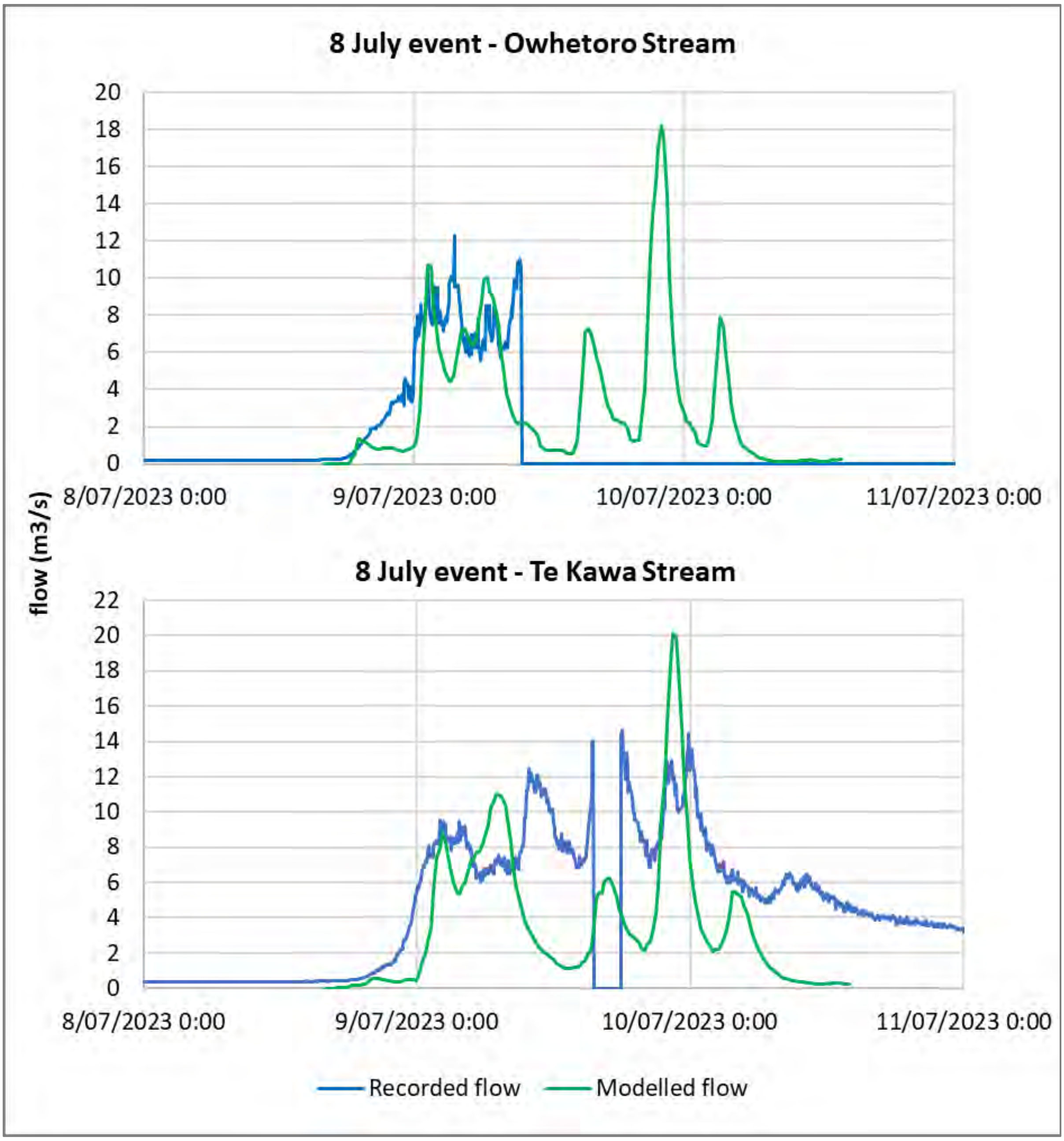


Figure 4.3: Gauge flow and modelled flow - 8 July event.

Figure 4.3 indicates that the model predicts comparable flows compared to the gauge flows during the 8 July event when adopting the Diamond Harbour EWS rainfall.

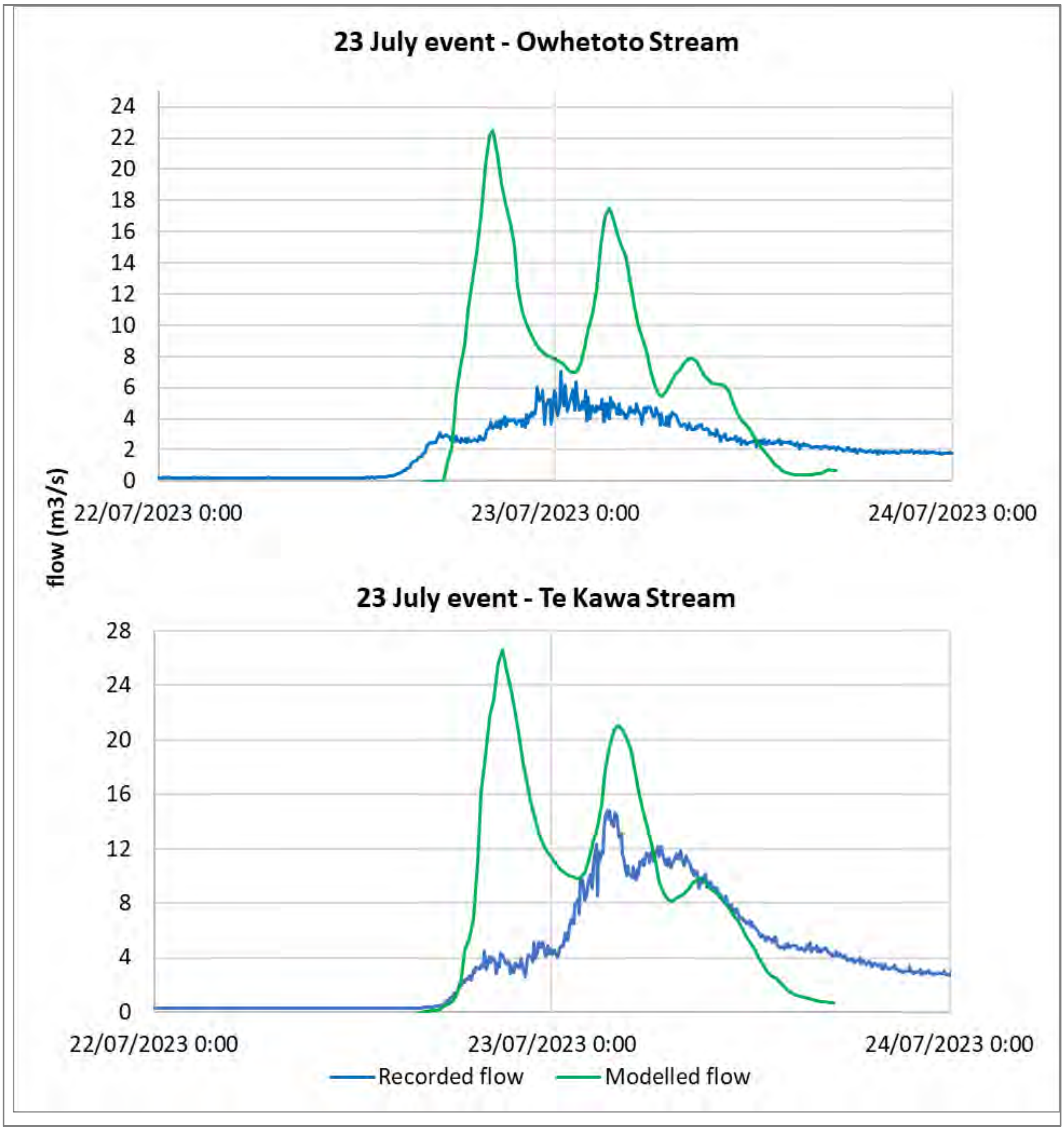


Figure 4.4: Recorded and modelled flow - 23 July event.

Figure 4.4 indicates that the model predicts higher flows compared to the gauge flow within the Owhetoro and Te Kawa Streams during the 23 July event when adopting the Diamond Harbour EWS rainfall.

The modelled flow in the Owhetoro Stream during the 23 July 2023 event is significantly higher than the gauge flow. However, the gauge flow is significantly lower than the Te-Kawa gauge flow even though catchment areas are similar. It is likely that during the 23 July event, the Owhetoro catchment received significantly less rainfall than the Te Kawa catchment.

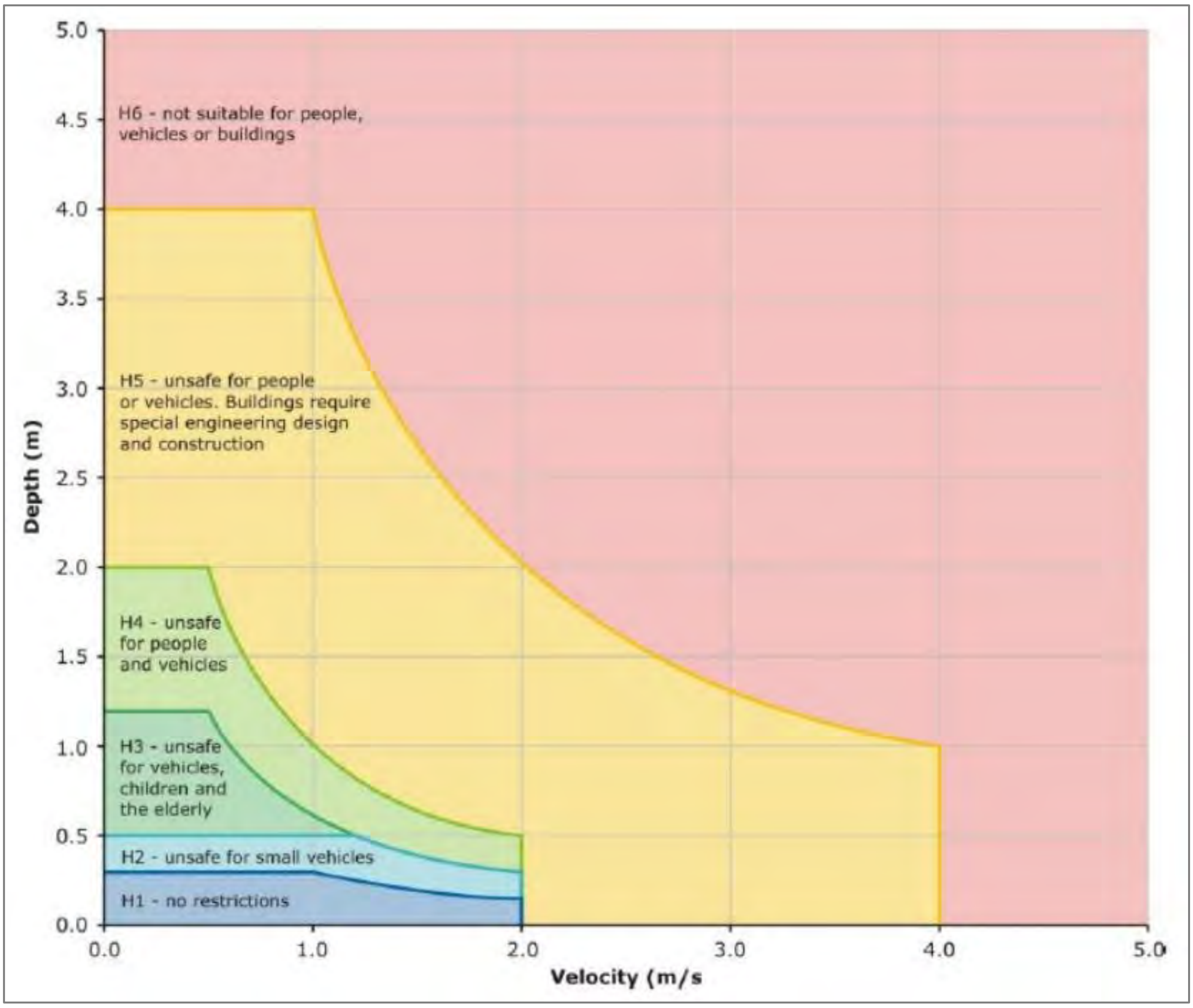
Overall, the modelled flows show a reasonable correlation to the gauge flows. It is important to consider the high degree of uncertainty associated with the rainfall data that may have fallen within the Owhetoro and Te Kawa catchments during the July events.

5 Model output maps

Maximum modelled water depth and flood hazard maps are provided in Appendix B1 to B12 the T+T summary report for the following events:

- 5-year ARI rainfall with 10-year ARI tide.
- 10-year ARI rainfall with 10-year ARI tide.
- 20-year ARI rainfall with 10-year ARI tide.
- 50-year ARI rainfall with 10-year ARI tide.
- 250-year ARI rainfall with 10-year ARI tide.
- 20-year ARI rainfall with 100-year ARI tide.

Flood depths less than 0.1 m have been removed from flood maps as this is the threshold depth above which flooding has been considered with confidence as “real” and not potentially an artefact of inaccuracies in the DEM. Flood hazard maps adopt the hazard criteria from Smith et al. (2014)[6] shown in Figure 5.1.



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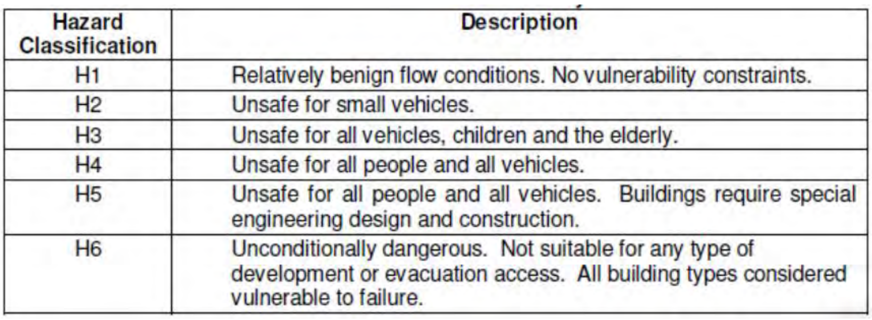
[6] Smith, G.P., Davey, E.K. and Cox, R.J. (2014), Flood Hazard UNSW Australia Water Research Laboratory Technical Report 2014/07 30 September 2014.



Hazard Classification	Description
H1	Relatively benign flow conditions. No vulnerability constraints.
H2	Unsafe for small vehicles.
H3	Unsafe for all vehicles, children and the elderly.
H4	Unsafe for all people and all vehicles.
H5	Unsafe for all people and all vehicles. Buildings require special engineering design and construction.
H6	Unconditionally dangerous. Not suitable for any type of development or evacuation access. All building types considered vulnerable to failure.

Figure 5.1: Flood hazard rating criteria.

All provided maps are represented as “peak of peak” maximum modelled flood depth and hazard for each of the simulated ARI events. “Peak of peak” outputs are the enveloped maximums reached at any one cell in the model extent across the 1-hour and 6-hour duration events. The “peak of peak” overlays does not come from any single event simulation but are compiled from all event simulations.

6 Model sensitivity

Four sensitivity tests were undertaken where modelling parameters were varied to determine the confidence in baseline flood outputs for the 100-year ARI events. Sensitivity scenarios run included:

- Manning’s ‘n’ roughness +20%.
- Manning’s ‘n’ roughness -20%.
- Continuing loss +20%.
- Continuing loss -20%.

Sensitivity differencing maps for the Manning’s ‘n’ roughness +-20% scenarios are provided in Appendix B14 to B16 of the T+T summary report, where difference is calculated from the start parameters. For the continuing loss +-20% scenarios, flood level differences were all less than 0.1 m and therefore, no maps are provided.

7 Model limitations

The following limitations apply to this model:

- While the model build methodology described in this report is appropriate for these purposes, caution should be taken when using model outputs for other means beyond the scope of this work.
- The modelling undertaken has been based on remotely sensed ground levels (LiDAR survey) and on HIRDS rainfall events, both of which have accuracy limitations. The model results have generally been presented only to show flooding where maximum depth in excess of 100 mm has been estimated. Furthermore, a direct rainfall approach has been applied, which can highlight accuracy deficiencies in input data by showing small “puddles” in predicted flooding. It is usual with flood depth results from this kind of modelling approach that the results be “cleaned” by removing puddles before publication.
- In modelling of wide areas such as these reported on in this document, accuracy is limited, and field verification of flood predictions is strongly recommended. The modelling approach adopted has been aimed at determination of flooding extent for the events considered and does not necessarily deliver design flood levels to be applied. We recommend that if flood levels are to be considered, that this field verification be undertaken. This is particularly the case where a minor degree of flooding (both in depth and in extent) has been predicted on a

parcel which, given accuracy limitations in the approach, may or may not be real. This approach (field verification) is also recommended where consequence associated with flooding is high.

- The DEM represents a bare earth terrain with all buildings and above-ground features having been removed. Using this approach, it is sometimes possible that flooding is shown to occur through the area occupied by large buildings. This is because the model does not recognise these as buildings and works only off the DEM. Care should therefore be exercised in the interpretation of results, particularly in areas where there is a high percentage of ground area covered by above-ground features (trees, buildings, etc). Other features, such as major bridge structures are removed from the terrain, such that these are represented as open channels in the model.

8 Applicability

This report has been prepared for the exclusive use of our client Christchurch City Council with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose, or by any person other than our client, without our prior written agreement.

Tonkin & Taylor Ltd

Report prepared by:	Authorised for Tonkin & Taylor Ltd by:
....	....
Ed Fairclough	Peter Cochrane
Water Resources Engineer	Project Director

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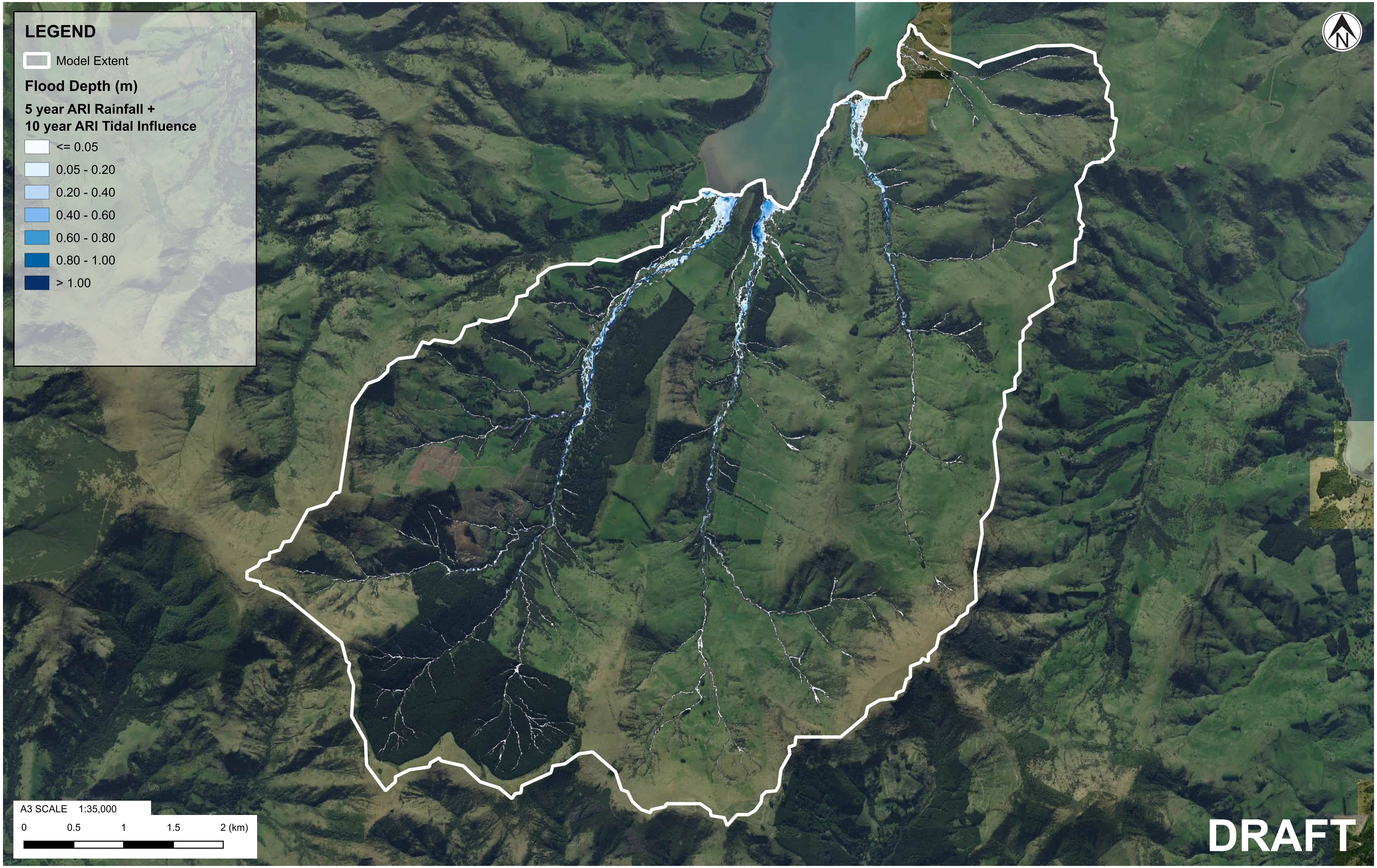

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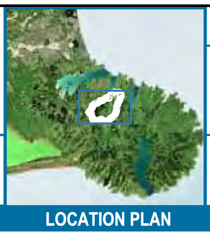

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PROJECT **KOUKOURĀRATA / PORT LEVY AREA DRINKING WATER SCHEME**

TITLE PRESENT DAY CLIMATE 5-YEAR ARI RAINFALL +
10-YEAR TIDE, MAXIMUM DEPTH

SCALE (A3) 1:35,000   FIG No. FIGURE B1   REV 0

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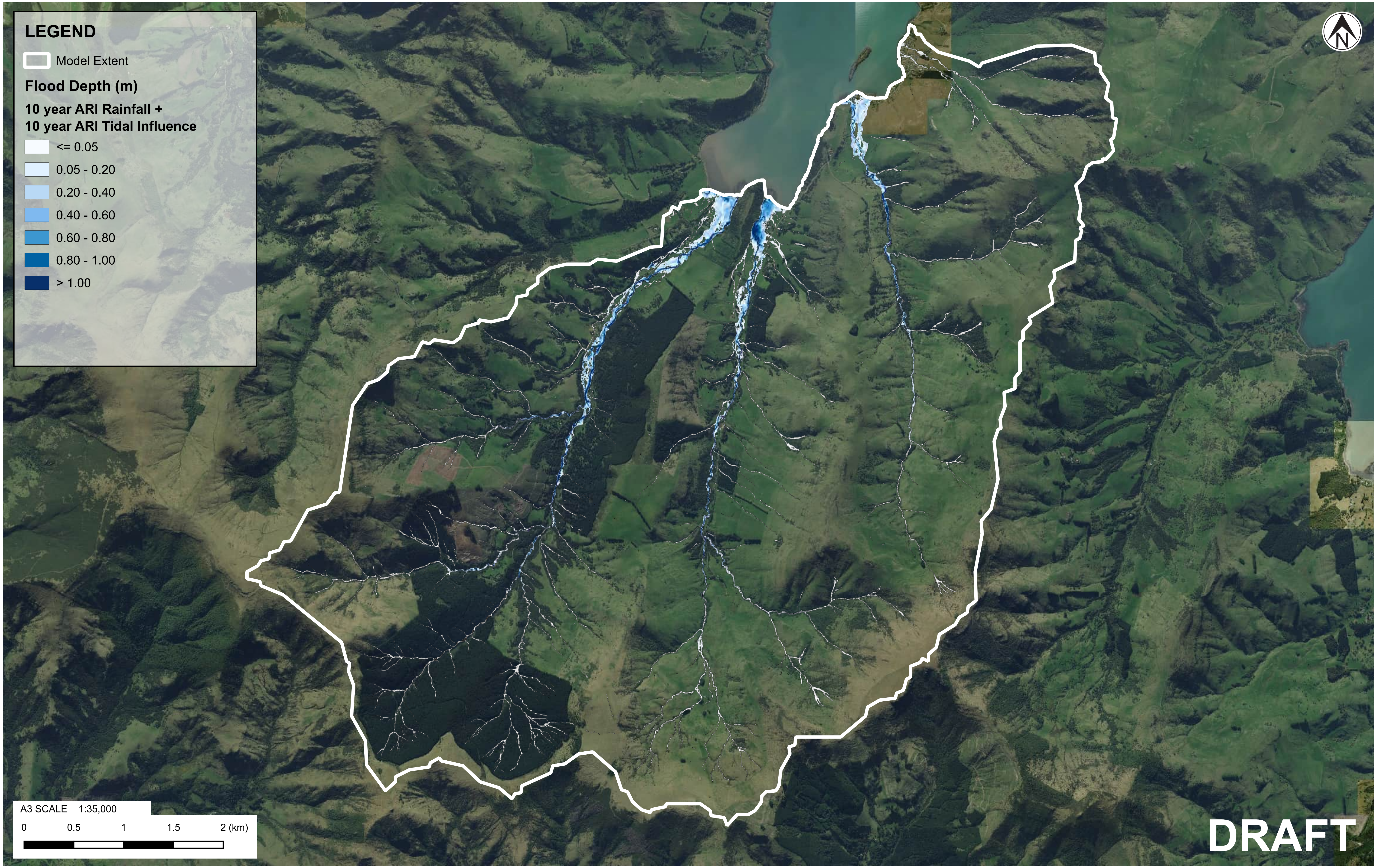

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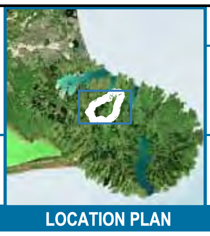

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TITLE PRESENT DAY CLIMATE 10-YEAR ARI RAINFALL +
10-YEAR TIDE, MAXIMUM DEPTH

SCALE (A3) 1:35,000 **FIG No.** FIGURE B2 **REV** 0

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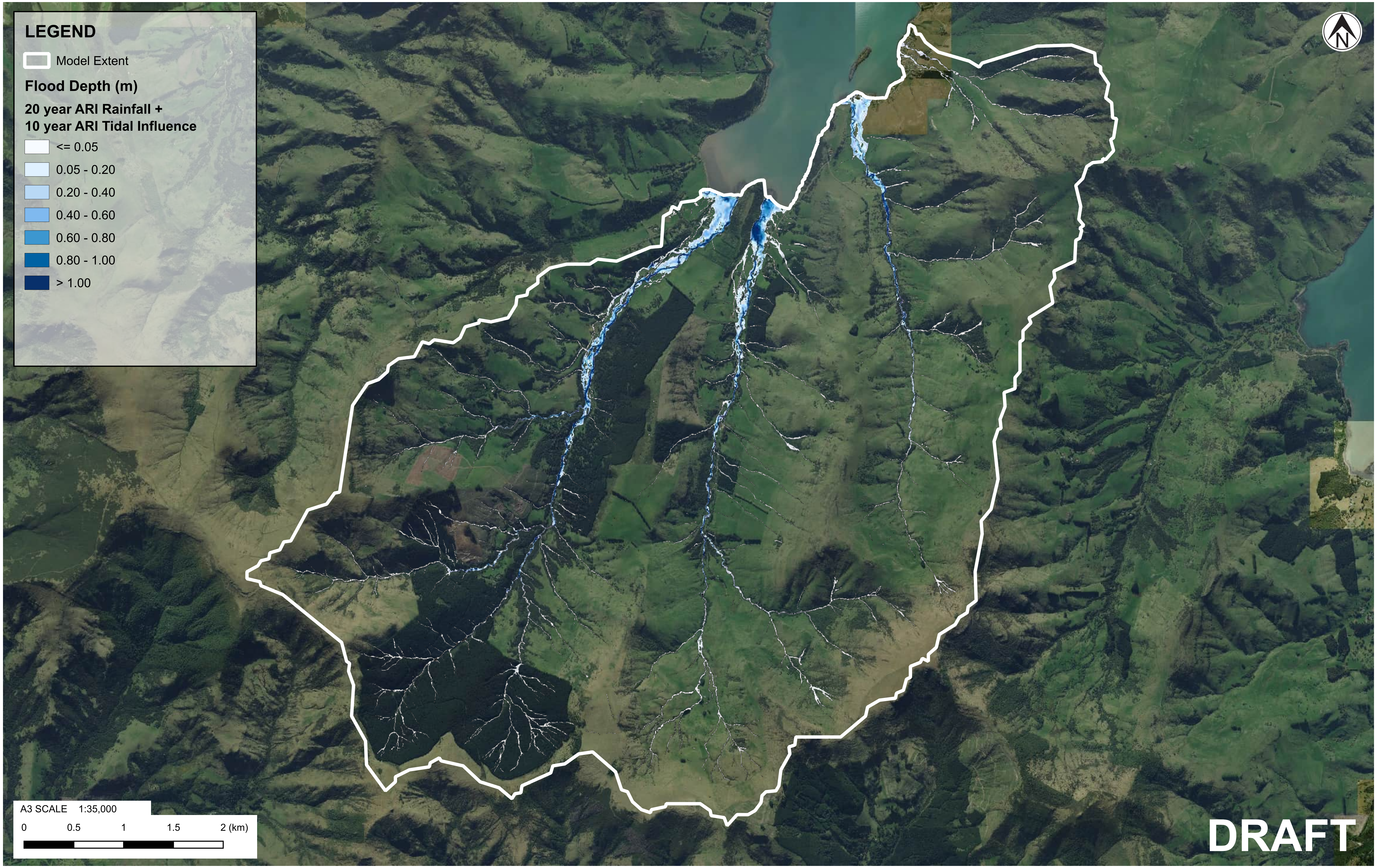

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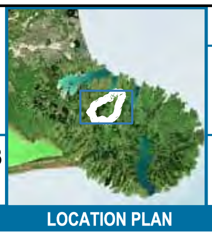

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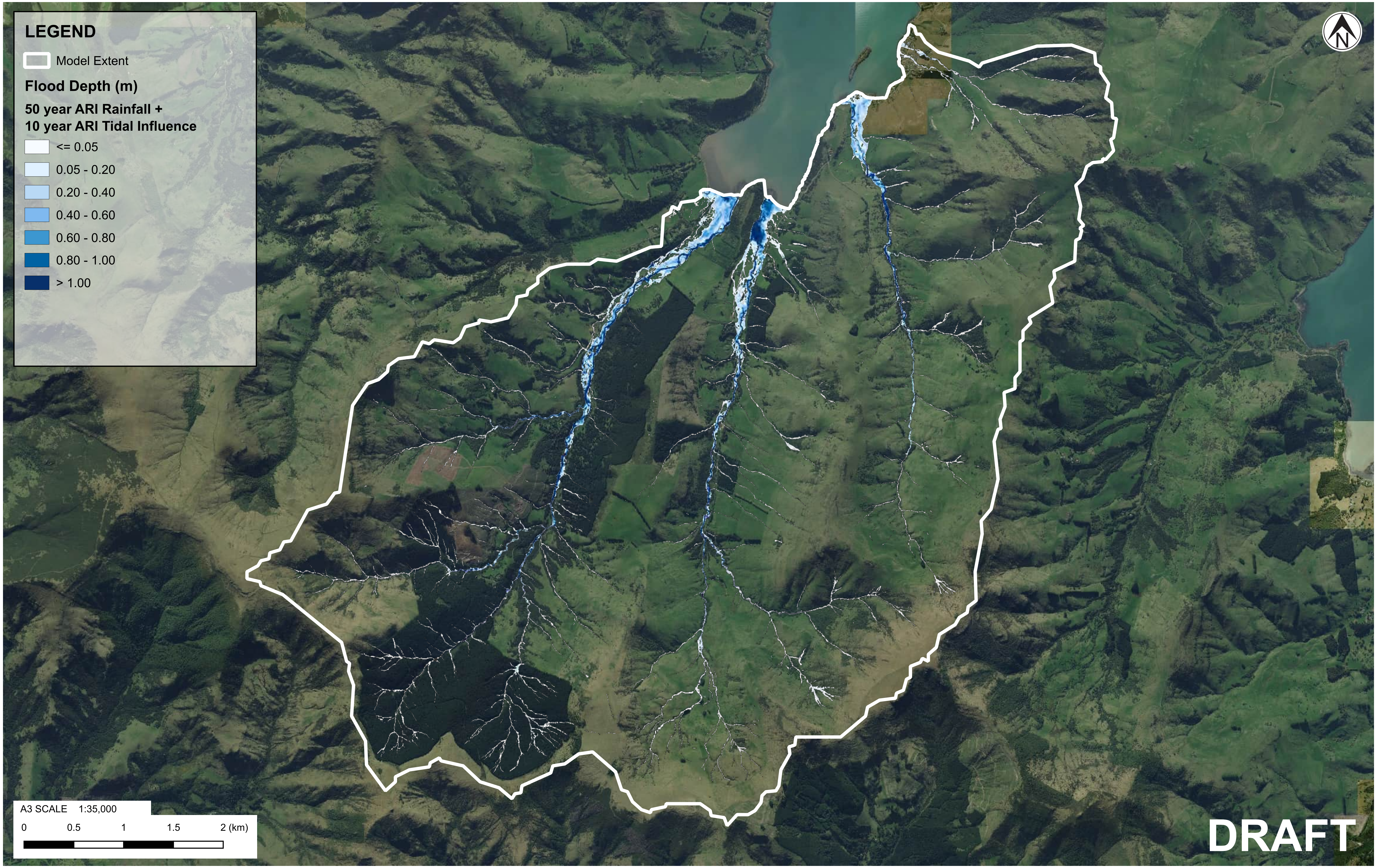
TITLE PRESENT DAY CLIMATE 20-YEAR ARI RAINFALL + 10-YEAR TIDE, MAXIMUM DEPTH

SCALE (A3) 1:35,000 FIG No. FIGURE B3 REV 0



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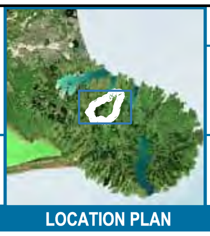

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TITLE PRESENT DAY CLIMATE 50-YEAR ARI RAINFALL +
10-YEAR TIDE, MAXIMUM DEPTH

SCALE (A3) 1:35,000 FIG No. FIGURE B4 REV 0

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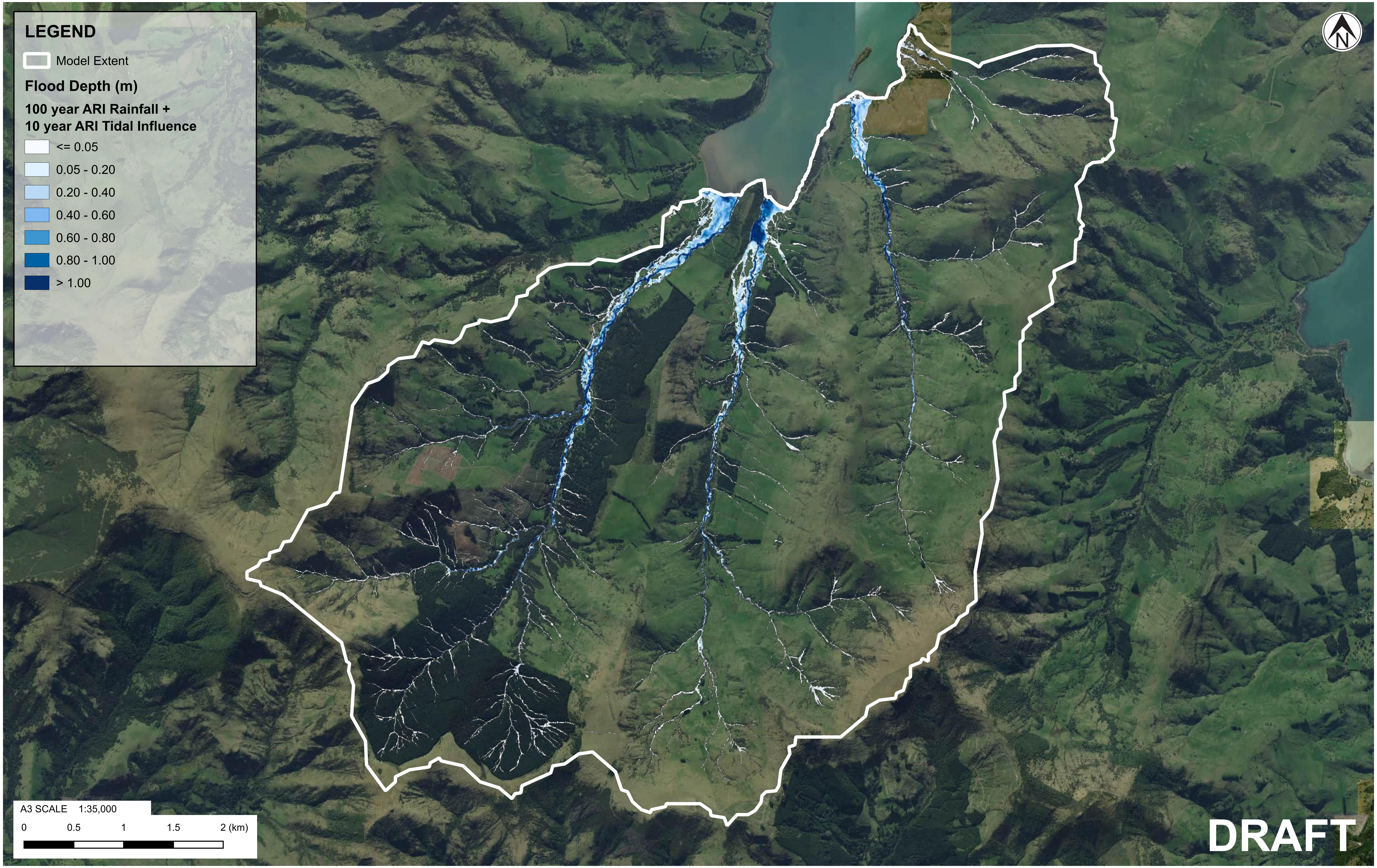

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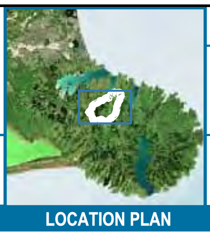

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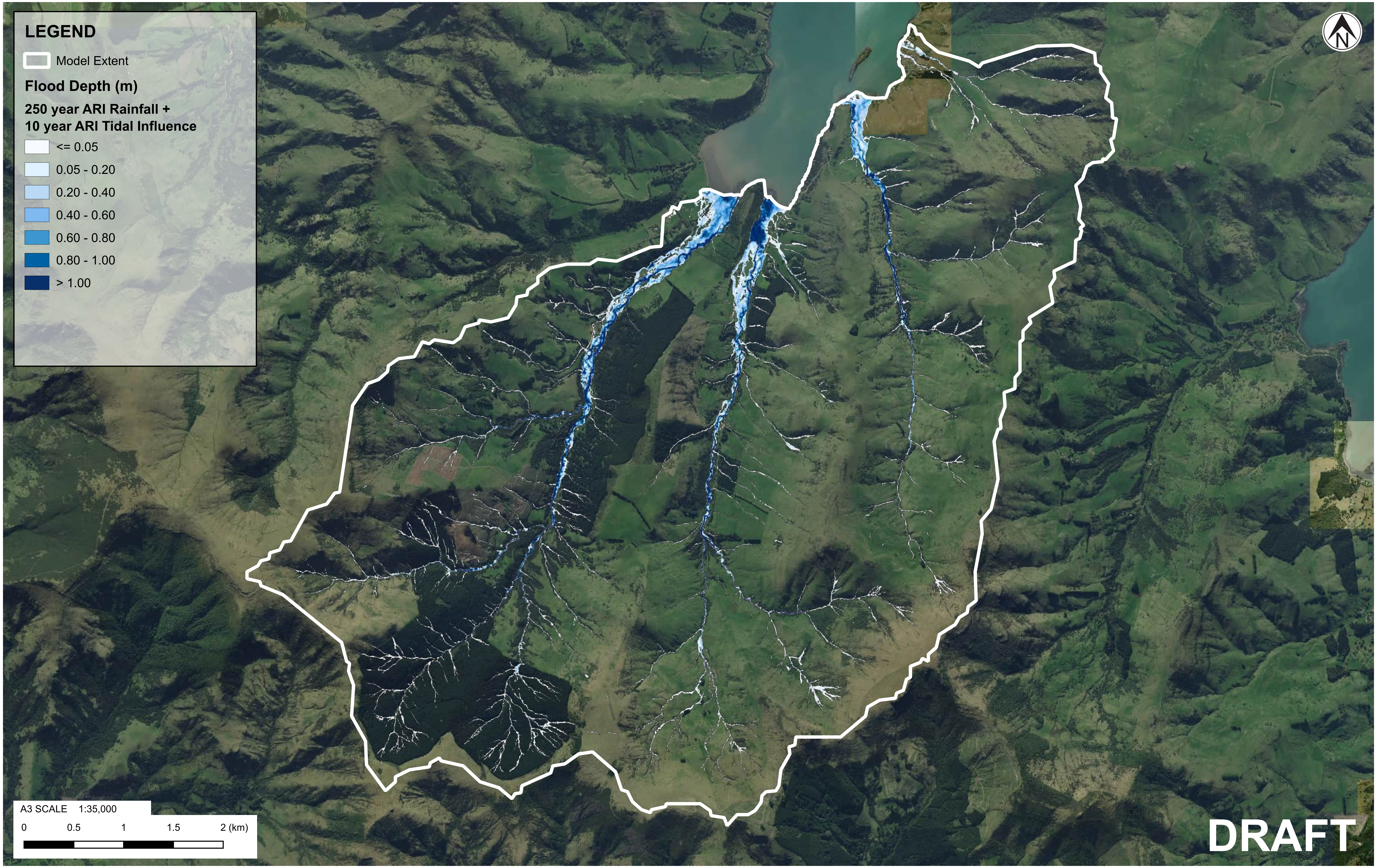
TITLE PRESENT DAY CLIMATE 100-YEAR ARI RAINFALL + 10-YEAR TIDE, MAXIMUM DEPTH

SCALE (A3) 1:35,000 FIG No. FIGURE B5 REV 0



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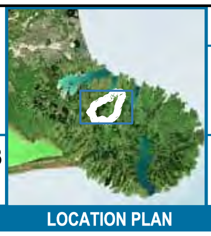

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TITLE PRESENT DAY CLIMATE 250-YEAR ARI RAINFALL +
10-YEAR TIDE, MAXIMUM DEPTH

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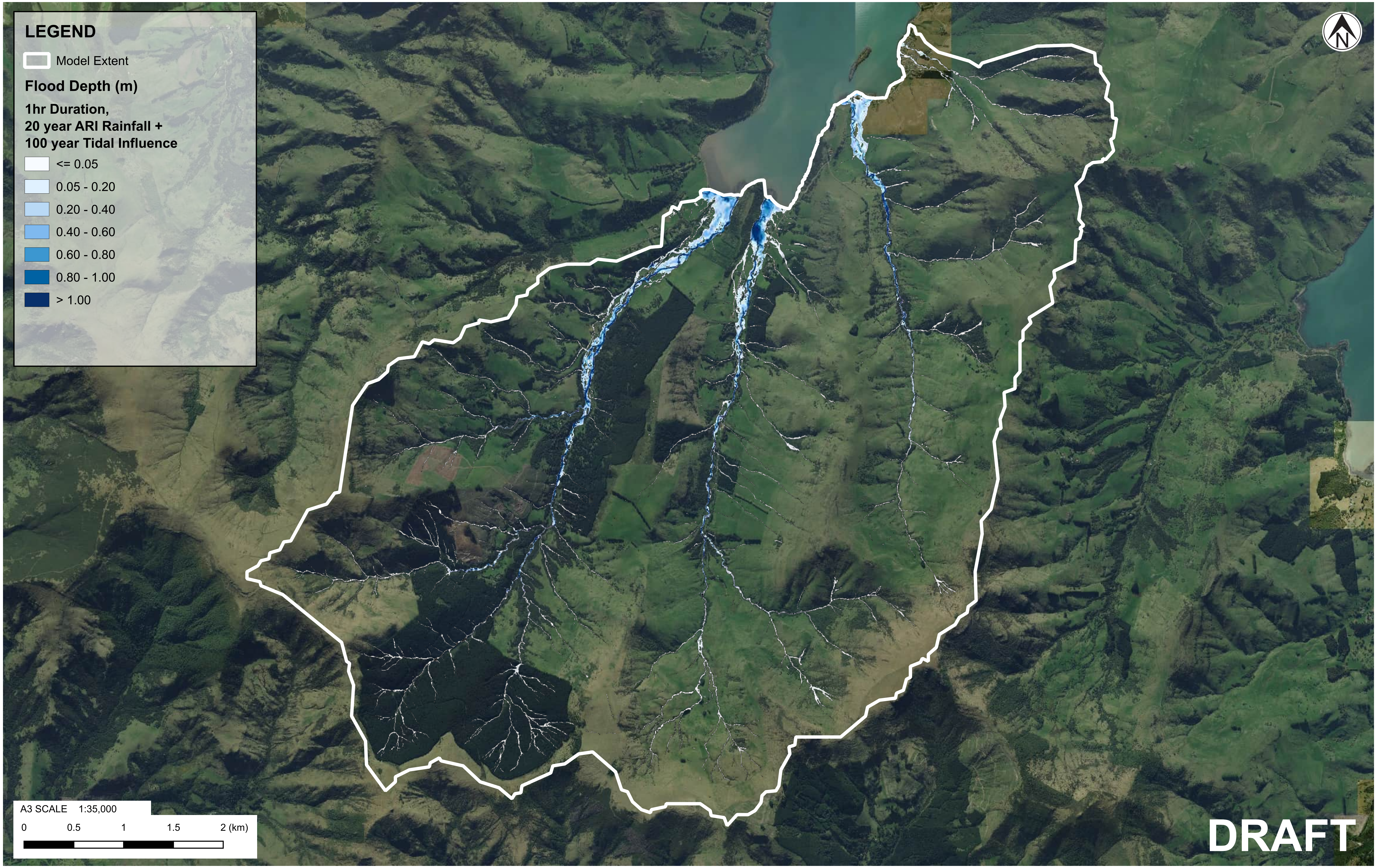

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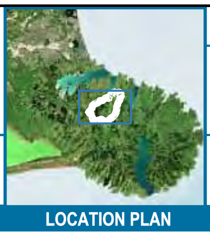
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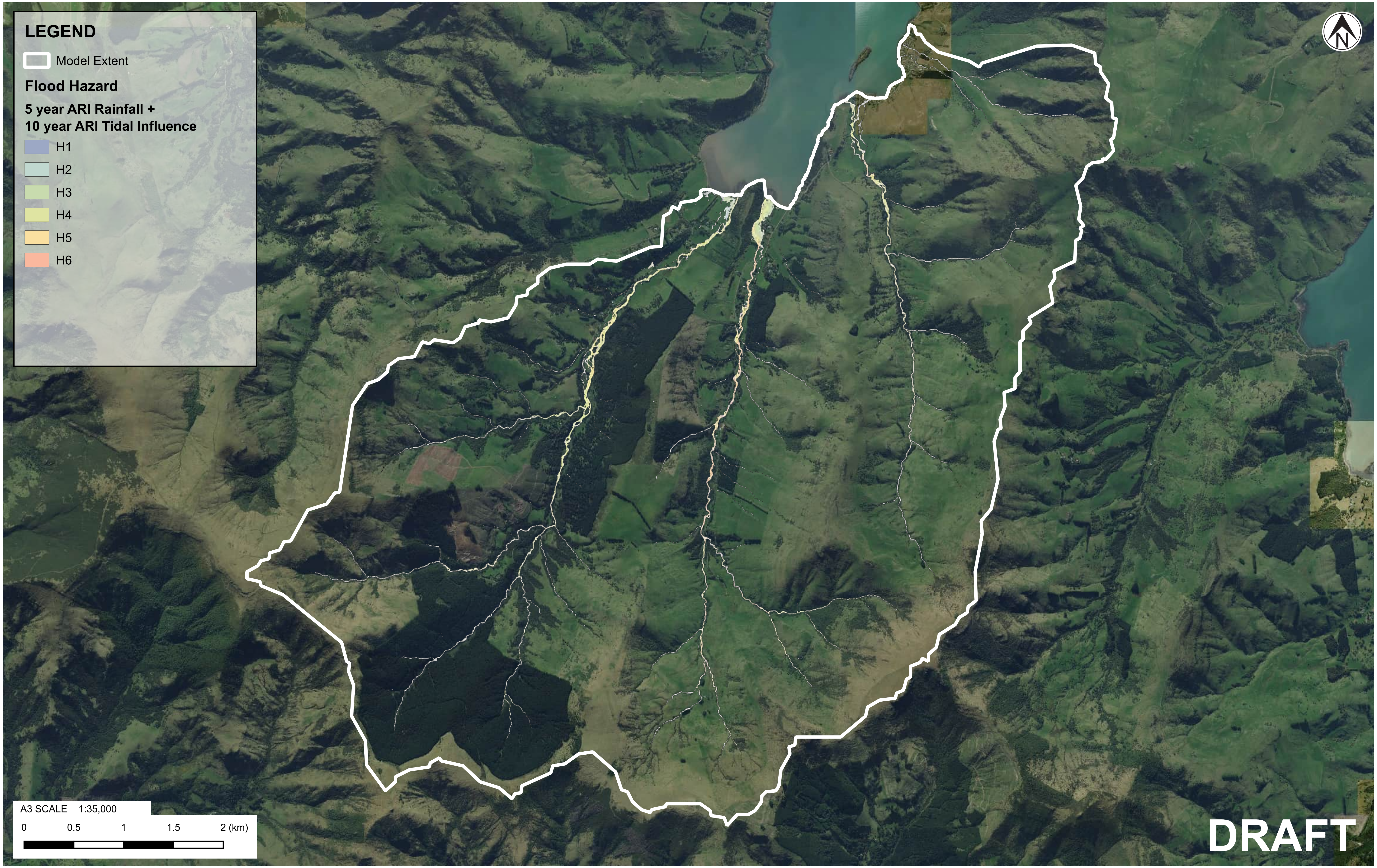
TITLE PRESENT DAY CLIMATE 20-YEAR ARI RAINFALL +
100-YEAR TIDE, MAXIMUM DEPTH

SCALE (A3) 1:35,000 **FIG No.** FIGURE B7 **REV** 0



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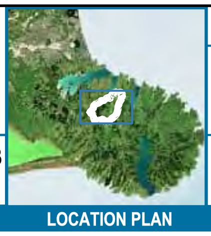

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TITLE PRESENT DAY CLIMATE 5-YEAR ARI RAINFALL +
10-YEAR TIDE, MAXIMUM HAZARD

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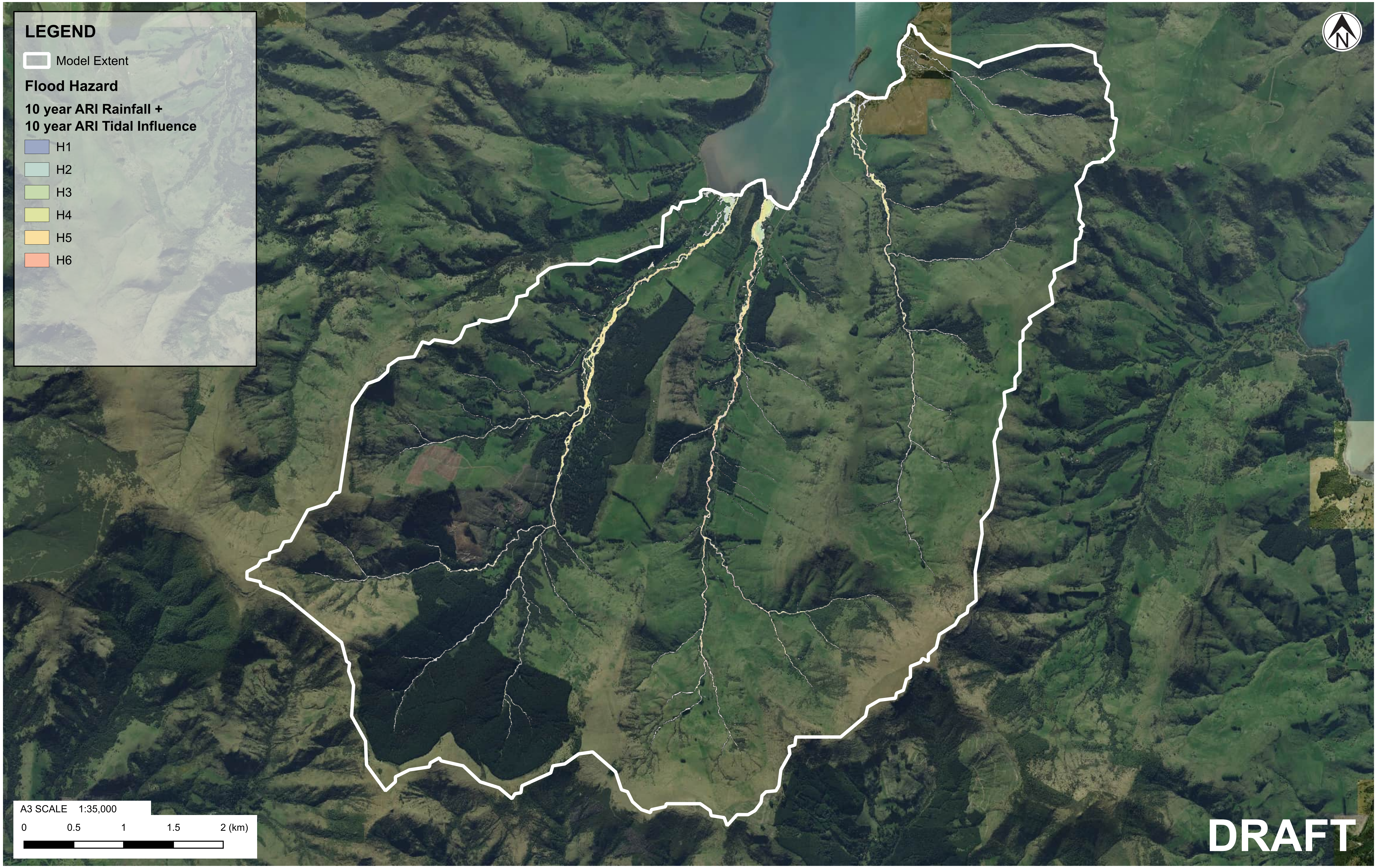

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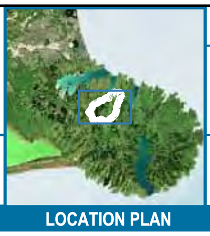

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PROJECT KOUKOURĀRATA / PORT LEVY AREA DRINKING WATER SCHEME

TITLE PRESENT DAY CLIMATE 10-YEAR ARI RAINFALL + 10-YEAR TIDE, MAXIMUM HAZARD

SCALE (A3) 1:35,000 FIG No. FIGURE B9 REV 0

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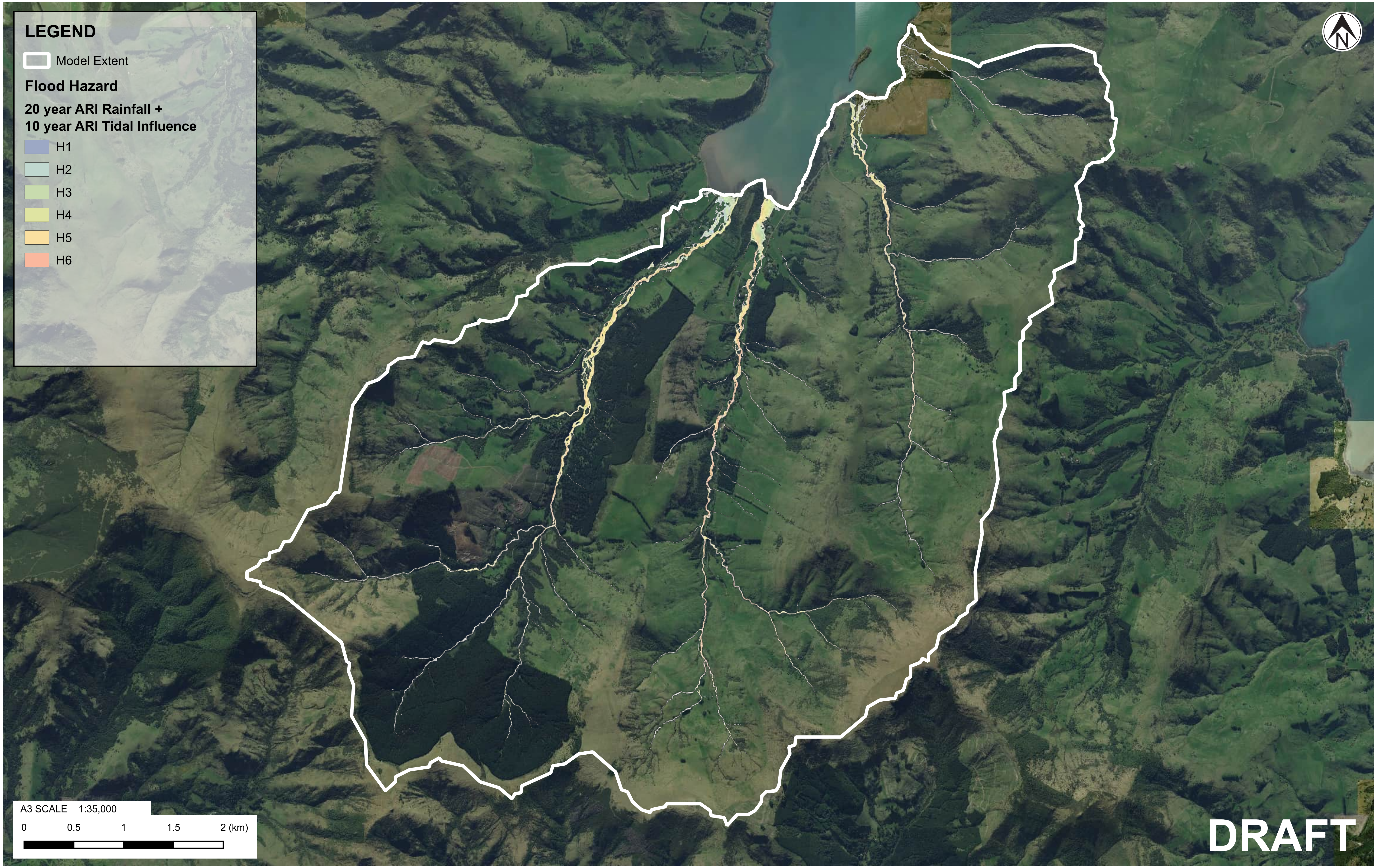

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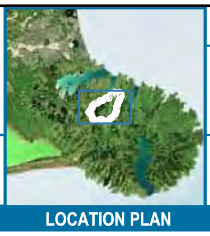

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TITLE PRESENT DAY CLIMATE 20-YEAR ARI RAINFALL + 10-YEAR TIDE, MAXIMUM HAZARD

SCALE (A3) 1:35,000 **FIG No.** FIGURE B10 **REV** 0

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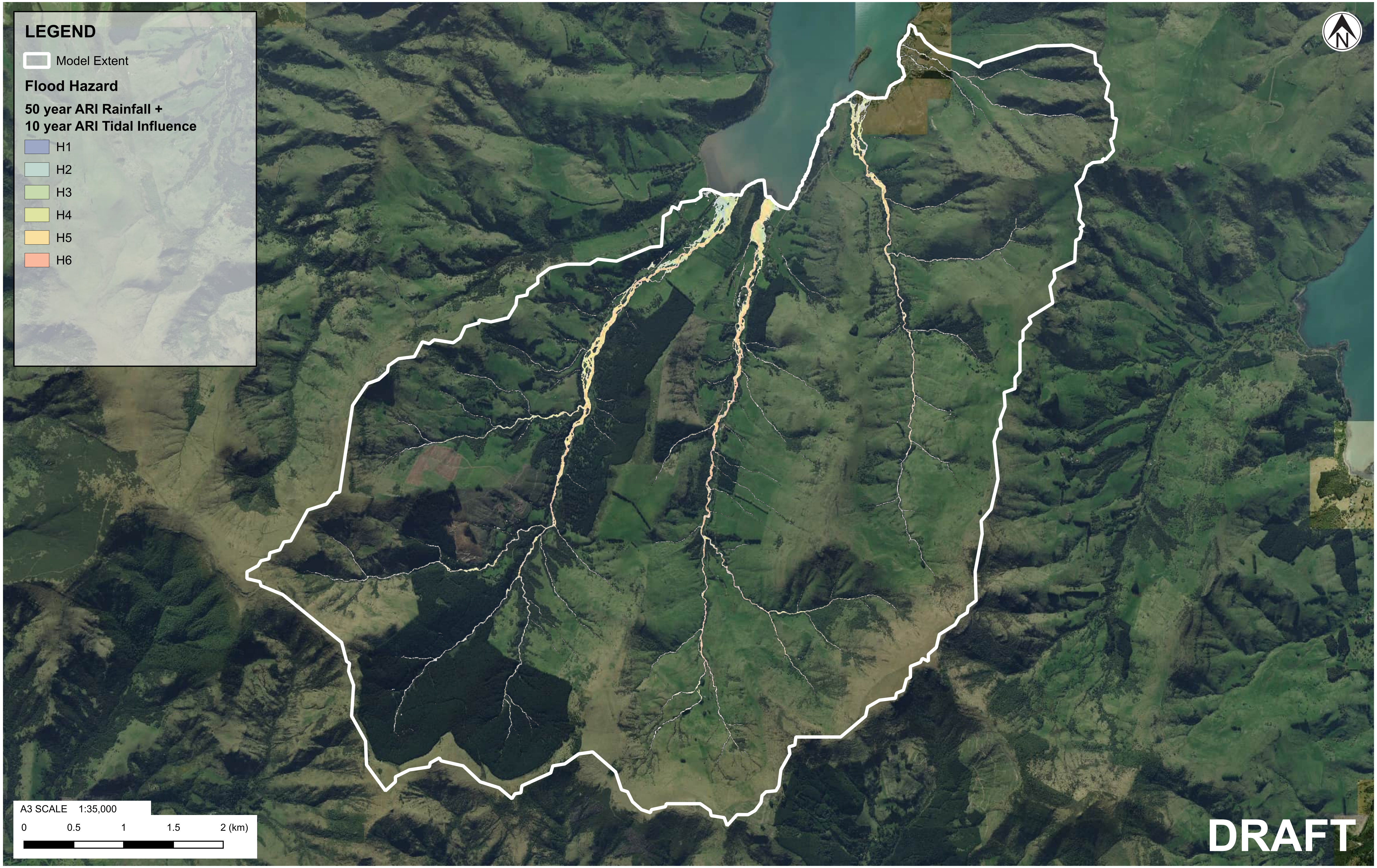

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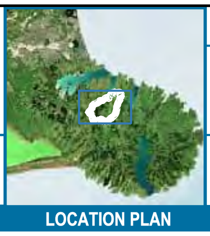
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CLIENT **CHRISTCHURCH CITY COUNCIL**

PROJECT **KOUKOURĀRATA / PORT LEVY AREA DRINKING WATER SCHEME**

TITLE PRESENT DAY CLIMATE 50-YEAR ARI RAINFALL + 10-YEAR TIDE, MAXIMUM HAZARD

SCALE (A3) 1:35,000 FIG No. FIGURE B11 REV 0

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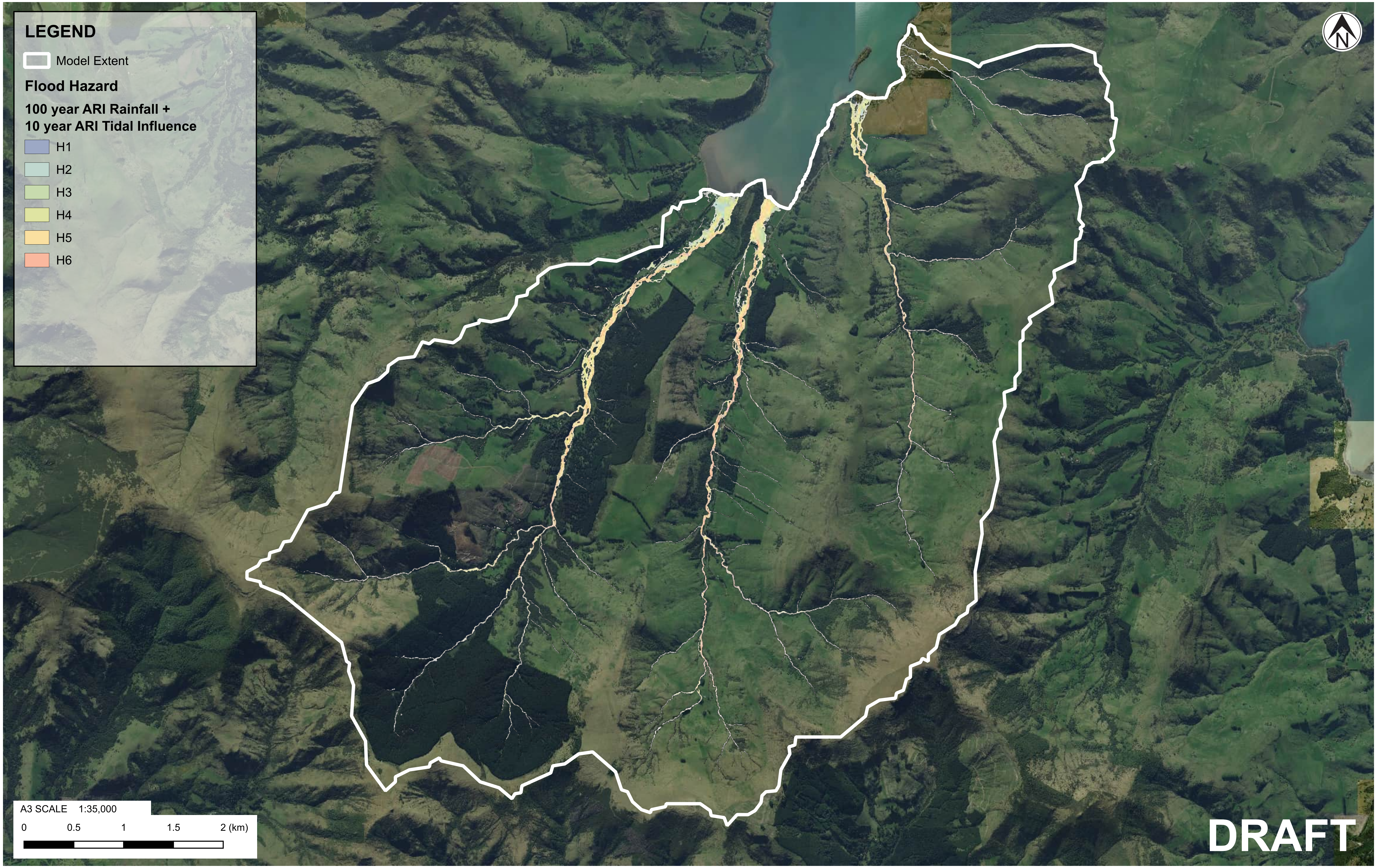

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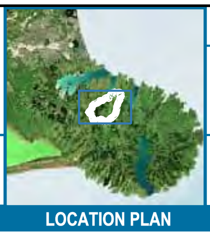
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PROJECT **KOUKOURĀRATA / PORT LEVY AREA DRINKING WATER SCHEME**
TITLE PRESENT DAY CLIMATE 100-YEAR ARI RAINFALL +
10-YEAR TIDE, MAXIMUM HAZARD
SCALE (A3) 1:35,000   **FIG No.** FIGURE B12   **REV** 0

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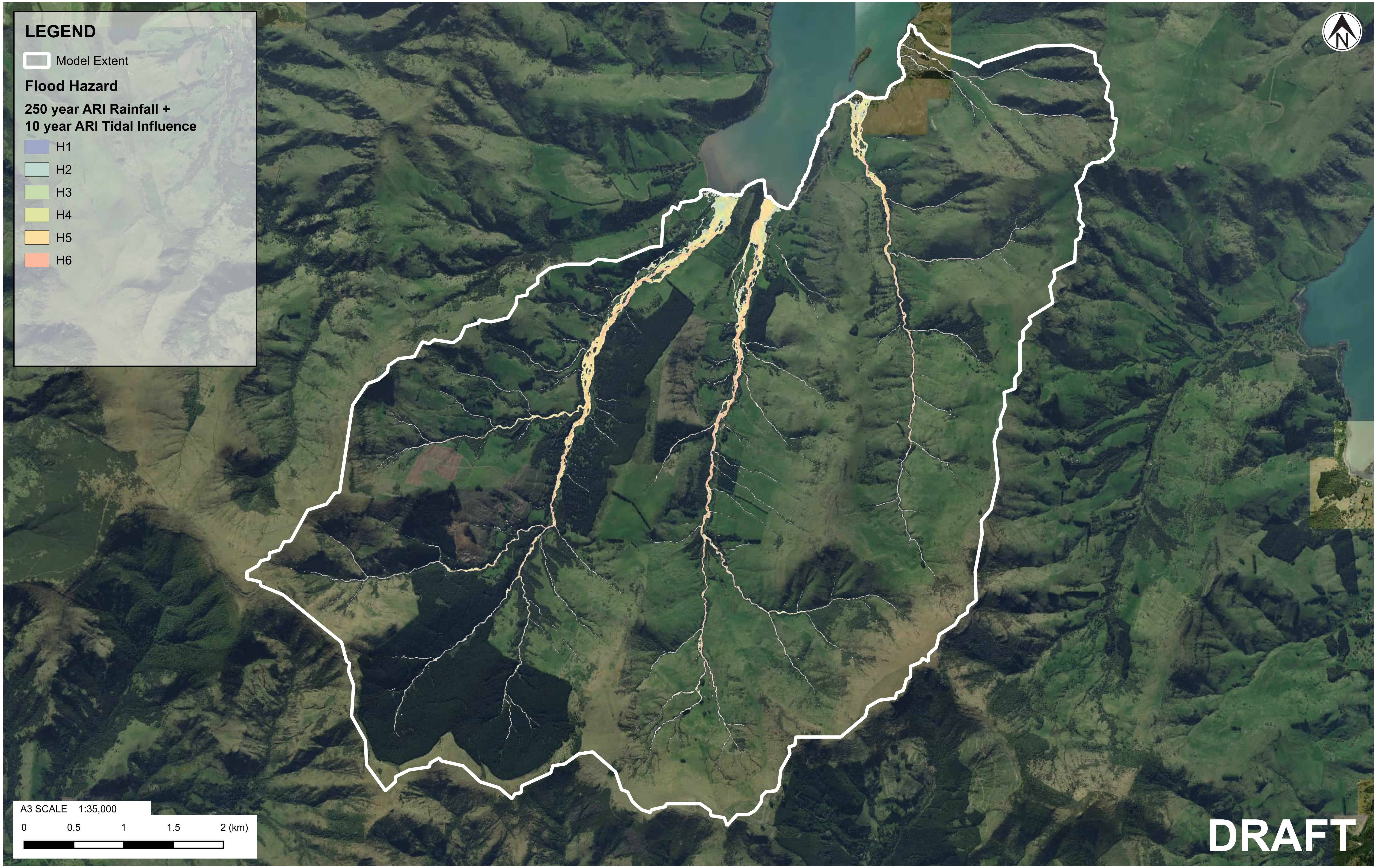

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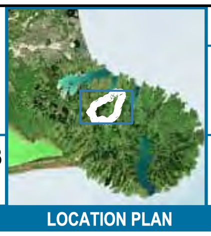

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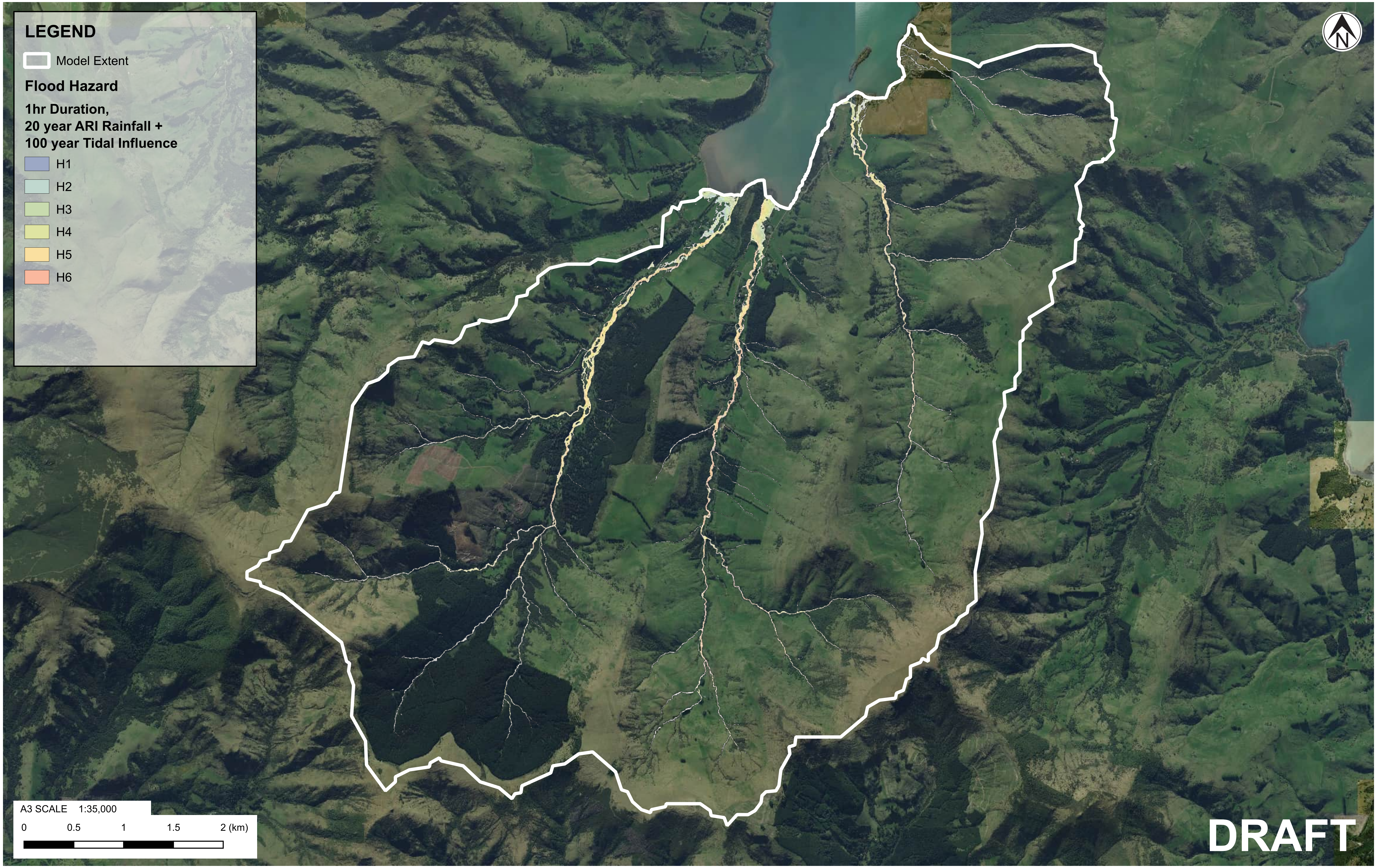
PROJECT **KOUKOURĀRATA / PORT LEVY AREA DRINKING WATER SCHEME**

TITLE PRESENT DAY CLIMATE 250-YEAR ARI RAINFALL + 10-YEAR TIDE, MAXIMUM HAZARD

SCALE (A3) 1:35,000   **FIG No.** FIGURE B13   **REV** 0



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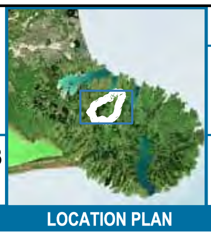

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PROJECT **KOUKOURĀRATA / PORT LEVY AREA DRINKING WATER SCHEME**

TITLE PRESENT DAY CLIMATE 20-YEAR ARI RAINFALL + 100-YEAR TIDE, MAXIMUM HAZARD

SCALE (A3) 1:35,000   FIG No. FIGURE B14   REV 0

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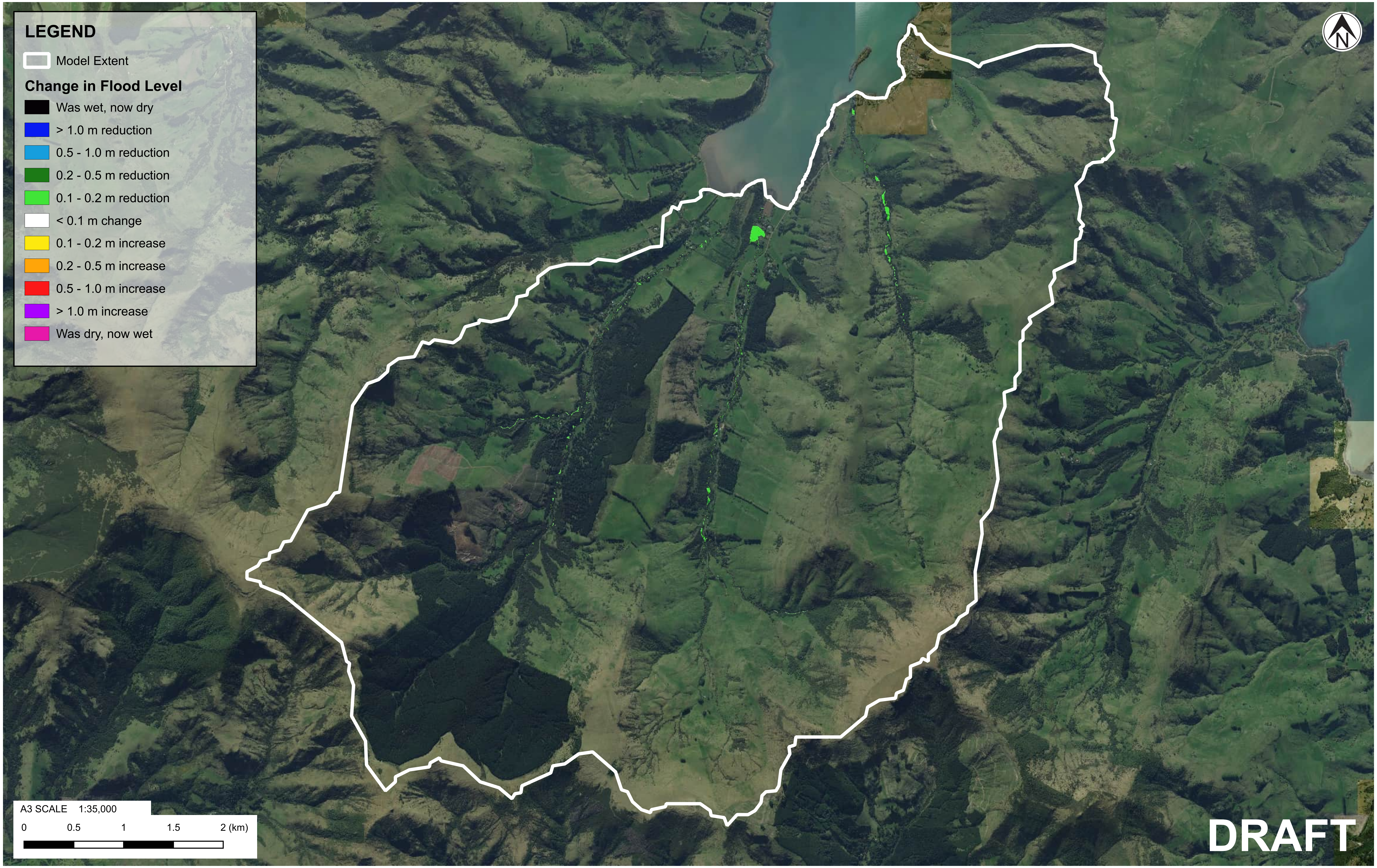

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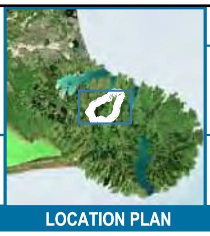
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PROJECT **KOUKOURĀRATA / PORT LEVY AREA DRINKING WATER SCHEME**

TITLE 100-YEAR ARI RAINFALL + 10-YEAR TIDE,
LOW ROUGHNESS (-20%) DIFFERENCE MAP

SCALE (A3) 1:35,000 **FIG No.** FIGURE B15 **REV** 0

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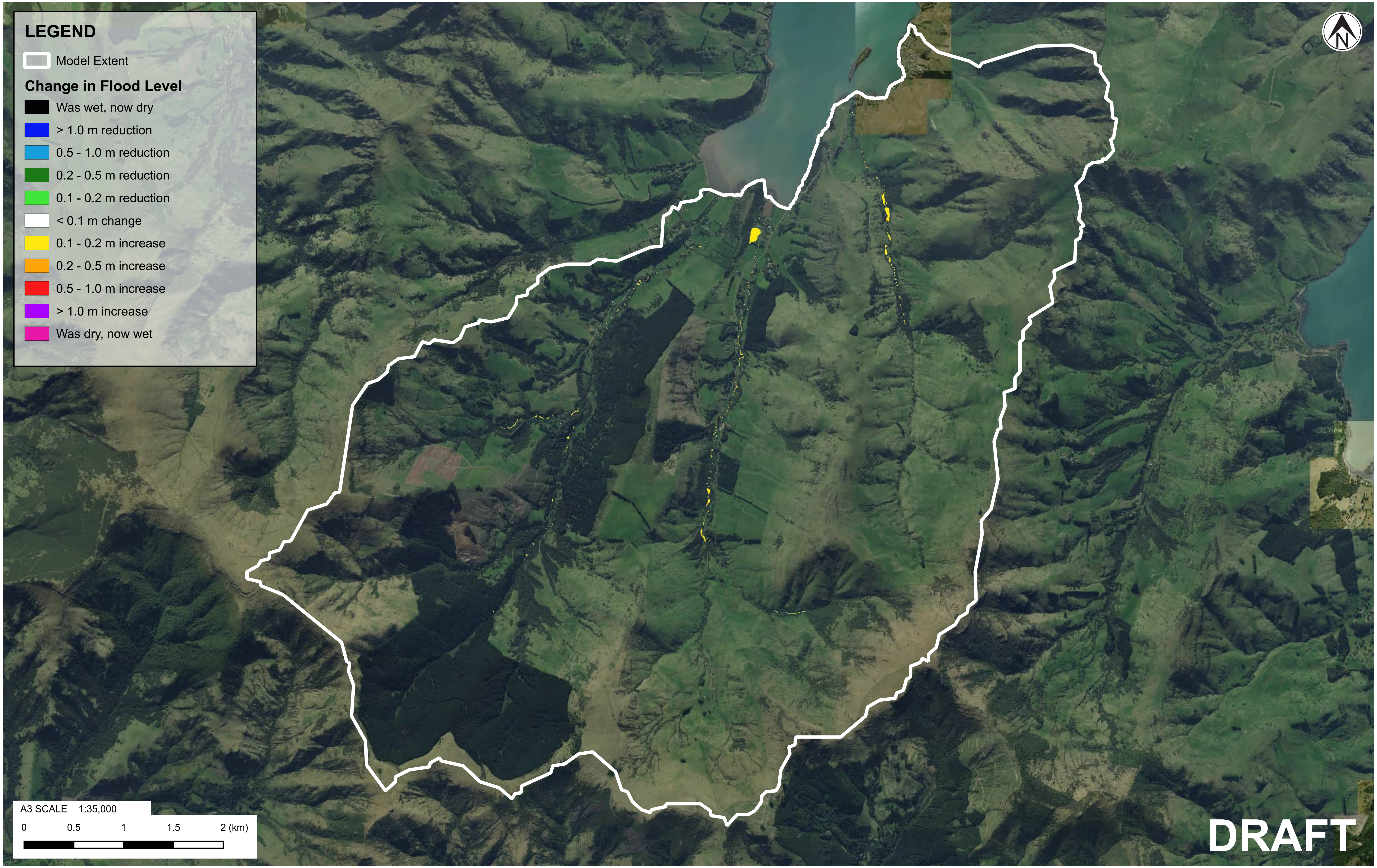

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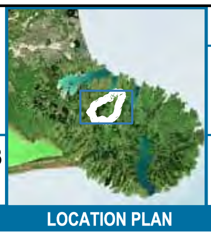

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PROJECT **KOUKOURĀRATA / PORT LEVY AREA DRINKING WATER SCHEME**

TITLE 100-YEAR ARI RAINFALL + 10-YEAR TIDE,
HIGH ROUGHNESS (+20%) DIFFERENCE MAP

SCALE (A3) 1:35,000   FIG No. FIGURE B16   REV 0

Appendix C Coastal hazards assessment report

C.10 **Coastal erosion map**

C.12 – 14 **Coastal inundation maps**

C.16 – 17 **Coastal groundwater maps**

REPORT

Koukourārata / Port Levy Area Drinking Water Scheme

Coastal Hazards Assessment

Prepared for
Christchurch City Council
Prepared by
Tonkin & Taylor Ltd
Date
July 2024
Job Number
1091788 v2`

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Document control

Title: Koukourārata / Port Levy Area Drinking Water Scheme					
Date	**Version**	**Description**	**Prepared by:**	**Reviewed by:**	**Authorised by:**
19/12/23	1	Draft for client review	R Haughey	P Knook	P Cochrane
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Table of contents

1 Introduction Equation 6.1: Areas Susceptible to Coastal Erosion (ASCE)

Tonkin & Taylor Ltd (T+T) was engaged by Christchurch City Council (CCC) to undertake a flood risk and coastal hazards assesment to inform the design and location of the new Koukourārata / Port Levy area drinking water supply scheme.

The purpose of this technical report is to provide more detailed methodology and analysis relating to the coastal erosion, inundation and groundwater information overviewed in the flooding and coastal hazards risk assessment[1] (herein the 'T+T summary report'). For clarity, appendices referenced in this report can be found in the T+T summary report.

2 Coastal setting

Port levy is approximately 6.5 km long embayment, with a maximum width of 1.5 km, on the north side of Banks Peninsula. The following coastal hazard assessment has been completed for 4 km of shoreline at the south-eastern end of the embayment (Figure 2.1).

Figure 2.1: Overview of the Port Levy shoreline extent included within the coastal hazard assessment.

2.1 Geology and sediments

The shoreline is characterised by a mixture of low, weakly consolidated banks located on Quaternary alluvial gravel fans and higher consolidated cliffs comprising Lyttelton basalt (hawaiite). The foreshore seaward of the banks typically comprises a mixture of sand and gravel sediments (Figure 2.2).

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[1] Koukourārata / Port Levy Area Drinking Water Scheme, Flooding and Coastal Hazards Assesment, Job No: 1091788.000 v1, dated December 2023.

Due to the location of the shoreline within the upper reaches of the embayment, coastal sediment supply to the shoreline is likely to be minimal. The three local streams (Te Kawa Stream, Owhetoro Stream and Koukourārata Stream) are likely to provide some sediment to the shoreline.

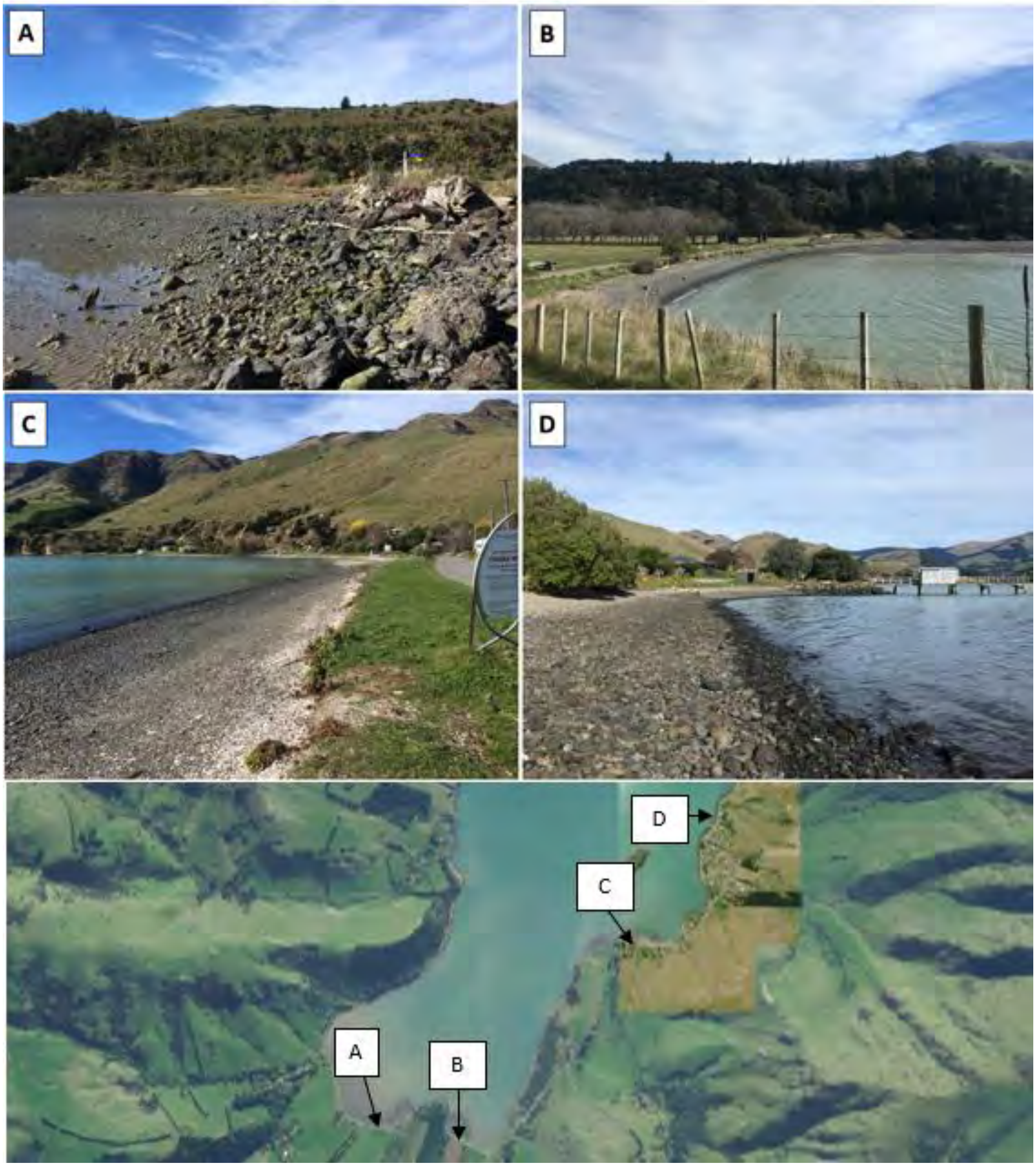

Figure 2.2: Site photos taken along the Port Levy shoreline by T+T (2021).

2.2 Water levels

Coastal water levels play an important role in determining coastal erosion and inundation hazards. Water levels influence the amount of wave energy reaching the backshore, causing erosion during storm events and by controlling the mean shoreline position on longer time scales. The key components that determine water level are:

- Astronomical tides.
- Storm surge (barometric and wind effects).
- Long term changes in sea level.
- Wave transformation processes through wave setup and run-up.

2.2.1 Astronomical tide

Astronomical tidal levels for Lyttelton Port which is approximately 10 km northwest of Port Levy, are presented in Table 2.1. The tidal levels for Lyttelton Port are likely to be applicable for Port Levy. The spring tidal range is approximately 2.2 m and the mean sea level is -0.22 m NZVD2016.

Table 2.1: Astronomical tide levels at Lyttelton Port (Source: LINZ, 2023)

Tide state	m NZVD2016
Highest Astronomical Tide (HAT)	1.10
Mean High Water Springs (MHWS)	0.84
Mean Sea Level (MSL)	-0.21
Mean Low Water Springs (MLWS)	-1.38
Lowest Astronomical Tide (LAT)	-1.51

2.2.2 Storm surge

Storm surge results from the combination of barometric setup from low atmospheric pressure and wind stress from winds blowing along or onshore which elevates the water level above the astronomical tide. The combined elevation of the astronomical tide and storm surge is known as the storm tide.

Based on GHD (2021) analysis of the Sumner tide gauge data the 100-year Average Recurrence Interval (ARI) storm tide level is 1.8 m NZVD16 (Table 2.2). Sumner storm tide levels are assumed to be representative of storm tide levels within Port Levy.

Table 2.2: Storm tide levels (m NZVD16) based on GHD (2021)

Tide gauge	1-year ARI	10-year ARI	100-year ARI
Sumner	1.37	1.59	1.80

2.2.3 Sea level rise

Historic rise in mean sea level around New Zealand has averaged 1.8 ± 0.0.5 mm/year with Christchurch region exhibiting a higher rate of 2.12 ± 0.09 mm/year (Hannah & Bell, 2018).

Climate change is predicted to accelerate the rate of sea level rise. The Ministry for the Environment (MfE, 2022) interim sea level rise guidance recommends using a range of “medium confidence” sea level rise scenarios to cover the range of predicted future sea levels that reflect the inherent uncertainty. The scenarios are based on the most recent IPCC Assessment Report 6 (IPCC, 2022) and are shown in Figure 2.3.

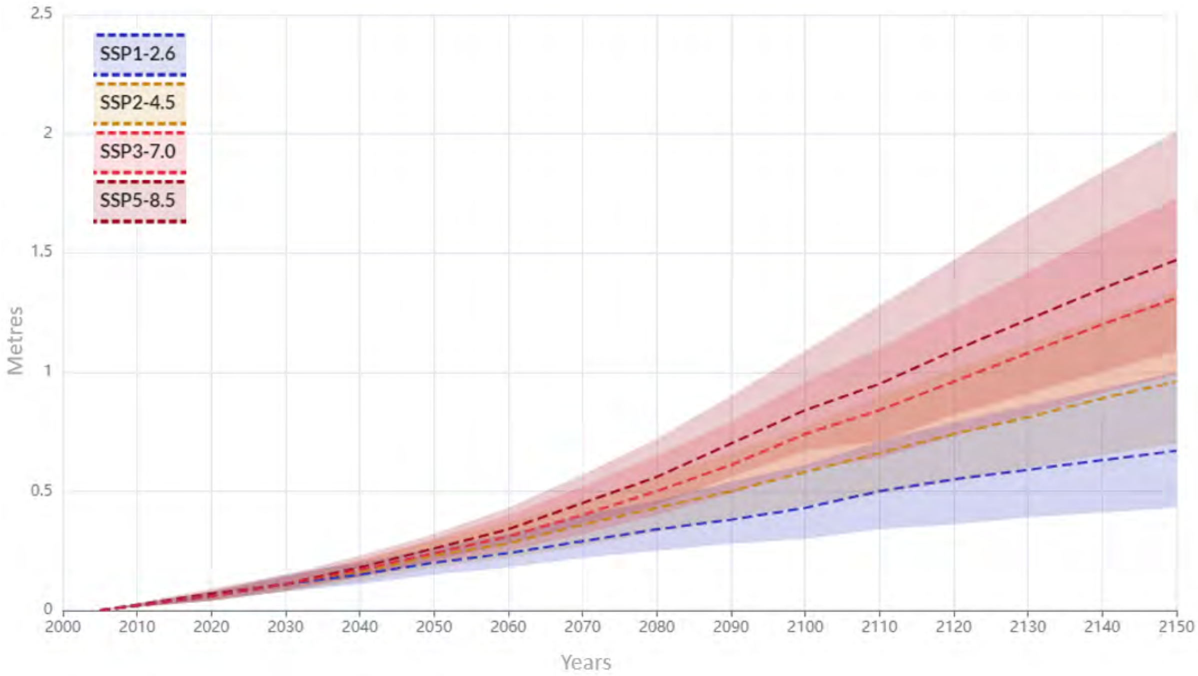

Figure 2.3: Four scenarios of New Zealand-wide regional sea-level rise projections as stipulated by the MfE 2022 guidance (modified from NZ SeaRise 2022).

2.2.4 Impact of vertical land movement

MfE (2022) also recommends consideration of vertical land movement (VLM), such as tectonic uplift or subsidence, as changes in land level can accelerate or decelerate the local effects of a rise in absolute sea level.

The MfE (2022) guidance recommends adopting the VLM projections provided by NZ SeaRise at 2 km intervals around the New Zealand coast. The rates of VLM provided by NZ SeaRise are based on Envisat Synthetic Aperture Radar (SAR) data from 2003 to 2011. This period was selected to reduce temporal biases introduced by local earthquakes (GNS, 2022). Based on this dataset the average VLM rate along the Port Levy shoreline indicates land subsidence of -1.74 mm/year.

A more recent study has looked at the co- and post-seismic land deformation due to the 2010/11 Canterbury earthquakes, the 2016 Valentine's Day earthquake and the 2016 Kaikōura earthquake and re-estimates the VLM projections across the Christchurch region (GNS, 2023). Findings from the study show that land around Port Levy has been subsiding at a much higher rate of -6.6 mm/year following the local earthquakes. While the land is currently subsiding at a significant rate, there is uncertainty in what the future VLM rates, and subsequently the relative rise in sea level will be. GNS (2023) indicate that it is unlikely the current post-seismic trends will continue over longer timescales (i.e., out to 2130).

A comparison between the relative sea level rise projections for the different VLM rates out to 2080 and 2130 is presented in Table 2.3. For this assessment, the average VLM rate from NZ SeaRise has been adopted. A sensitivity analysis has also been completed with GNS (2023) VLM rate out to 2130 with the SSP5-8.5H+ scenario (2.27 m SLR).

Table 2.3: Relative sea level rise values based on the NZ SeaRise and GNS (2023) VLM rates

Timeframe	Sea level rise scenario	Sea level rise projection (m)[1]	Relative sea level rise based on NZ SeaRise (m)[2]	Relative sea level rise based on GNS (2023) (m)[3]
2080	SSP5-8.5	0.49	0.59	0.87
2130	SSP5-8.5+	1.56	1.75	2.27

1 Projected sea level rise for Port Levy adjusted to 2022 baseline (sourced from MfE, 2022).

2 Relative sea level rise accounting for -1.7 mm/yr VLM.

3 Relative sea level rise accounting for -6.6 mm/year VLM.

2.3 Wind and waves

MetOcean wave hindcast data indicates the 100-year ARI wave at the entrance of the Lyttelton Harbour is 4.3 m (Table 2.4). However, the upper reaches of Port Levy are largely sheltered from the open coast swell waves. Waves reaching the shoreline are predominantly fetch and depth-limited wind waves which form during northerly winds. Based on Lyttelton Harbour wind data prevailing winds are from the north-east (Figure 2.4). Horomaka Island which is approximately 150 m offshore near the centre of the site, is also likely to provide sheltering for some of the shoreline.

Table 2.4: Extreme open coast wave heights (H_s) (m) derived from MetOcean hindcast data

Site	Average Recurrence Interval (ARI)		
	1-year	10-year	100-year
Lyttelton Harbour Entrance	3.4	4.0	4.3

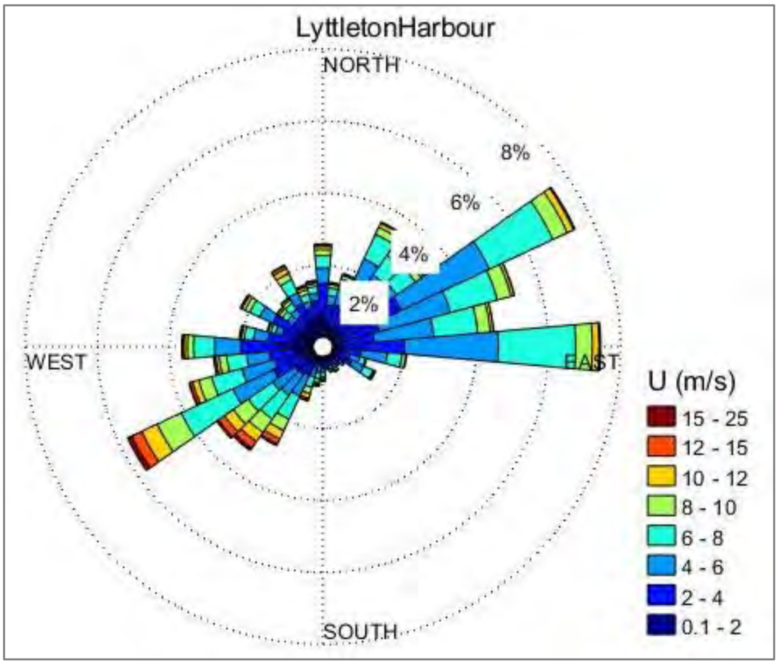

Figure 2.4: Lyttelton Harbour weather station (4903) wind rose 1978 to 2013.

SWAN modelling has been used to assess the wave transformation from the open coast into the embayment (Figure 2.5). The SWAN model was run for both swell and extreme wind waves based on the extreme offshore wave heights from Table 2.4 and extreme wind speeds based on ANZS1170.2. The largest waves reaching the upper reaches of Port Levy were generated by strong northerly winds. Maximum wave heights along the Port Levy shoreline were shown as 1.5 m based on the 100-year ARI wind speed.

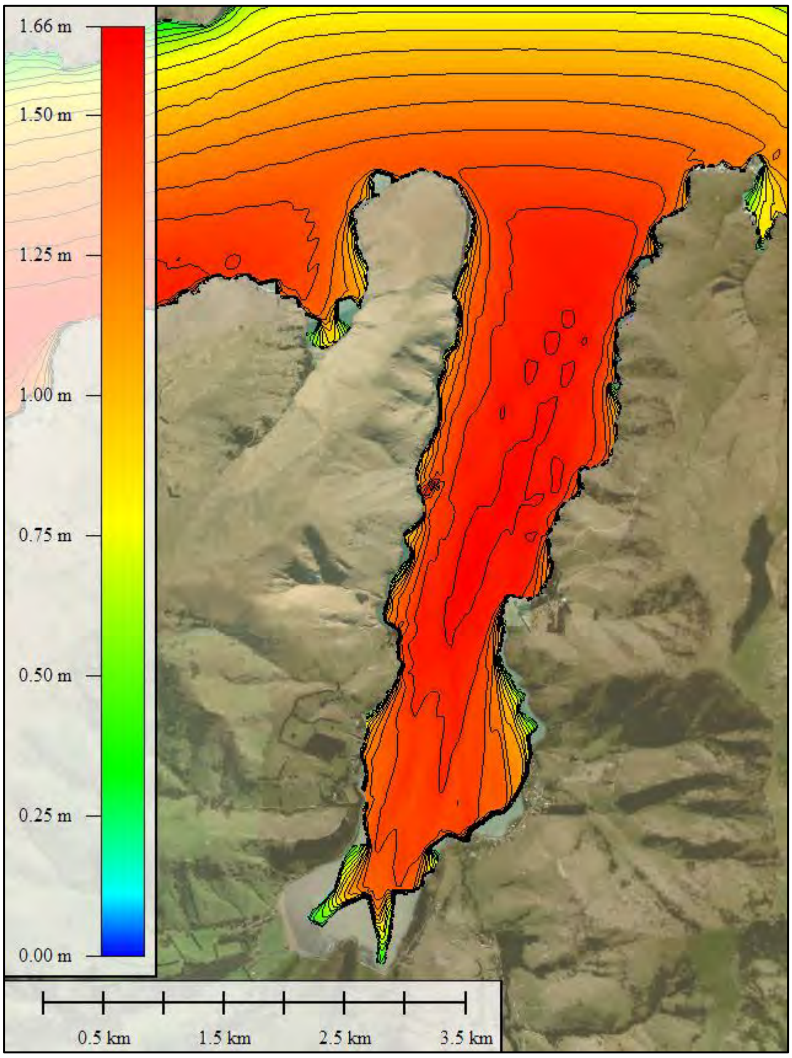

Figure 2.5: Example of SWAN results based on 100-year ARI northerly wind speeds.

2.3.1 Wave effects

Wave effects at the shoreline include wave setup and wave runup. Wave set-up is an increase in the mean water level elevation on the foreshore, caused by the momentum of breaking waves through the surf-zone. Wave runup is the sum of the wave setup and wave swash and is the maximum level that the waves reach on the shoreline relative to the still water level. Both wave setup and runup are highly dependent on the nearshore bathymetry and topography.

For the regional assessment (T+T, 2021) the wave setup component for Port Levy was based on the open coast values for northern Banks Peninsula and was subsequently highly conservative. For this assessment, the wave setup component has been refined based on the range of significant wave heights generated from the SWAN model.

Based on Guza & Thornton (1981)[2] the wave setup for 1.5 m wave is estimated to be 0.25 m. The range of estimated setup values for 1-year, 10-year and 100-year ARI events are presented in Table 2.5.

---

[2] Wave setup = 0.17*Hs.

Wave runup effects within sheltered environments like Port Levy can be estimated based on a simplified approach where runup is similar to the nearshore wave height. This approach has been adopted within other inundation studies (T+T, 2018) and results in runup levels similar to the Stockdon et al. (2006) empirical formula. For this assessment wave runup is estimated to range from 1 to 1.5 m for 1-year to 100-year ARI wave events.

Table 2.5: Summary of estimated wave setup values within Port Levy

Return period	Range of typical significant wave heights (m)	Adopted setup value (m)	Adopted runup value (m)
1 year ARI	0.5-1.0	0.17	1.0
10-year ARI	0.7-1.2	0.20	1.2
100-year ARI	1.0-1.5	0.25	1.5

3 Coastal erosion assessment

3.1 Conceptual models

Coastal erosion hazard methodologies vary depending on the shoreline type. The Port Levy shoreline includes a combination of weakly consolidated banks and consolidated basalt cliffs. Cliffs and banks comprising consolidated materials are not able to rebuild following periods of erosion but rather are subject to a one-way process of retreat. Coastal erosion of consolidated shorelines typically has two components:

- **Toe erosion**

  A gradual retreat of the bank/cliff toe caused by weathering, marine and bio-erosion processes. This retreat will be affected by global process such as sea level rise and potential increases in soil moisture.
- **Slope instability**

  Episodic instability events are predominately due to the decrease in material properties of the bank or yielding along a geological structure. Instability causes the slope to flatten to an angle under which it is ‘stable’. Slope instabilities are influenced by processes that erode and destabilise the bank toe, including marine processes, weathering and biological erosion or change the stress within the slope.

For the sections of shoreline characterised by consolidated basalt cliffs, the cliff Area Susceptible to Coastal Erosion (ASCE) defined in by T+T (2021) has been adopted. The basalt cliffs typically show very minimal toe erosion and the hazard along the slopes tends to be dominated by general slope instability hazard across the upper slope (refer to T+T, 2021). The cliff ASCE model used by T+T (2021) identifies the steep coastal edge which is potentially unstable due to coastal processes (assumed to be 1(H):1(V) and includes a 20 m setback which accounts for a range of factors including the physical scale of potential cliff failure mechanisms, long-term toe erosion and precision limitations involved with defining the unstable slope area.

For the sections of shoreline characterised by weakly consolidated banks, the erosion hazard has been assessed based on the conceptual model shown in Equation C1 and in Figure 3.1.

$$Future\ ASCE_{Bank} = (LT\ x\ T)\ x\ SL + SS \qquad \text{(C1)}$$

Where:

LT = Long-term retreat (regression rate), (m/year).

T = Timeframe over which erosion occurs (years).

SL = Factor for the potential increase in future long-term retreat due to sea level rise effects.

SS = Slope stability allowance. This is the horizontal distance from the base of the eroded bank toe to the crest at a stable angle of repose (m).

Equation 6.1: Areas Susceptible to Coastal Erosion (ASCE).

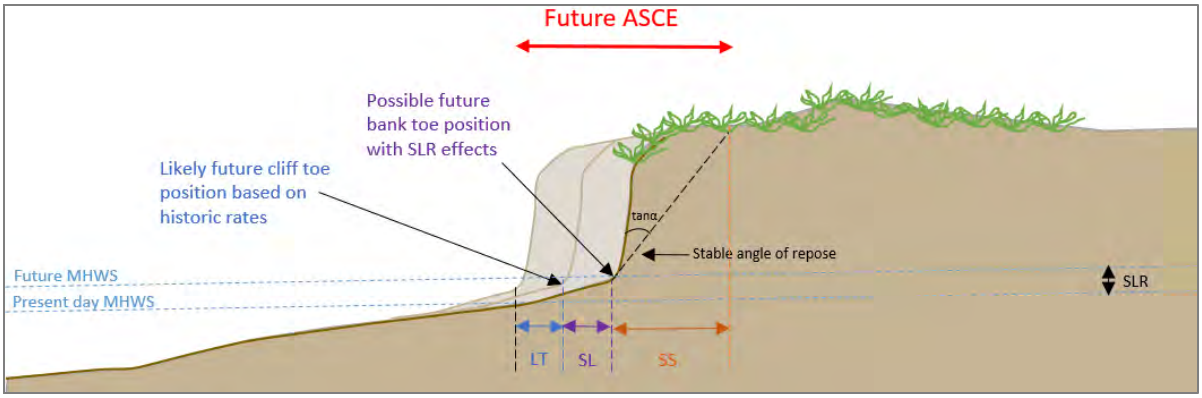

Figure 3.1: Schematisation of components contributing to the Areas Susceptible to Coastal Erosion (ASCE).

The total ASCE distances have been assessed probabilistically based on a range of values adopted for each component value (see Section 3.3 and 3.3.5) and the resulting ASCE have been offset from a baseline defined by the 2021 bank toe.

3.2 Coastal cells

The Port Levy shoreline has been divided into coastal cells based on the shoreline morphology, composition and historical shoreline trends which influences the resultant hazard. An overview of the cells splits is presented in Figure 3.2.

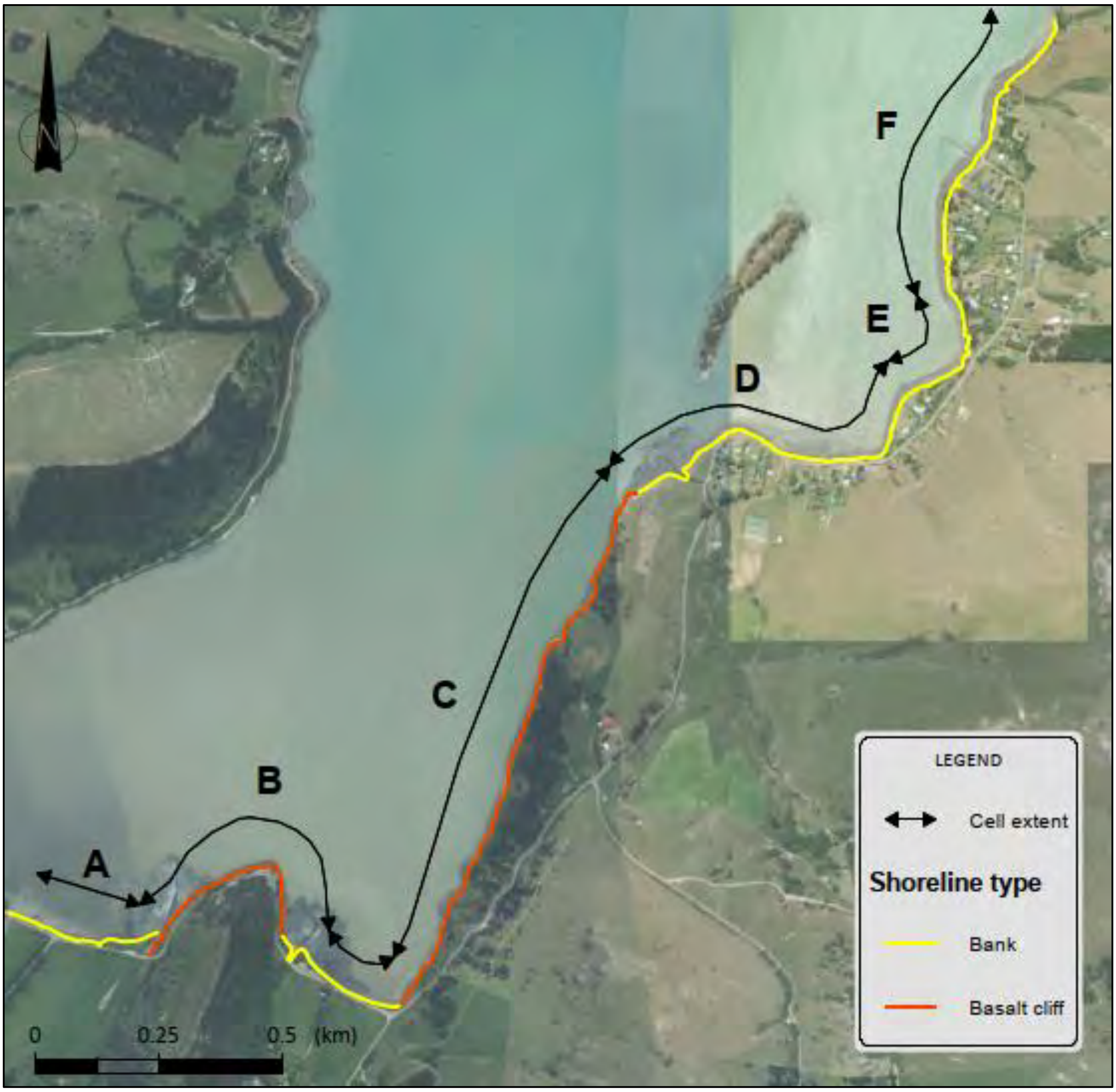

Figure 3.2: Overview of cell splits along the Port Levy shoreline.

3.3 Component values

3.3.1 Long-term trends (LT)

Shoreline data has been derived from geo-referenced historic aerials from 1940, 1974 and 2019. Comparison of the bank/cliff toe across the aerial photographs shows minimal erosion since 1940 (Figure 3.3). While the historic aerials show negligible change in the toe position, the site observations indicate there has been some active erosion along the bank toe. As there is no further information available for measuring erosion rates along the Port Levy shoreline, a range of long-term rates have been estimated based on the site observations and erosion rates measured on similar shorelines around Lyttelton Harbour by T+T (2021). The range of adopted long-term rates for Port Levy are presented in Table 3.1.

Figure 3.3: 1940 aerial photograph overlaid with 2019 shoreline position (black line).

3.3.2 Slope stability (SS)

The slope stability factor delineates the area potentially susceptible to erosion landward of the erosion scarp. The slope stability width is dependent on the height of the existing bank and angle of repose for underlying material, as shown in Equation C2,

$$SS = \frac{H_C}{2\,(tan\alpha)} \tag{C2}$$

Where:

H_c = Bank height from the eroded base to the crest.

α = Stable angle of repose for underlying material (ranging from 18 to 34 degrees).

In reality, the formation of a talus slope at the toe will allow the scarp to stand at steeper slopes (unless subsequently removed), hence the bank height is divided by 2.

Parameter bounds are defined based on the variation in bank height within the coastal cell and potential range in stable angle of repose, which for weakly consolidated banks is assumed between 18 to 34 degrees (1[V]:2[H] to 1[V]:3[H]). The bank heights for each coastal cell have been obtained from the 2021 LiDAR and are presented in Table 3.1.

3.3.3 Shoreline response to sea level rise (SL)

Sea level rise may increase the amount of wave energy able to propagate over a fronting platform or beach to reach a bank/cliff toe, removing talus more effectively and increasing the potential for hydraulic processes to affect erosion and recession. However, in some locations, the existence of a talus will provide self-armouring, and may slow bank recession due to waves. Ashton et al. (2011) proposes a generalised expression for future recession rates of cliff coastlines shown in Equation C3:

$$SL = \left(\frac{S_2}{S_1}\right)^m \qquad \text{(C3)}$$

Where:

S_1 = Historic rate of sea level rise.

S_2 = Rate of future sea level rise.

m = Coefficient, determined by the response system (sea level rise response factor).

An instantaneous response (m = 1) is where the rate of future recession is proportional to the increase in sea level rise. An instant response is typical of unconsolidated or weakly consolidated shorelines. No feedback (m = 0) indicates that wave influence is negligible, and weathering dominates. The most likely response of consolidated shorelines is a negative/damped feedback system (m = 0.5), where rates of recession are slowed by development of a shore platform or fronting beach.

For the banks within Port Levy a sea level rise response factor (m) ranging from 0.3 to 0.5 has been adopted. This is in line with what has been adopted for other weakly consolidated banks throughout the Christchurch region which are likely to have similar erosion susceptibility as the Port Levy banks (T+T, 2019, 2021, 2022).

3.3.4 Adopted component values

The component values adopted for defining the ASCE for each coastal cell are presented in Table 3.1.

Table 3.1: Adopted component values for defining the ASCE along the Port Levy shoreline

Cell		A	B	C	D	E	F	G
Morphology		Bank	Basalt cliff	Bank	Basalt cliff	Bank	Bank	Bank
Bank height (m)	Lower bound	1	Cliff ASCE[1] adopted	1	Cliff ASCE[1] adopted	1	5	1
	Mode	1.3		1.5		1.5	10	1.5
	Upper bound	1.5		2		2	16	2
Stable slope (°)	Lower bound	18		18		18	18	18
	Mode	26		26		26	26	26
	Upper bound	34		34		34	34	34
	Lower bound	-0.02		-0.02		0	0	0

Cell		A	B	C	D	E	F	G
Long-term trends (m/year)	Mode	-0.05		-0.05		-0.02	-0.02	-0.02
	Upper bound	-0.07		-0.07		-0.05	-0.05	-0.05
Sea level rise factor	Lower bound	0.3		0.3		0.3	0.3	0.3
	Mode	0.35		0.35		0.35	0.35	0.35
	Upper bound	0.4		0.4		0.4	0.4	0.4

3.3.5 Probabilistic approach

The resulting ASCE distances for each coastal cell have been assessed using a probabilistic approach which is supported by MfE (2017). The probabilistic approach combines parameter bounds for each contributing erosion component to determine a probabilistic forecast of potential erosion distance over a selected timeframe. The potential erosion distances have been assessed using a Monte Carlo simulation that was repeated 10,000 times with the defined parameter distributions for each component (minimum, mode and maximum). Figure 3.4 presents an example of the component histograms and cumulative distribution functions for cell E at 2130.

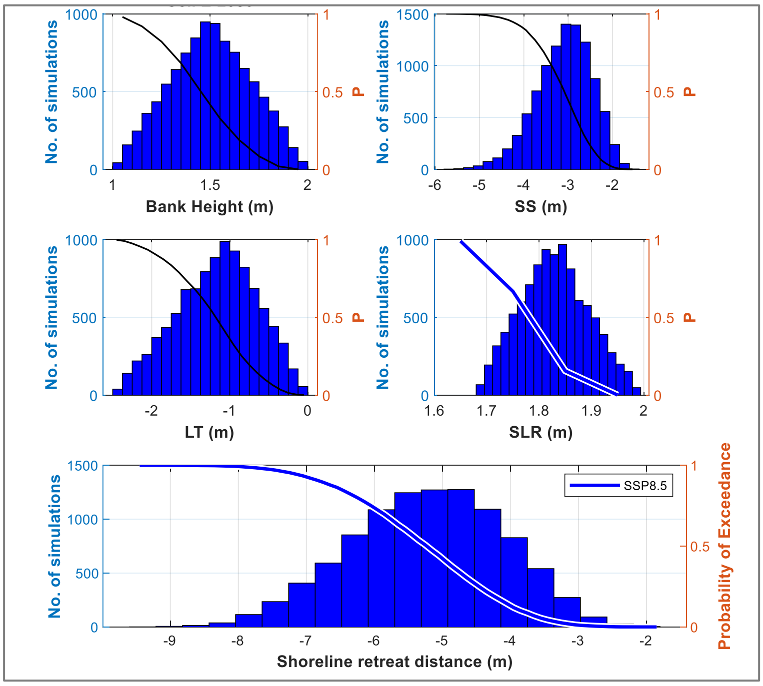

Figure 3.4: Example of histograms and cumulative distribution functions of component samples and resultant ASCE distances (m) for cell E at 2130.

3.4 Resulting ASCE distances

Based on the conceptual model outlined in Equation C1, ASCE distances have been derived using the parameter values described in 3.3. A summary of the ASCE distances for different timeframes and sea level rise scenarios is provided in Table 3.2. $P_{50\%}$ means there is 50% chance of an erosion distance being exceeded within that timeframe and can be considered a likely scenario. $P_{5\%}$ means there is a 5% change of an erosion distance being exceeded within that timeframe and can be considered a very unlikely or potential scenario. The resulting ASCE for 2080 SSP5-8.5 $P_{5\%}$ and 2130 SSP5-8.5+ $P_{5\%}$ have been mapped in Figure 3.4.

The assessment indicates that current erosion rates along the Port Levy shoreline are typically low, however the weakly consolidated banks do show undercutting in some locations and once the bank material is eroded away by the sea it is unable to rebuild. As the sea level rises, there is expected to be increased wind-wave energy reaching the shoreline due increased water depths which will increase the rates of erosion. The results show that by 2130 there is potential for -13 to -35 m of erosion from the present-day shoreline. The future erosion will likely impact the access roads around Port Levy including, Pa Road, Fernlea Point Road and Wharf Road, as well as some residential properties which are on the current coastal edge.

A sensitivity analysis for the high VLM rates provided by GNS (2023) has also been undertaken. The higher VLM rate provided by GNS (2023) (-6.6mm/year) increases the relative sea level rise by 0.5 m out to 2130 under the SSP5-8.5+ scenario. This increase in sea level rise is anticipated to only increase the erosion distances by no greater than 1 m over the 2130 timeframe. Given the small difference in erosion rates, this scenario has not been mapped.

Table 3.2: Summary of future ASCE distances (m from 2021 bank toe) for the bank coastal cells

Cell	Timeframe	Sea level rise scenario	Probability of Exceedance	
			$P_{50\%}$	$P_{5\%}$
A	2080	SSP5-8.5	-7	-9
	2130	SSP5-8.5H+	-14	-18
C	2080	SSP5-8.5	-8	-10
	2130	SSP5-8.5H+	-14	-18
E	2080	SSP5-8.5	-5	-7
	2130	SSP5-8.5H+	-8	-13
F	2080	SSP5-8.5	-21	-31
	2130	SSP5-8.5H+	-24	-35
G	2080	SSP5-8.5	-5	-7
	2130	SSP5-8.5H+	-8	-13

4 Coastal inundation assessment

Coastal inundation includes both static inundation which is a combination of storm tide, wave set up and sea level rise, and dynamic inundation which also includes wave runup but is typically confined to the coastal edge, decreasing with distance inland (Figure 4.1). Coastal inundation levels for Port Levy are based on the following combinations:

$$Extreme\ static\ water\ level = ST + SU + SLR \qquad \text{(C4)}$$

$$Extreme\ dynamic\ water\ level = ST + RU + SLR \qquad \text{(C5)}$$

Where:

ST = Storm tide level defined by the combination of astronomical tide, storm surge and mean sea level fluctuations.

SU = Wave set-up caused by wave breaking and onshore directed momentum flux across the surf zone.

RU = Wave run-up being the maximum potential vertical level reached by individual waves above the storm tide level (note this component implicitly includes wave set-up). Run-up extent has not been mapped within this assessment.

SLR = Sea level rise over the defined planning timeframes.

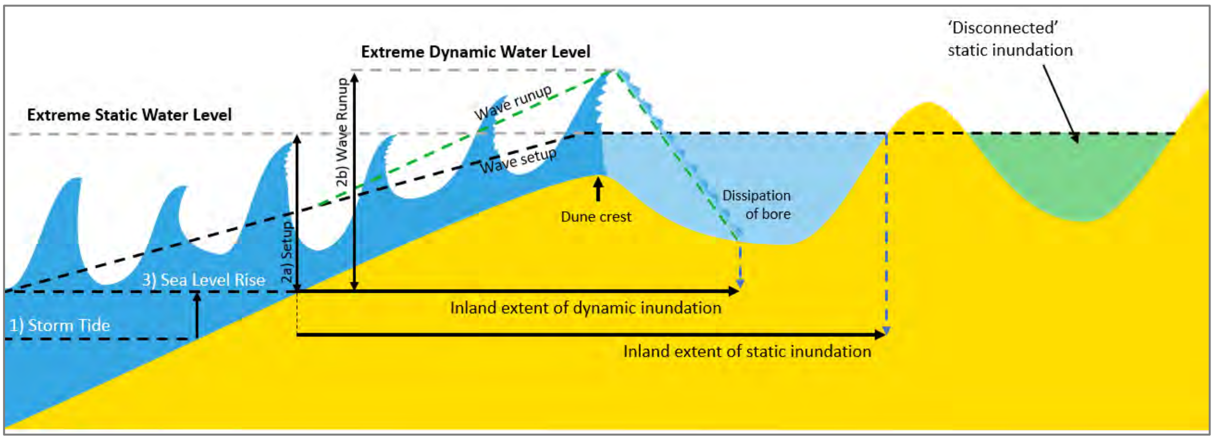

Figure 4.1: Schematisation of components contributing to coastal inundation levels.

Based on equations C4 and C5, and the components outlined in Section 2.2 and 2.3, the present-day and future 10-year and 100-year ARI extreme static and dynamic water levels have been calculated for Port Levy and are presented in Table 4.1.

The inundation extent and depth associated with 100-year ARI static water levels for 2080 SSP5-8.5 and 2130 SSP5-8.5+ have been mapped based on a bathtub approach using the 2021 LiDAR. Figure 4.1 and Figure 5.1 shows the static inundation extent and depths for the 2080 and 2130 scenarios, respectively.

The low-lying coastal areas in Port Levy, in particular along Wharf Road and Fernlea Point Road, are the most susceptible to static coastal inundation. The assessment indicates that by 2130 the 100-year ARI static water level could extend up to 250 m landward of present-day MHWS. The low-lying properties along Pa Road are also susceptible to future coastal inundation.

The extent of dynamic inundation is highly variable and dependant on the nearshore and backshore topography. As waves run up the shoreface they reach a maximum potential height at the coastal edge before decreasing with distance inland due to friction and energy loss. The reduction in run-up height with distance from the coastal edge can be assessed at a site-specific scale however it is generally restricted to 15 to 30 m from the coastal edge. Due to the alongshore variability in topography, the extent of wave run-up (i.e. dynamic inundation) has not been mapped within this assessment. There is also high uncertainty in the future extent of the wave run-up effects as the sea level rises.

A sensitivity analysis for the high VLM rates provided by GNS (2023) has also been undertaken. The comparison between the 2130 inundation extents for the NZ SeaRise VLM rate (-1.7 mm/year) and the GNS (2023) VLM rate (-6.6 mm/year) is shown in Table 4.1. The comparison shows that based on the topography there is only minor difference in the inundation extent for the different VLM scenarios. The high VLM rate provided by the recent GNS (2023) study increases the static inundation extent up by up to 50 m landward across the low coastal areas near Fernlea Road.

Table 4.1: Summary of present-day and future 10-year and 100-year ARI static water levels

Timeframe	Sea level rise scenario	Relative sea level rise (m)	Extreme static water level (m NZVD16)[1]		Extreme dynamic water level (m NZVD16)[2]	
			10-year ARI	100-year ARI	10-year ARI	100-year ARI
Present-day	N/A	0	1.8	2.1	3.0	3.6
2080	SSP8.5	0.59	2.4	2.6	3.6	4.1
2130	SSP8.5+	1.75	3.5	3.8	4.7	5.3
2130	SSP8.5+	2.27[3]	4.1	4.4	5.3	5.9

[1] Storm tide level + wave setup + sea level rise.

[2] Storm tide level + wave runup (implicitly includes wave setup) + sea level rise.

[3] Sensitivity scenario based on GNS (2023) VLM rate of -6.6 mm/year.

5 Rising groundwater assessment

As outlined in Section 4 sea level rise is expected to increase the magnitude and frequency of coastal inundation across the coastal margin, however it is also likely to result in rising groundwater levels in coastal lowlands.

A high-level rising groundwater assessment has been undertaken and relates to two of the primary groundwater issues which may be exacerbated by sea level rise:

- Inundation due to groundwater ponding (either temporary or permanent).
- A rise in the groundwater table level (which can impact buildings, infrastructure and how people can use the land).

Low-lying coastal margins generally have a relationship between groundwater level and sea level. Areas where the land level is only slightly above high tide level (or below it) are more likely to experience flooding or wet ground caused by high groundwater, and sea level rise could cause groundwater to become higher in these areas.

The screening assessment completed by T+T (2021) assumed that for land which is low-lying (below 5 m RL) and close to the coast (within 5km) the 85th percentile groundwater level is approximately equal to the MHWS high tide level. A rise in sea level is assumed to cause an equal rise in groundwater level along the coastal margin (it is acknowledged that the sea level influence on groundwater level will dissipate with distance further inland from the coast). By comparing this groundwater level to the land level, a modelled depth to the 85th percentile groundwater level has been derived. This is illustrated conceptually in Figure 5.1.

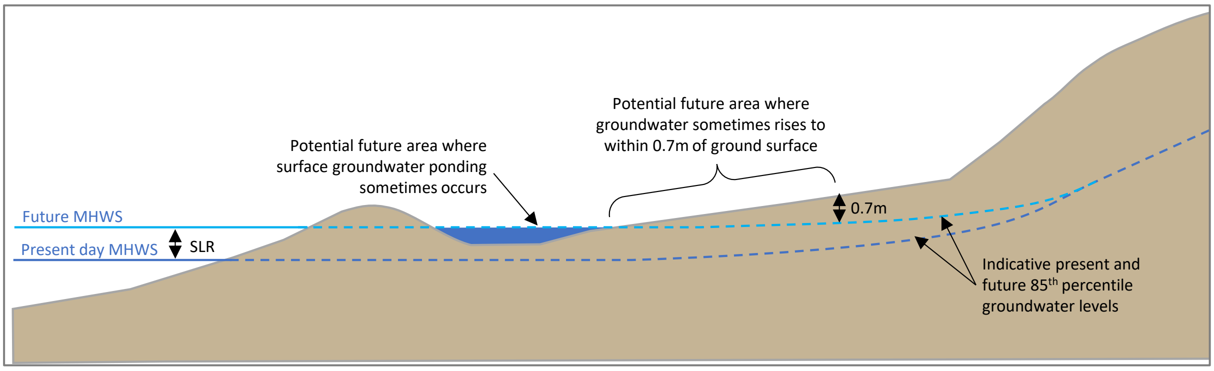

Figure 5.1: Conceptual model for indicative present-day and future groundwater levels for low-lying areas close to the coast within Port Levy.

Using 2021 LiDAR data and the sea level rise scenarios outlined in Table 5.1, mapping has been completed to identify the potential areas where future groundwater may be within 70 cm or above ground level. The 70 cm threshold is consistent with the T+T (2021) approach and indicates the level where the ground will either be inundated, wet/soft underfoot or affecting buildings and infrastructure.

The following two categories have been mapped:

1. Projected groundwater levels sometimes rise up to or above the ground surface (e.g., surface ponding or increased land drainage demands).
2. Projected groundwater levels sometimes rise to within 0.7 m of the ground surface (e.g., wet/soft ground underfoot or affecting buildings and infrastructure).

The groundwater hazard maps for 2080 and 2130 are presented in Figure 4.1 and Figure 5.1, respectively. The groundwater assessment shows a similar hazard extent as the coastal inundation hazard. The low-lying areas around Wharf Road, Fernlea Point Road and Pa Road are likely to be susceptible to elevated groundwater levels in the future as the sea level rises.

Table 5.1: Scenarios and levels used to map potential ground water susceptibility near the coastal margin

Timeframe	Sea level rise scenario	Relative sea level rise (m)	85th percentile groundwater level up to or above ground surface (m NZVD16)	85th percentile groundwater level within 70cm of ground surface (m NZVD16)
Present-day	N/A	0	0.8	1.5
2080	SSP5-8.5	0.59	1.4	2.1
2130	SSP5-8.5+	1.75	2.6	3.3
2130	SSP5-8.5+	2.27[1]	3.1	3.8

[1] Sensitivity scenario based on GNS (2023) VLM rate of -6.6 mm/year.

6 Applicability

This report has been prepared for the exclusive use of our client Christchurch City Council with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose, or by any person other than our client, without our prior written agreement.

Tonkin & Taylor Ltd
Environmental and Engineering Consultants

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Coastal Scientist	Project Director

RHAU
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PROJECT PORT LEVY FLOODING AND COASTAL HAZARD ASSESSMENT
TITLE GROUNDWATER HAZARD 2080 SSP5-8.5

SCALE (A3) 1:12,500 **FIG No.** FIGURE C.16 **REV** 0

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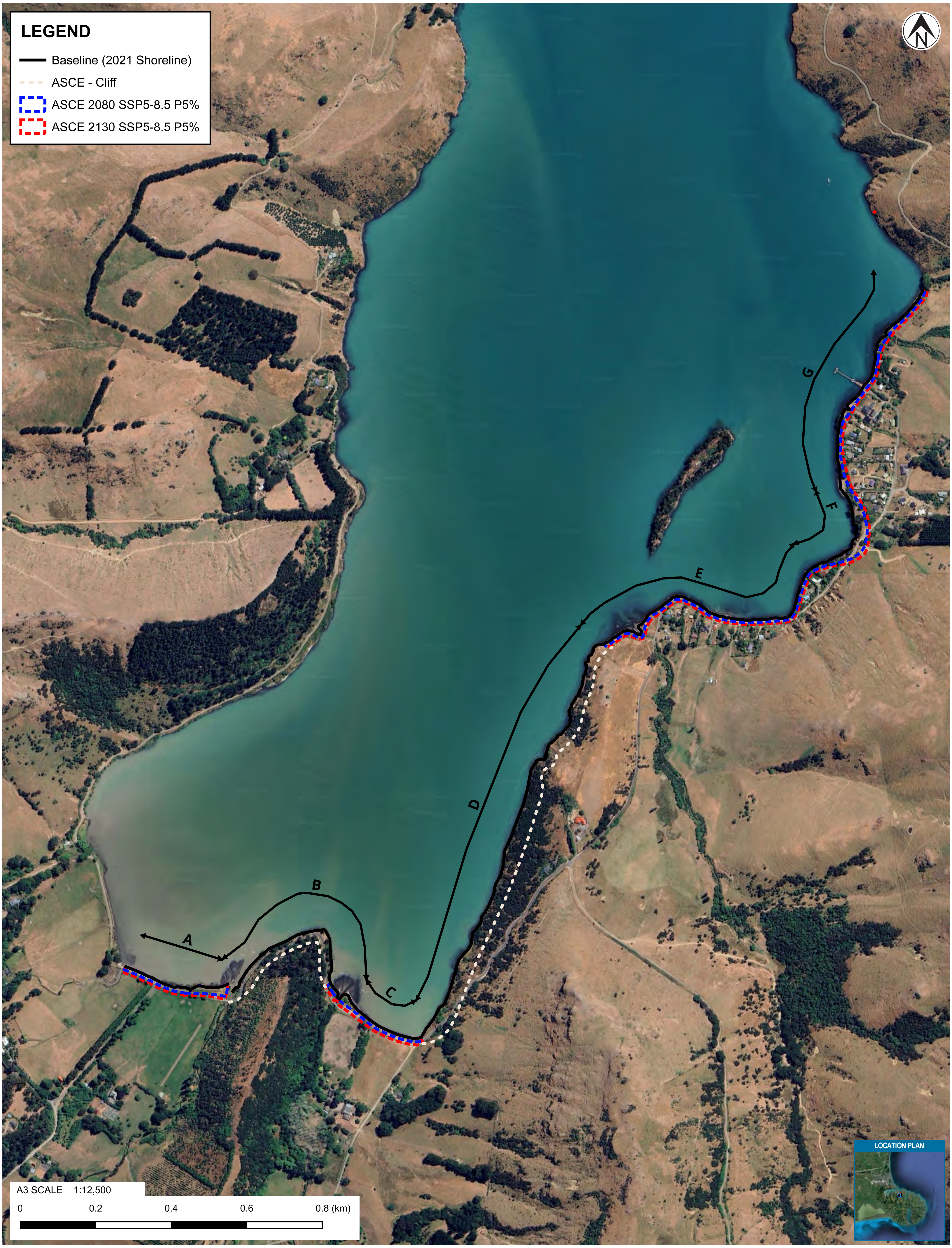
TITLE GROUNDWATER HAZARD 2130 SSP5-8.5+
SCALE (A3) 1:12,500 **FIG No.** FIGURE C.17 **REV** 0



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TITLE AREAS SUSCEPTIBLE TO COASTAL EROSION (ASCE)
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PROJECT **PORT LEVY FLOODING AND COASTAL HAZARD ASSESSMENT**
TITLE COASTAL INUNDATION EXTENTS
INUNDATION DEPTH 2080 SSP5-8.5 100-YEAR ARI

SCALE (A3) 1:12,500 FIG No. FIGURE C.12 REV 0

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PROJECT PORT LEVY FLOODING AND COASTAL HAZARD ASSESSMENT
TITLE COASTAL INUNDATION EXTENTS
INUNDATION DEPTH 2130 SSP5-8.5+100-YEAR ARI

SCALE (A3) 1:12,500 **FIG No.** FIGURE C.13 **REV** 0

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TITLE COASTAL INUNDATION EXTENTS
VLM SENSITIVITY SCENARIO
SCALE (A3) 1:12,500 **FIG No.** FIGURE C.14 **REV** 0