Ōhau-Manakau: Flood Modelling & Level of Service Assessment

PREPARED FOR HORIZONS REGIONAL COUNCIL | AUGUST 2021

We design with community in mind

Stantec

Revision Schedule

Rev No	Date	Description	Signature of Typed Name (documentation on file)			
			Prepared by	Checked by	Reviewed by	Approved by
01	26/07/2021	Draft (For HRC comment)	D Lee	T Lewis	A Craig	T Lewis
02	27/08/2021	Final		T Lewis	A Craig	T Lewis

Quality Statement

This document has been prepared for the benefit of Horizons Regional Council. No liability is accepted by this company or any employee or sub-consultant of this company with respect to its use by any other person.
This disclaimer shall apply notwithstanding that the report may be made available to Horizons Regional Council and other persons for an application for permission or approval to fulfil a legal requirement.

PROJECT MANAGER	PROJECT TECHNICAL LEAD
Tom Lewis	**Andrew Craig**

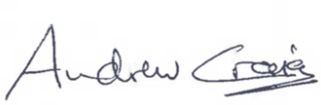
PREPARED BY
DJ Lee

27 / 08 / 2021

CHECKED BY
Tom Lewis

27 / 08 /2021

REVIEWED BY
Andrew Craig



27 / 08 / 2021

APPROVED FOR ISSUE BY
Tom Lewis

27 / 08 / 2021

WELLINGTON
Level 15, 10 Brandon Street, Wellington 6011
PO Box 13-052, Armagh, Christchurch 8141
TEL +64 4 381 6700

STATUS Final **|** **Project No** 310103515

Contents

List of Appendices

List of Tables

List of Figures

Abbreviations

Abbreviation	Full Name
AEP	Annual Exceedance Probability
ARF	Aerial Reduction Factor
DEM	Digital Elevation Model
HEC-HMS	Hydrologic Engineering Centre’s Hydrologic Modelling system
HDC	Horowhenua District Council
HRC	Horizons (Manawatu-Whanganui) Regional Council
KCDC	Kapiti Coast District Council
LiDAR	Light Detection and Ranging (airborne survey to prepare DEM)
LOS	Level of Service
NIWA	National Institute of Water and Atmospheric Research
Ō2NL	Ōtaki to North Levin new expressway
SH1	State Highway 1
1D	One-dimensional
2D	Two-dimensional

1 Introduction

1.1 Purpose and Scope

This assessment was requested by Horizons (Manawatu-Whangangui) Regional Council (HRC). The aim of the assessment is to inform the level of service (LOS) from the existing flood defences within the Ōhau-Manakau drainage scheme boundary. The results will help HRC understand current LOS performance, and to identify key assets that may require improvements to meet or increase the target LOS. To enable this assessment a new 2D hydraulic model was built to provide flood levels, depths and velocities. The model was used to calculate overtopping rates at different Annual Exceedance Probability (AEP) events, for stop banks bounding the Ōhau, Kuku, Waikawa, and Manakau watercourses. It was agreed for this initial assessment to run the 1:10, 1:25, 1:100 and 1:200 AEP events, all for current climate. Consideration may be given to adding climate impact assessments in future.

1.2 Reference Information

Key reference datasets obtained as foundation to this study are outlined below. The application of the datasets in analytical context is described later in the report.

1.2.1 Regional Information Sources and GIS

1.2.1.1 Horizons Regional Council

The Following relevant datasets have been obtained from Horizons Regional Council (HRC):

- LiDAR derived DEM covering the study area. This data was captured in the Wellington 1953 vertical datum. The majority of the area LiDAR coverage was flown in 2018, with smaller areas north of the Ōhau dating back to 2013.
- Indicative 1:200 AEP flood extents for the larger rivers in the region, although limited metadata or supporting information on this dataset was provided.
- Flow data for the Ōhau River at the Rongomatane river level gauge. A HRC flood frequency analysis was also provided.
- Flow data for Koputaroa, Manakau and Waikawa streams.
- Rainfall data.
- Aerial imagery for the area, captured in the summer of 2016-17, obtained via the LINZ data service.
- Surveyed cross section data for the Ōhau, Waikawa and Manakau Streams (2016-2021).
- Flood Defence Information – including the Ōhau-Manakau scheme boundary, stop-bank locations and asset information for the key HRC culverts/ gates.
- January 2008 flood event information including known flood extents.

1.2.1.2 Horowhenua District Council

The following relevant datasets have been obtained from Horowhenua District Council (HDC):

- Existing bridges and drainage asset information obtained from HDC GIS portal.

1.2.1.3 Waka Kotahi New Zealand Transport Agency

The following relevant datasets have been obtained from the Waka Kotahi NZTA BDI database:

- Existing State Highway bridges and drainage asset information.

1.2.1.4 KiwiRail

The following relevant datasets have been obtained from Kiwi:

- Existing railway bridge ID, names and locations within the region.

1.2.1.5 Landcare Research

The following relevant datasets have been obtained online from Landcare Research using the Land Resource Information Systems (LRIS) portal :

- Land Environments of New Zealand (LENZ) soil drainage layer – national level dataset.
- Land Cover Database version 5.0 (LCDB v5) was extracted from the LRIS portal to classify the land cover on the hydraulic modelling extent. The LCDB v5 is a multi-temporal, thematic classification of New Zealand's land cover. It identifies 33 mainland land cover classes (35 classes once the offshore Chatham Islands are included). LCDB v5 was released in January 2020.

1.2.1.6 NIWA

The following relevant datasets have been obtained from NIWA:

- HIRDS v4 rainfall digital dataset, which is key in determining design rainfall.
- Levin MAF and Levin AWS rain gauge data.

1.3 Assumptions and Limitations

The modelling approach adopted for this assessment provided reasonable representation of hydrological and hydraulic processes within the catchment, as a basis for the overtopping assessment. The assessment has focused on the 4hr and 6 hour storm durations for the entire drainage area. Sensibility checks on previous recorded flood extents provides good level of confidence in the outputs from the model. The model replicated key flow routes and spill locations within the areas of interest. This assessment has not applied climate change and this should be considered in future updates.

There is minor uncertainty due to the scale of the catchment model and slight deficiencies within the input data. In the following sections a number of the uncertainties have been highlighted including assumptions surrounding key structures. In addition, there is no gauge data downstream of Ō2NL model extent in the catchments available. Hence, no additional model calibration activity has been undertaken other than the qualitative comparison with the January 2008 flood outlines.

2 Hydrology

2.1 Introduction

The Ōhau and Waikawa watercourses originate in the Tararua ranges and discharge at two downstream tidal locations. The Ōhau River discharges into the sea near Kuku Beach. The Waikawa Stream discharges approximately 4km to the south at Waikawa Beach.

In the upper reaches of the catchments in the Tararua ranges, there is much higher rainfall expected compared to the downstream coastal plains. The hydrological approach has considered this rainfall distribution. The approach is similar to that used within the Ō2NL baseline flood risk assessment[1]. The larger upstream catchments (>5km^2) have derived point inflow hydrographs. Direct rainfall has been applied for the smaller catchments and covering the coastal plains. Details on the hydrological approach are outlined in the following sections. Figure 2-1 shows the location of the Ōhau-Manakau drainage scheme boundary against the local terrain and adjacent watercourses.

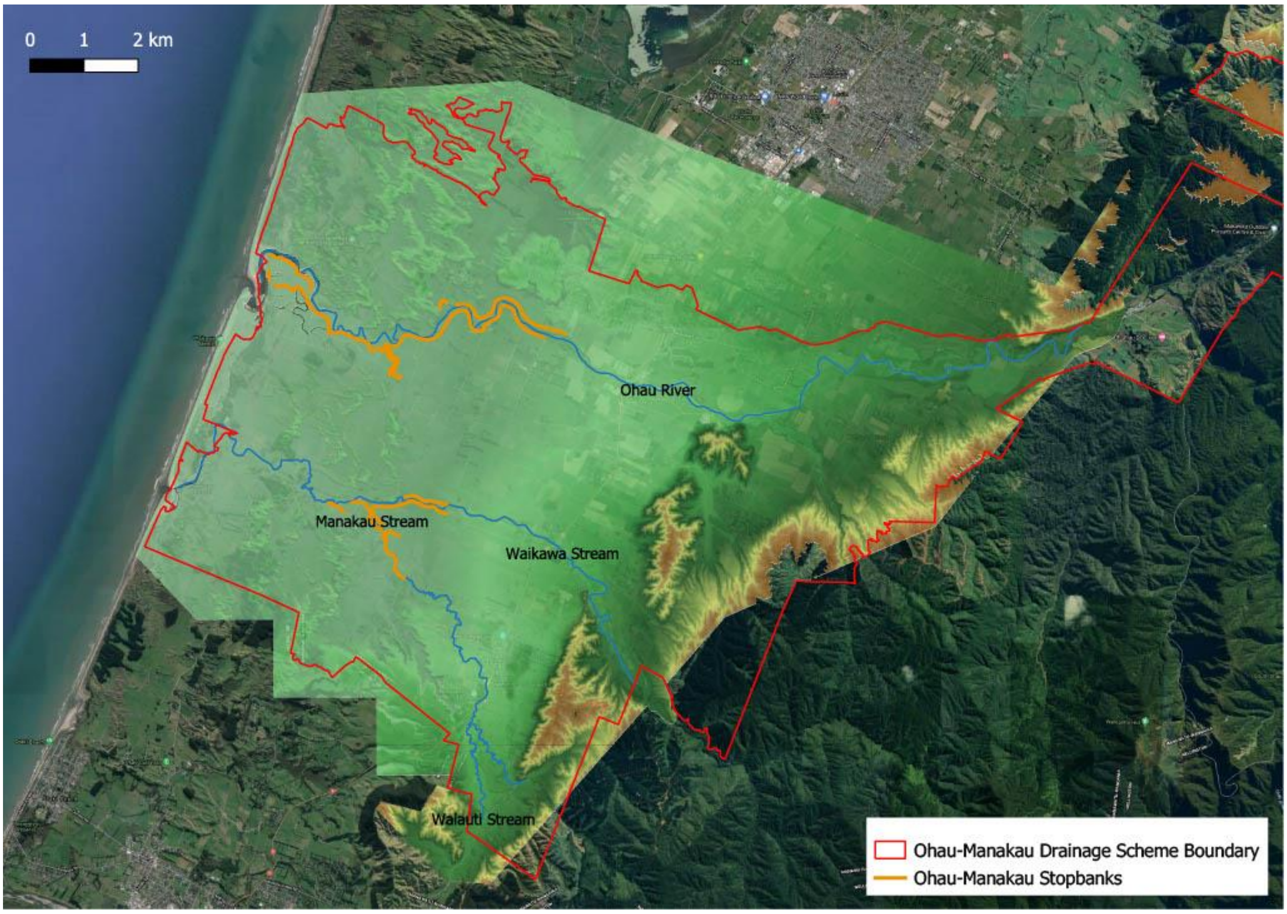


Figure 2-1: Drainage Scheme Boundary

2.2 Catchments

2.2.1 Catchment Boundaries for Input into the Hydraulic Model

This assessment has adopted upstream catchment hydrology from the Ō2NL baseline flood risk assessment. Slight modifications were made to account more explicitly for the incremental area on the Ōhau River between the

[1] Ōtaki to North of Levin: Baseline Flood Assessment Report. Waka Kotahi (NZTA). February 2021

Rongomatane gauge and the start of the Ō2NL model extent. The model domain was also extended downstream towards the tidal extents. The following sections discuss the hydrological approach to determine inflow boundaries to the new hydraulic model.

Catchments were delineated to points upstream of the proposed Ō2NL corridor for the larger rivers, namely Waiauti (South_1), Manakau (South_2), Waikawa (South_3), Kuku (South_4) and Ōhau River. Please note Catchment 33 (Ōhau River to Muhunoa East Rd) contains two smaller sub-catchments that drain into the Ōhau downstream of Rongomatane Gauge. To account for these additional flows two additional sub-catchment inflows have been determined (33d & 33e).

Direct rainfall was then applied to the small catchments upstream of and some distance downstream of the Ō2NL corridor. Similarly, direct rainfall was applied within a separate area to the west of the Ō2NL corridor model extent, towards the sea. Catchment boundaries are shown in Figure 2-2.

Upstream sub-catchments were delineated where necessary within the larger catchments to allow a more detailed representation of their respective contribution and timing in the hydrological modelling (refer to Section 2.5). The application of the catchments within the modelling are discussed further in the subsequent sections of this report.

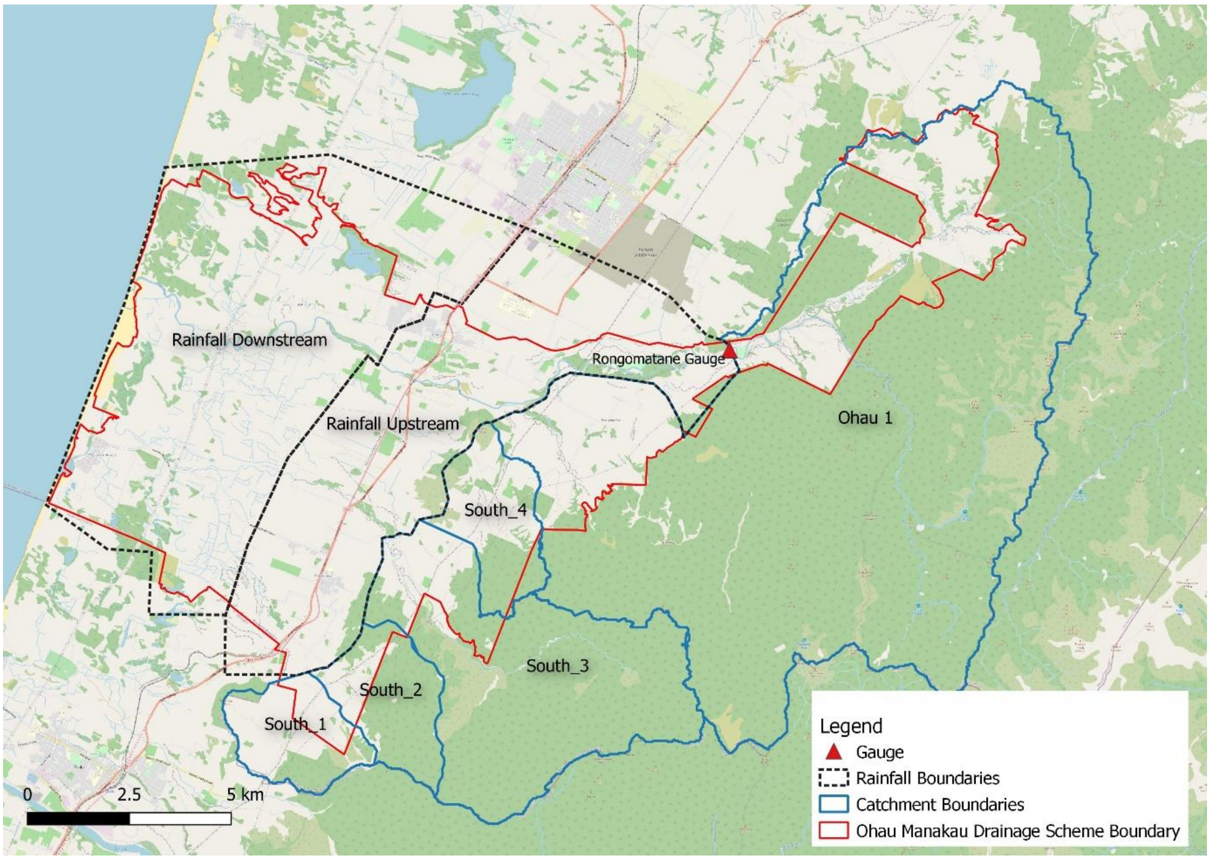


Figure 2-2: Catchment Boundaries

2.2.2 Additional Validation Catchments

Additional catchments were delineated where suitable flow gauge data was available to aid validation of the hydrological model. These included the Manakau at SH1 bridge, Waikawa at North Manakau Road and the Koputaroa at Tavistock Road. Refer to Section 2.4 for discussion regarding flow gauge & data suitability.

Catchment 39 (one of the catchments draining to a large culvert under the proposed Ō2NL expressway, within the Koputaroa catchment to Tavistock Rd) was used as an additional comparison point between the hydrological and hydraulic model results. Please note North 1, Catchment 39 and the Koputaroa all drain away from the Ōhau-Manakau drainage scheme therefore, calculated flows have not been included within the hydraulic model for this assessment, but were used as part of the overall hydrological validation process. These additional catchments are shown in Figure 2-3.

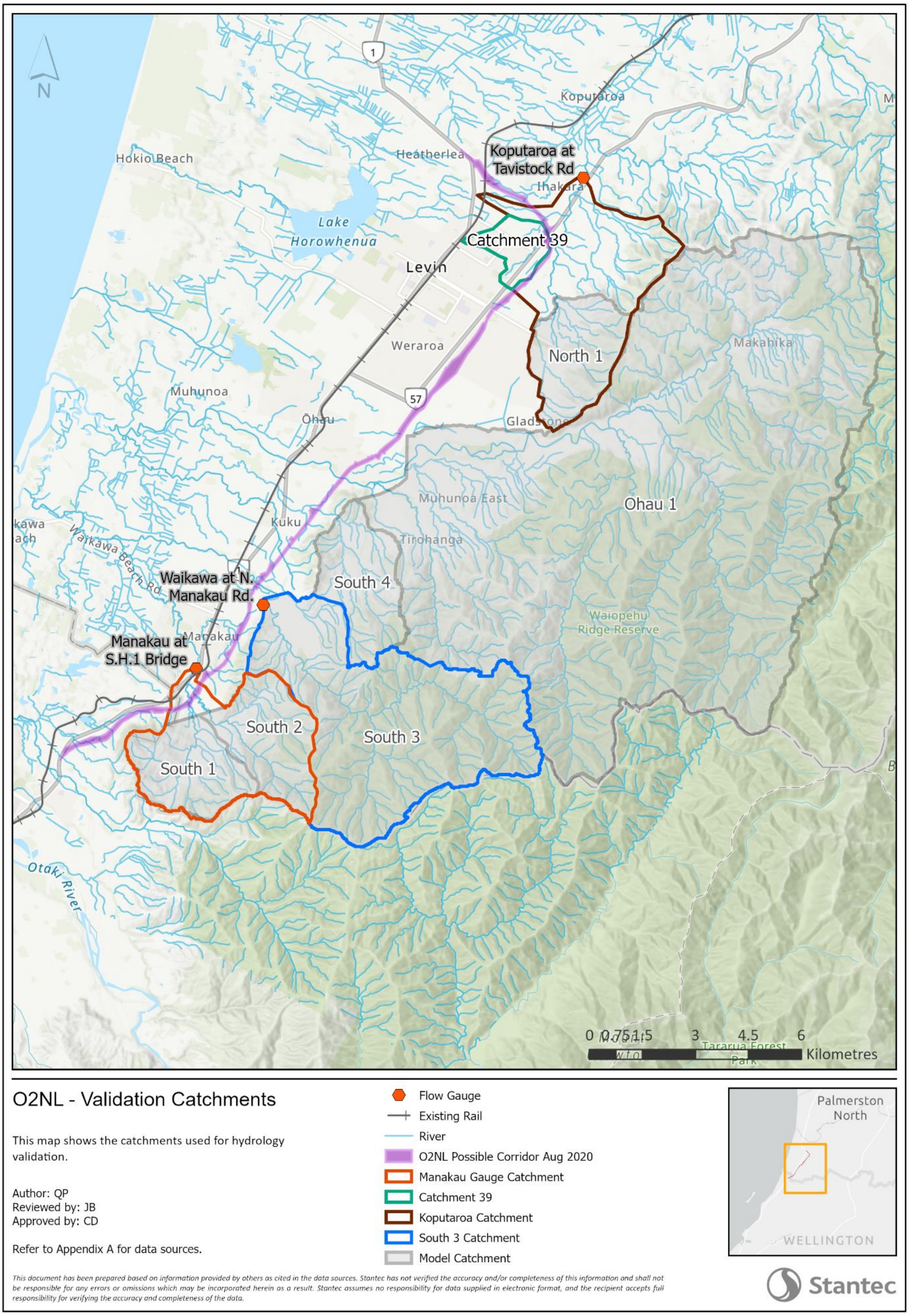


Figure 2-3: Catchments Used for Validation

2.3 Rainfall

2.3.1 Rain Gauges

There are 8 rainfall gauges in or near the study area, where data has been collected for potential use in the calibration of rainfall runoff models. The temporal availability of data and the locations are shown on Figure 2-4 and Figure 2-5.

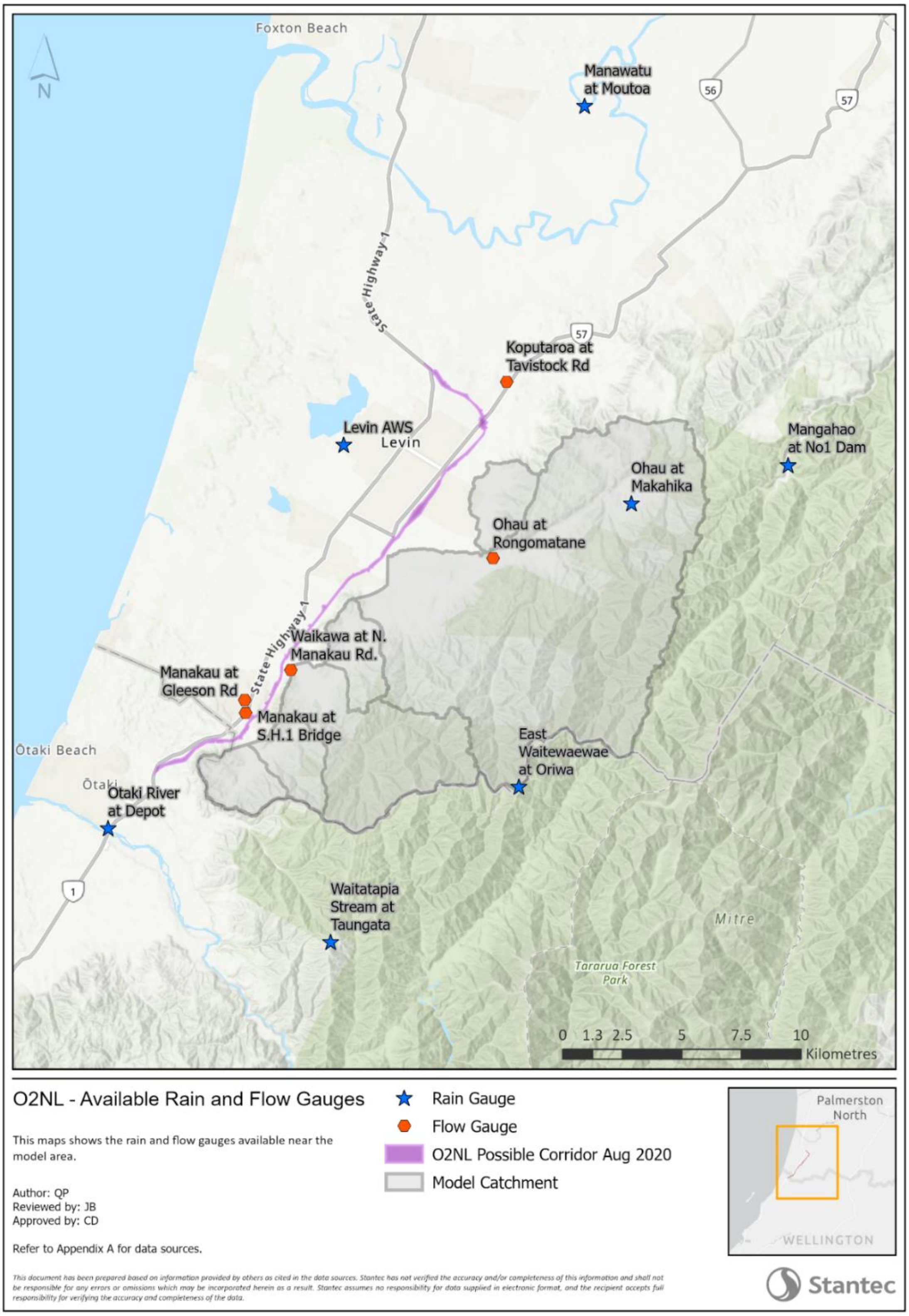


Figure 2-4: Available Rain and Flow Gauges

The available gauge information is summarised in Table 2-1 below.

Table 2-1: Rain Gauges in or near the Catchments

Name	Site Number	Latitude	Longitude	Recording Authority	Start of Record	End of data
Manawatu at Moutoa	55303	-40.4914	175.37207	HRC	Oct-99	Jun-20
Mangahao at No1 Dam	56403	-40.6252	175.47793	HRC	Jan-00	Jun-20
Ōhau at Makahika	56404	-40.6413	175.40065	HRC	Dec-09	May-20
Levin AWS	3275	-40.622	175.257	NIWA	Jan-95	Jan-13
Levin MAF	3277	-40.622	175.257	NIWA	Jan-86	Jan-91
East Waitewaewae at Oriwa	57302	-40.7496	175.34851	GWRC	Sep-91	Dec-20
Waitatapia Stream at Taungata	58201	-40.8102	175.25687	GWRC	Sep-91	Dec-20
Ōtaki River at Depot	57106	-40.7693	175.14467	GWRC	Jun-92	Sep-20

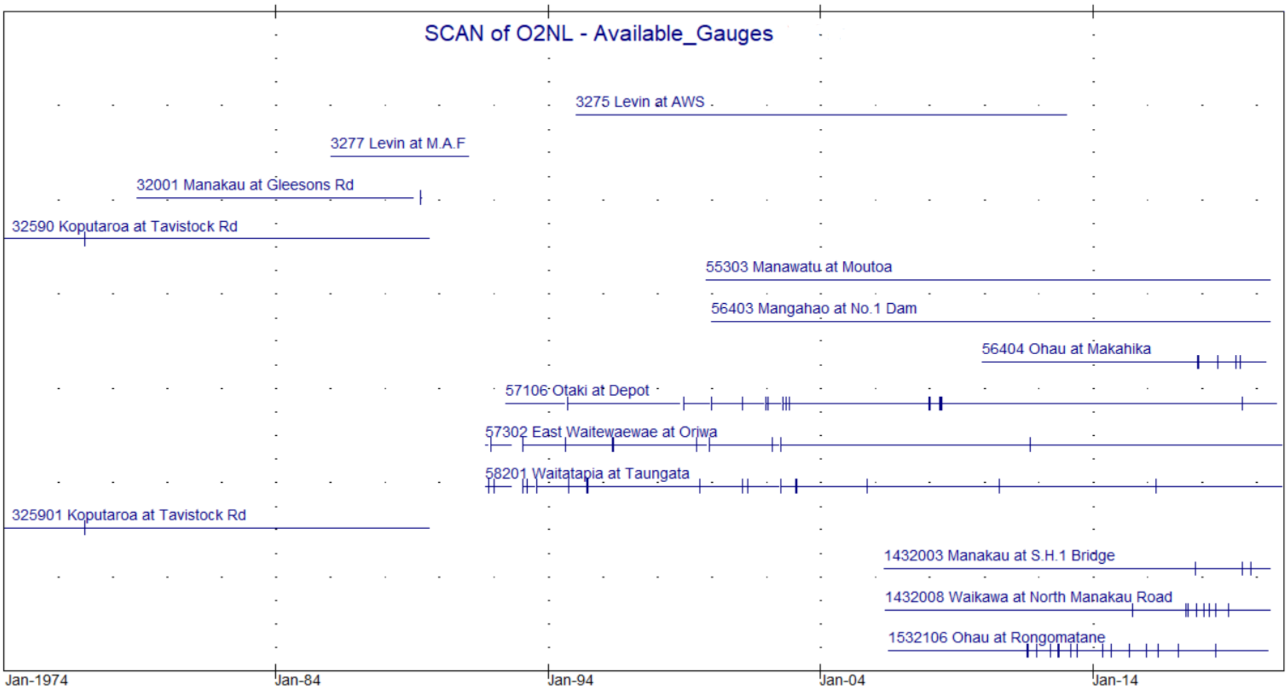


Figure 2-5: Graph Showing Availability of Rainfall and Flow Gauge Data

As illustrated in Figure 2-4 there are multiple gauges at low elevations close to the Ō2NL road corridor. There are also gauges at high elevation in the Tararua ranges which aid in the representation of the orographic precipitation gradient present in the larger catchments. For the gauges located in these ranges, the recording authority notes that they suffer from large evaporation discrepancies.

Figure 2-6 shows cumulative rainfall plots for each gauge. This shows increasing rainfall gradient with elevation, with the gauge at Tangata receiving the highest rainfall (steepest gradient) and gauges on the coastal plain showing a flatter gradient. Generally, there are no significant changes in cumulative rainfall gradient for these gauges which if present would indicate an issue with data quality or a change in gauge exposure. Gaps in the data are indicated by squares.

Thiessen polygons were created based on the available gauge data for each observed event, to derive a weighted catchment-average rainfall for use in the calibration process. An example of Thiessen polygons for the January 2008 event is shown in Figure 2-7.

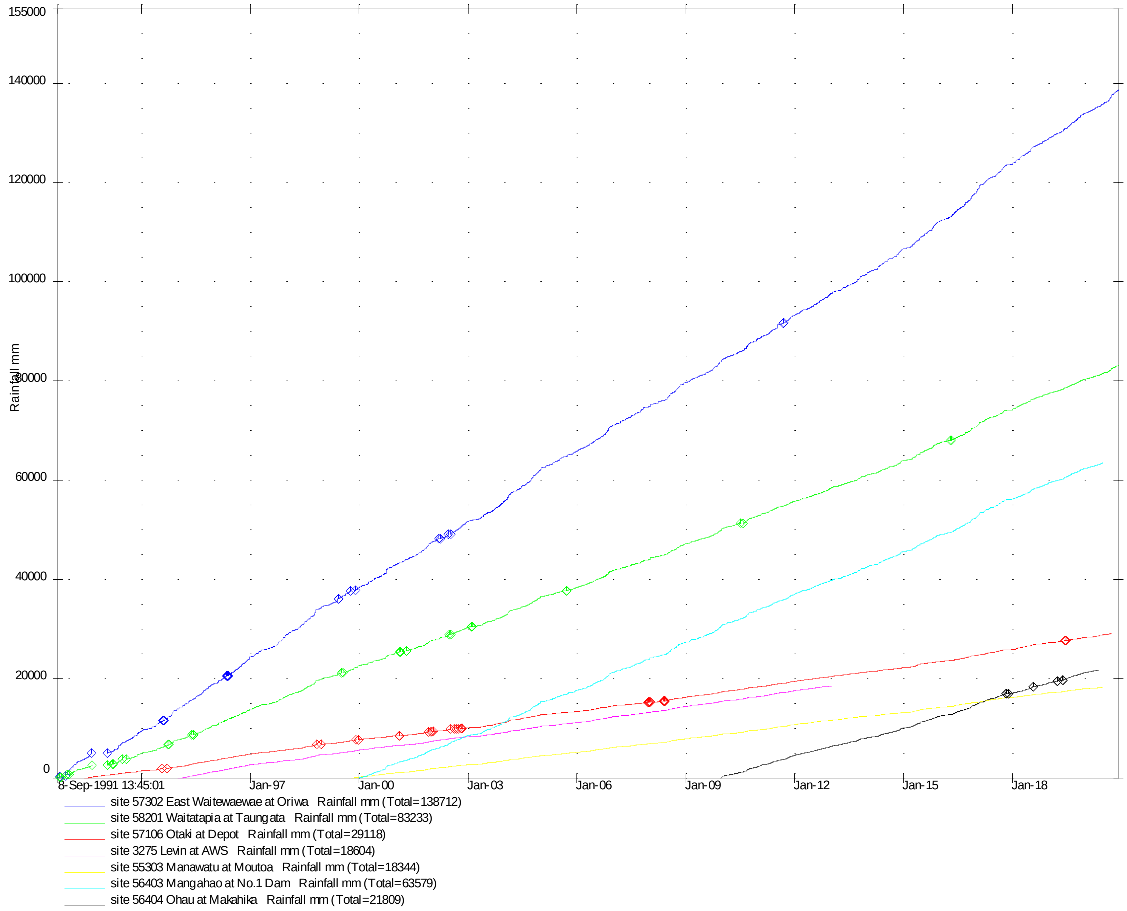


Figure 2-6: Cumulative Rainfall Plots

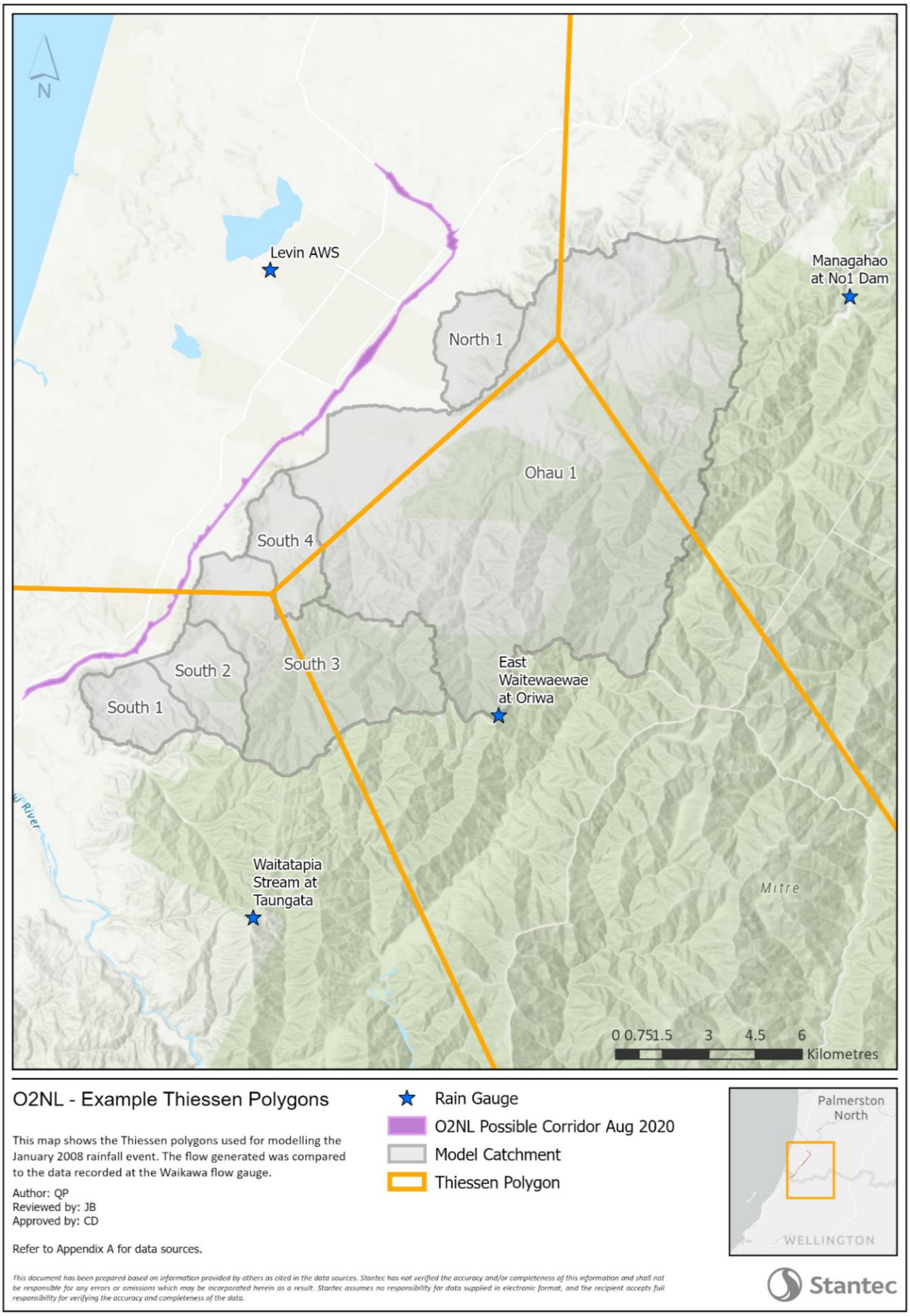


Figure 2-7: Thiessen Polygons Created & Used for the January 2008 Event

2.3.2 Design Rainfall up to 1:200 AEP

Design rainfall was required as input to the different hydrological approaches or processes that feed into the baseline flood modelling, notably:

- Design rainfall input to HEC-HMS rainfall runoff models (used to derive point inflow boundaries for larger catchments).
- Design rainfall inputs to the Rational Method for a subset of catchments as an independent check on the HEC-HMS modelling and direct rainfall modelling.
- Design rainfall for use in the 2D direct rainfall hydraulic model domains covers two key areas. Upstream areas along the Ōhau extending up to Rongomatane flow gauge including catchments within the Ō2NL model extent. Secondly, downstream of the O2NL extent rainfall has been applied within the lower coastal plains (shown in Figure 3-2).

To prepare these rainfall inputs, HIRDSv4 design rainfall tables were downloaded for the centroid of each sub-catchment to account for spatial variation across the models. An average rainfall depth of each sub-catchment was taken to provide a single number per catchment. For the direct rain on grid area, a single centroid point was taken for the two polygons (Ō2NL model extent, and western coastal plains). A further description of rainfall spatial variation is provided in Section 2.3.3.

The critical storm duration for the larger river inflows is identified to be approximately 4 hours. As longer storm durations may be more suitable for some lower parts of catchment, 4 and 6 hour storm durations were used for the initial LOS assessment.

Table 2-2: Example Rainfall Depths (mm) for South 3 Sub-catchment 1, Current Climate from HIRDSv4

Event/Duration	10m	20m	30m	1h	2h	4h	6h	12h	24h
1:10 AEP	13.1	17.9	21.5	29.5	40.1	53.8	63.5	82.8	105
1:25 AEP	16.0	21.7	26.0	35.5	48.0	64.3	75.6	98.1	124
1:100 AEP	20.8	28.0	33.5	45.3	61.0	81.1	95.1	123	154
1:200 AEP	23.3	31.4	37.5	50.6	67.8	89.9	105.2	135.2	169.2

2.3.3 Spatial Variation

As described in Section 2.3.2, the location of the catchments between the coast and the Tararua Ranges is within an area of significant orographic influence. Therefore, HIRDS v4 depths were calculated to the centroid of each modelled sub-catchment, including the 2D direct rainfall modelling zones. Figure 2-8 shows the spatial distribution based on HIRDS v4 2 hour 1:100 AEP.

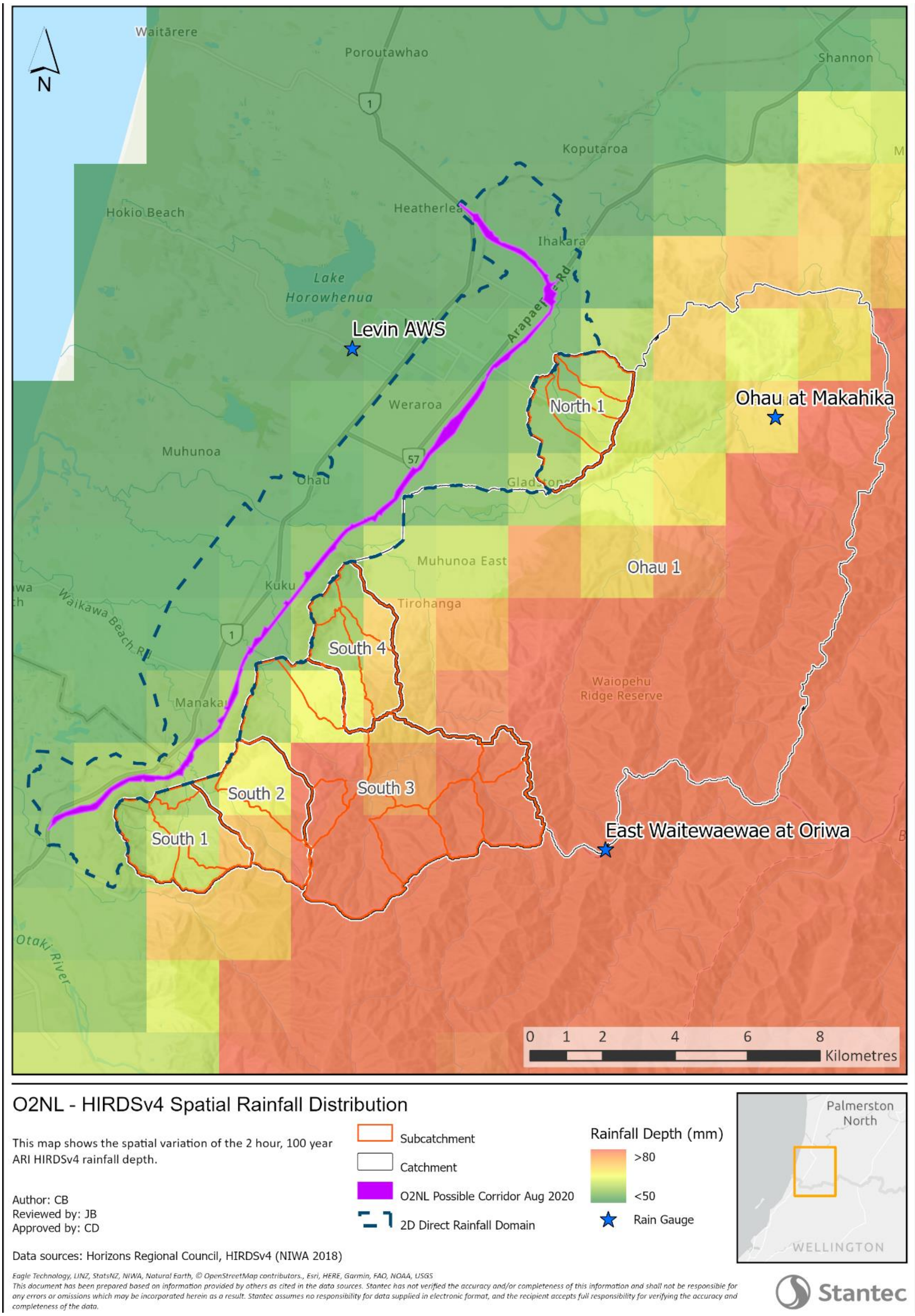


Figure 2-8: HIRDS v4 Spatial Rainfall Distribution

2.3.4 Temporal Profile

Design rain temporal profiles were based on the method outlined in the HIRDSv4 report (Carey-Smith, Henderson & Singh, 2018) using the Western North Island curves. Multiple curves were produced for 4h & 6h storm durations. As the 4hr profile is not a standard duration used in the HIRDs v4 method, a linear interpolation was used between the available four curve parameters to obtain temporal curve parameters for the 4hr duration which could then be scaled to the required event rainfall depth. Figure 2-9 below shows the 4 hour 1:100 AEP temporal profile created from the Western North Island curves, prior to final scaling for the various sub-catchment total rainfall depths (Table 2-3, in Section 2.3.6).

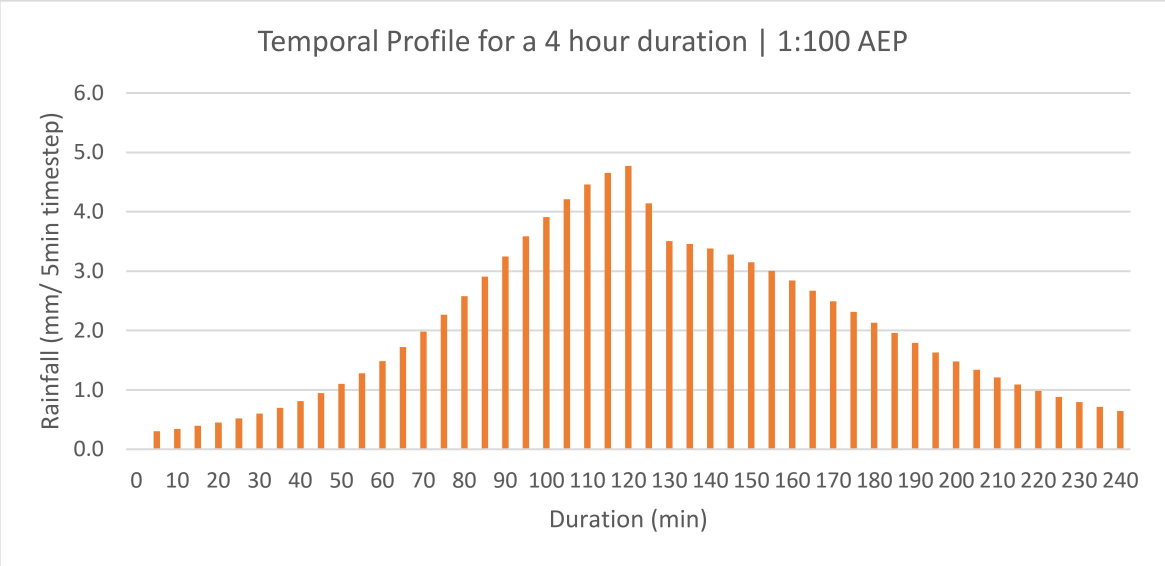


Figure 2-9: 4 Hour Temporal Profile for 1:100 AEP

2.3.5 Areal Reduction Factors

An Areal Reduction Factor (ARF) was not applied in this case, but given the relatively small constituent sub-catchments the rainfall will be slightly conservative (in the order of ~5% overestimated).

2.3.6 Summary of Adopted Rainfall Design Event Totals

Table 2-3 provides a summary of the final total rainfall depths for the adopted simulation events. The main factors that give rise to the differences between the various main catchments are the orographic effects (influence of higher elevation topography on rainfall) and the critical storm duration (for example the 4-hour duration has lower total rainfall but higher intensity in mm/hr compared to a 6-hour storm). The selection and confirmation of critical storm duration is discussed in Section 2.5.2.

Table 2-3: Adopted HIRDSv4 Rainfall Depths (mm) for Each Catchment with Current Climate

	1:10 AEP 4h (mm)	1:10 AEP 6h (mm)	1:25 AEP 4h (mm)	1:25 AEP 6h (mm)	1:100 AEP 4h (mm)	1:100 AEP 6h (mm)	1:200 AEP 4h (mm)	1:200 AEP 6h (mm)
Waiauti Sth_1 (3h duration used) - average across subcatchments	47.1	62.4	56.3	81.5	71.1	93.1	78.8	103.0
Manakau Sth_2 - average across sub-catchments	61.7	73.7	73.6	87.6	92.7	110.0	102.6	121.4
Waikawa Sth_3 - average across sub-catchments	80.5	100.0	95.9	118.7	120.4	148.6	133.1	164.0
Kuku Sth_4 - average across sub-catchments	52.9	62.4	63.1	74.4	79.8	93.5	88.4	103.5
Rain on grid area (Ō2NL model area including intervening area up to Ōhau River gauge)	49.1	57.2	58.7	68.2	74.3	86.0	82.5	95.3
Western downstream coastal plains area	43.3	50.4	51.7	60.1	65.5	75.7	72.6	83.9

2.4 Flow Gauges

Available flow gauging station records are summarised in Table 2-4 below. A graph of the data period of each gauge is shown in Figure 2-5 and a map of gauge locations shown in Figure 2-4.

The data was used to select flood events for calibration of rainfall-runoff models. Where the duration of the recorded flow timeseries was adequate, flood frequency analysis was carried out to compare with design event estimates from the rainfall runoff models and regional and rational methods.

Advice from Horizons Regional Council is that the Manakau, Waikawa and Koputoroa stream gauges are primarily for water resource assessment and are not rated with confidence for flood flows. Accordingly, flood frequency results and calibrated runoff model results based on flood records from these were not used on their own, but were also compared with results from other methods. Flow hydrographs for the three water resources flow sites are shown in Figure 2-10.

The gauging station for the Ōhau at Rongomatane provides a good record from 1978 to present with relatively few gaps. The station has a slack line cableway upstream of the site. If future design decisions are considered very sensitive to the design flow, then further investigation could be carried out on the confidence of the rating curve and flow data. Appropriate sensitivity testing and freeboard allowances should still be considered, depending on the level of conservatism required and tolerance of design decisions.

Table 2-4: Flow Gauges in or Near Catchments

Name	Site number	Latitude	Longitude	Recording Authority	Start of record	End of data
Koputaroa at Tavistock Road	32590	-40.59663923	175.337058	HRC	Jan-74	Aug-89
Ōhau at Rongomatane	1532106 1	-40.66345725	175.3326475	HRC	Jul-78	Sep-19
Waikawa at N. Manakau Road.	1432008	-40.70775371	175.2335565	HRC	May-06	Jun-20
Manakau at Gleeson Road	32001	-40.71952056	175.2110066	HRC	Nov-78	May-89
Manakau at S.H.1 Bridge	1432003	-40.72439913	175.2116174	HRC	May-06	Jun-20

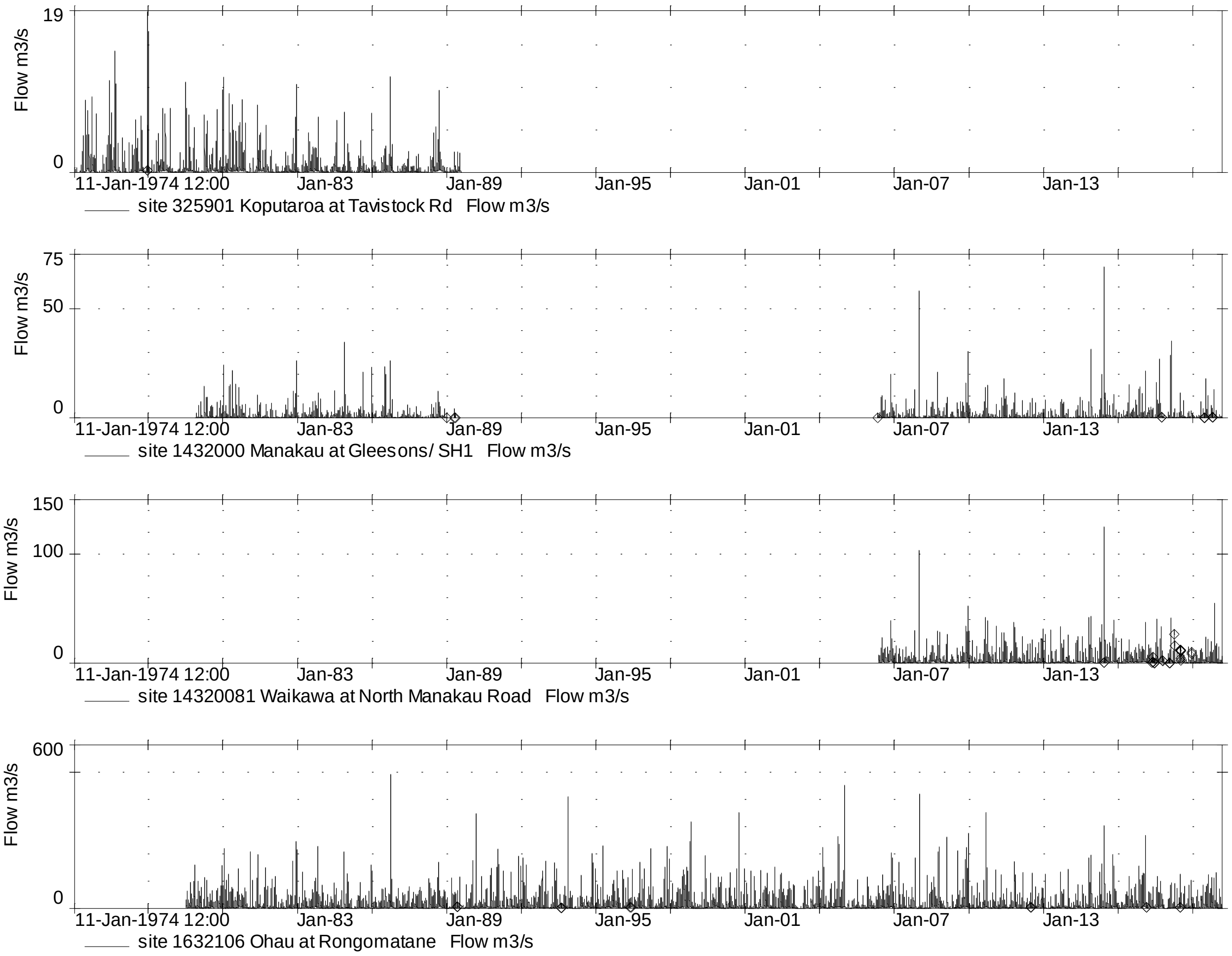


Figure 2-10: Overview of Recorded Flows

2.4.1 Flood Frequency Analysis

2.4.1.1 Koputaroa, Manakau and Waikawa Streams

Flood Frequency Analysis (FFA) was carried out on the limited data available for the Koputaroa, Manakau and Waikawa streams. As mentioned above, the primary purpose for these gauges is water resource assessment rather than flood monitoring. However, FFA was undertaken based on these records and compared with other methods. The results of the FFA are summarised in Table 2-5 and plots of annual maxima and fitted distributions are provided in Figure 2-11 to Figure 2-13 .

Table 2-5: Summary of Frequency Analysis Values

Flow Gauge	Catchment Area (km^2)	1:100 AEP Peak Flow (m^3/s)	Distribution
Koputaroa @ Tavistock Rd	21.4	20	GEV
Manakau @ Gleesons & SH1	16	86	GEV
Waikawa @ N. Manakau Rd	30.8	180	GEV

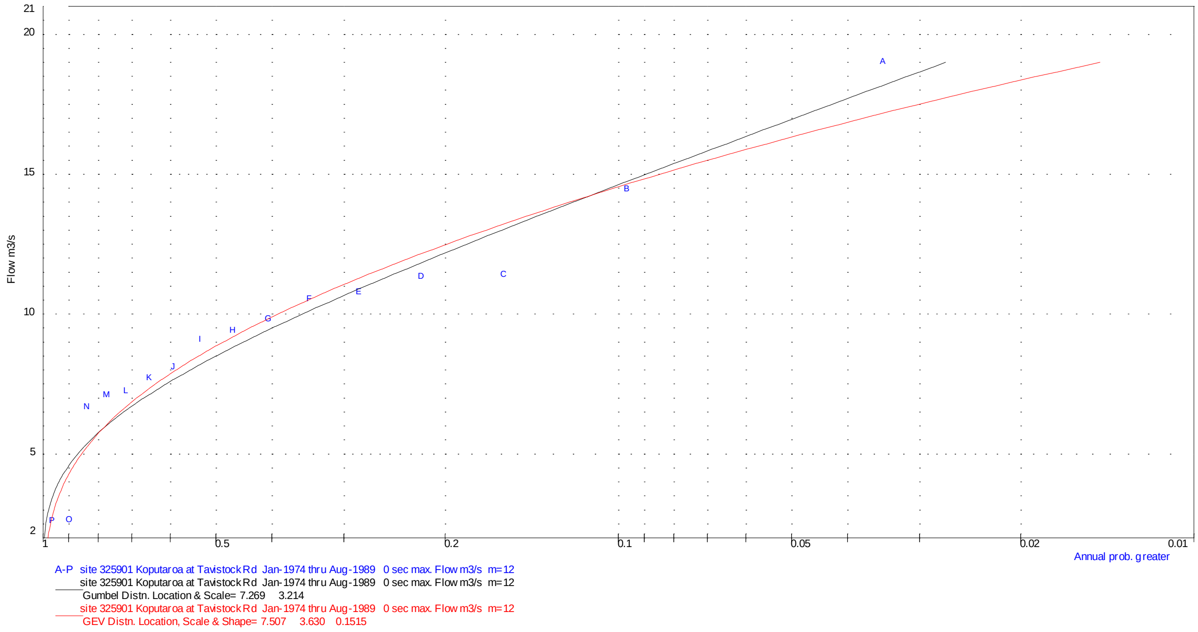


Figure 2-11: Koputaroa at Tavistock Road Flood Frequency Analysis

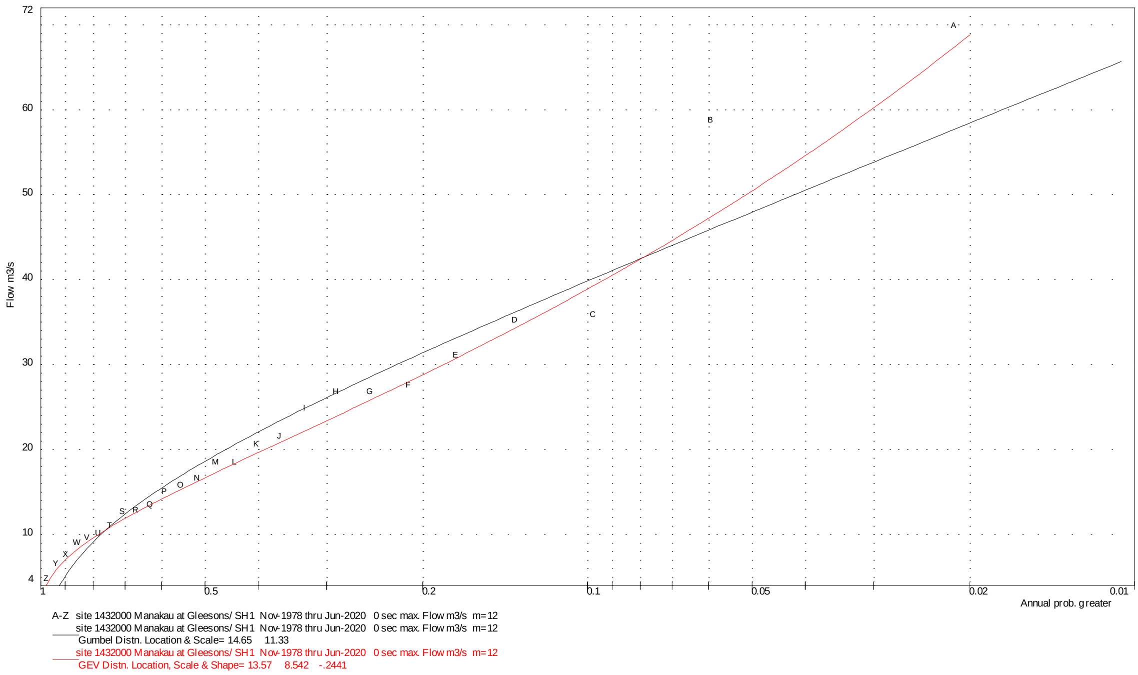


Figure 2-12: Manakau at Gleesons/SH1 Flood Frequency Analysis

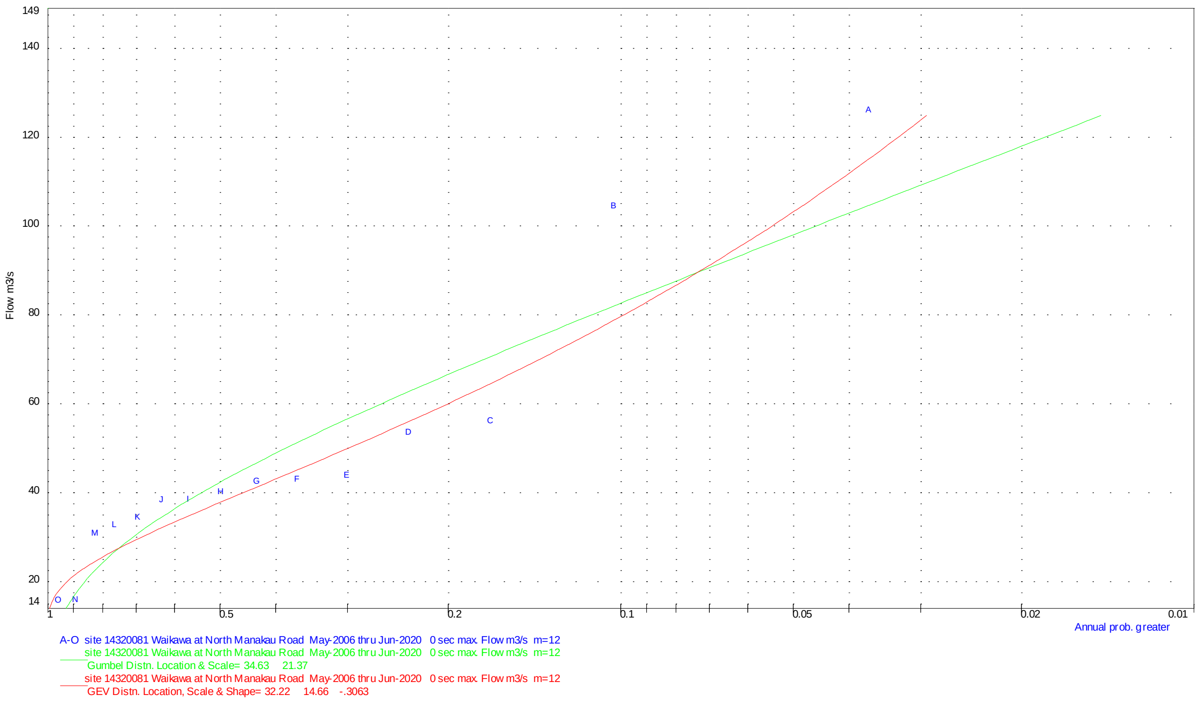


Figure 2-13: Waikawa at North Manakau Road Flood Frequency Analysis

2.4.1.2 Ōhau River

A flood frequency analysis was carried out for the Ōhau River based on flow data from 1978 to 2020 recorded at the Ōhau at Rongomatane gauging station. The analysis estimates an Ōhau 1:100 AEP flood peak at approximately 595 m^3/s.

Horizons Regional Council provided a spreadsheet of frequency analysis for Ōhau at Rongomatane flows for the period 1976 to 2006. The analysis tested the impact of including four historic floods from the 1940's and 50's and using different plotting position formulae and EV1, GEV and LP3 distributions. Results of the analysis gave 1:100 AEP peaks ranging between 545 m^3/s and 615 m^3/s with EV1 and GEV distributions and 656 m^3/s with a LP3 distribution.

To compare Stantec results with HRC's estimate, the frequency analysis was repeated for the period 1978 to 2006. This gave a GEV 1:100AEP flow of 627 m^3/s, which is fractionally higher than the HRC GEV value of 615m^3/s. This suggests that inclusion of the 4 additional historic events may have contributed to the lower value derived by HRC.

The frequency analysis carried out for this assessment and shown in Figure 2-14 uses an addition 14 years of flow data compared to the HRC analysis. It was found that a General Extreme Value (GEV - blue) distribution provided a better statistical fit to annual flood maxima than an EV1 (Gumbel - red) distribution. It is also the more conservative (higher) value for the 1:100 AEP event, and is therefore adopted for subsequent design calculations.

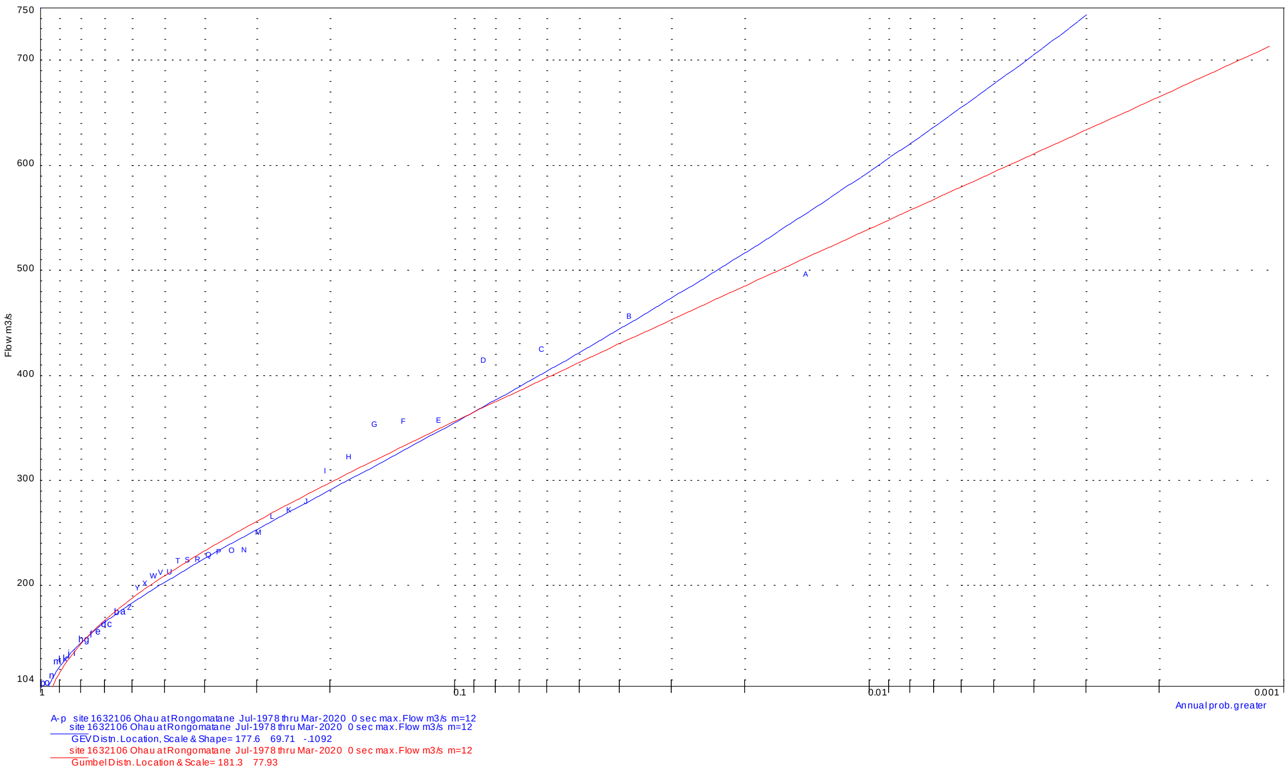


Figure 2-14: Ōhau River at Rongomatane Flood Frequency Analysis

The Ōhau peak flows were required for input to the hydraulic model to represent flows at the Rongomatane gauging station. Table 2-6 highlights the peak flows used within the hydraulic model. To generate a hydrograph using the reference peaks values, the shape from the Waikawa South 3 catchment was used, as analysis of historic events shows very similar timing between the Ōhau and Waikawa. The shape was adjusted for the 4hr and 6hr storm durations to correspond with the adjacent catchments. A 2 cumec baseflow has been applied to generate an initial wetting of the channel prior to the peak flow arriving.

Table 2-6: Peak Flows - River Ōhau (Rongomatane Gauge)

AEP Event	m3/s
1:10	353
1:25	443
1:100	594
1:200	679

2.5 Rainfall – Runoff Model

2.5.1 Model Build

The rainfall – runoff modelling software Hydrologic Modelling System (HEC-HMS), version 4.6.1, was used to simulate precipitation-runoff. The software is developed by the Hydrologic Engineering Center within the U.S. Army Corps of Engineers and is used widely within New Zealand and internationally. It was applied for catchments Waiauti South 1, Manakau South 2, Waikawa South 3, Kuku South 4, and the larger Manakau SH1 Gauge catchment (which combines South 1 & 2 and additional area downstream to the gauge). An example of Waikawa South 3 is featured in Figure 2-15 below.

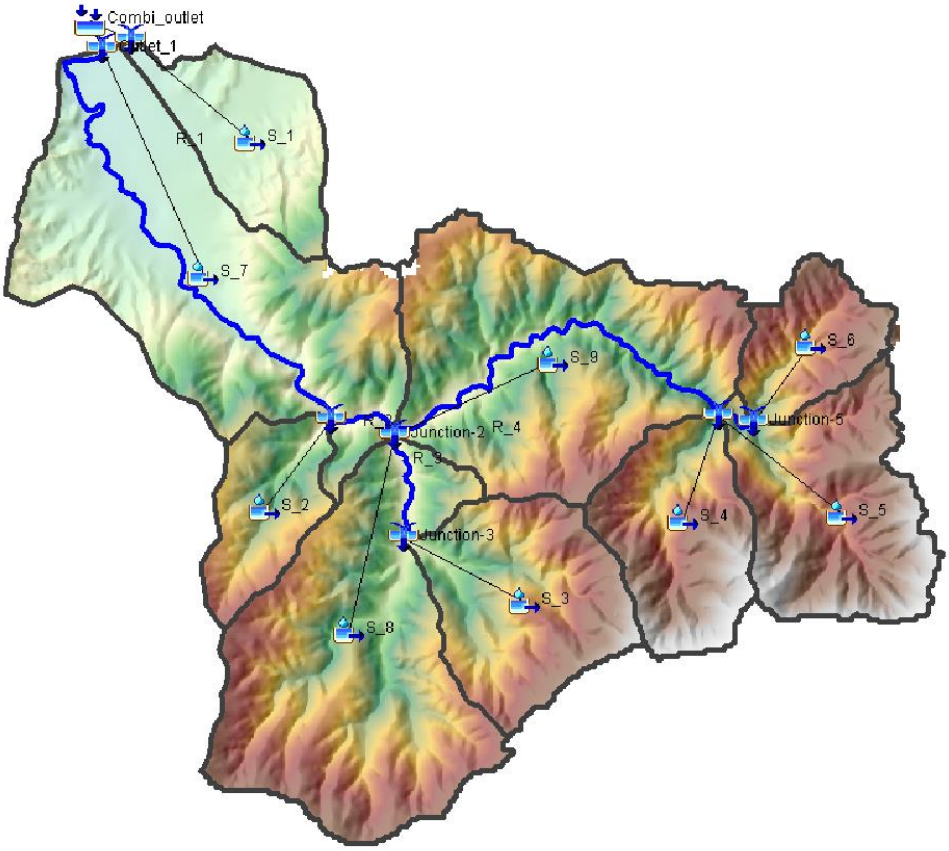


Figure 2-15: HEC-HMS Model Schematic Example of the Waikawa South 3 Catchment

The following is a summary of final hydrological model input parameters after the calibration had been confirmed as acceptable (as discussed in 0):

Loss: Initial and Constant

The initial and constant losses were informed by the Fundamental Soil Layer Drainage Class map from Land Resource Information Systems Portal. Whilst there is some variation in drainage class, the calibration and validation was satisfactory with a consistent set of runoff parameters across all hydrological models (refer to 2.5.3):

Initial Loss = 7mm

Constant Loss = 5mm/hr

Note the raw rainfall data has been applied to the hydraulic model. The application of Initial and Constant Losses within the TUFLOW hydraulic model is discussed separately in Section 3.6.

Transform: Clark Unit Hydrograph

Initially, default parameters were used and then adjusted based on a comparison with other methods and calibration, to reach the following:

Time of Concentration = Bransby-Williams

Storage coefficient = Time of Concentration * 3

Routing: Muskingham-Cunge

For the HEC-HMS models used as input boundaries for the hydraulic model, the Muskingham Cunge method was used to calculate the routing up to the point required for the hydraulic model. For the separate models that were solely used for model validation (Koputaroa & Manakau Gauge catchment), a simpler Lag routing method was used for the downstream reaches. This was tested and compared with the Muskingham Cunge method and was not found to make a significant difference. The net effect was also confirmed by comparison with the observed validation event hydrographs.

Temporal Rainfall Profiles

The temporal profiles mentioned in Section 2.3.4 were used to provide the rainfall hyetograph for the design events, with an override total rainfall depth applied to each sub-catchment as per Table 2-3 (Section 2.3.6).

2.5.2 Critical Storm Duration

Each HEC-HMS modelled catchment was initially run with 1:100 AEP current climate rainfall with various storm event durations from HIRDS data and the critical duration selected that resulted in the greatest peak modelled flow. See Figure 2-16 for an example of a hydrograph for Waikawa South 3 showing the critical duration as 4 hours. Once each catchment's critical duration was found, each model was then tested with 1:10 AEP current climate with various durations to confirm that the chosen duration was still applicable. Refer to Table 2-8 in Section 2.6 for final critical durations used in the model.

Figure 2-16 shows the varying durations used to find the critical storm duration for Waikawa South 3.

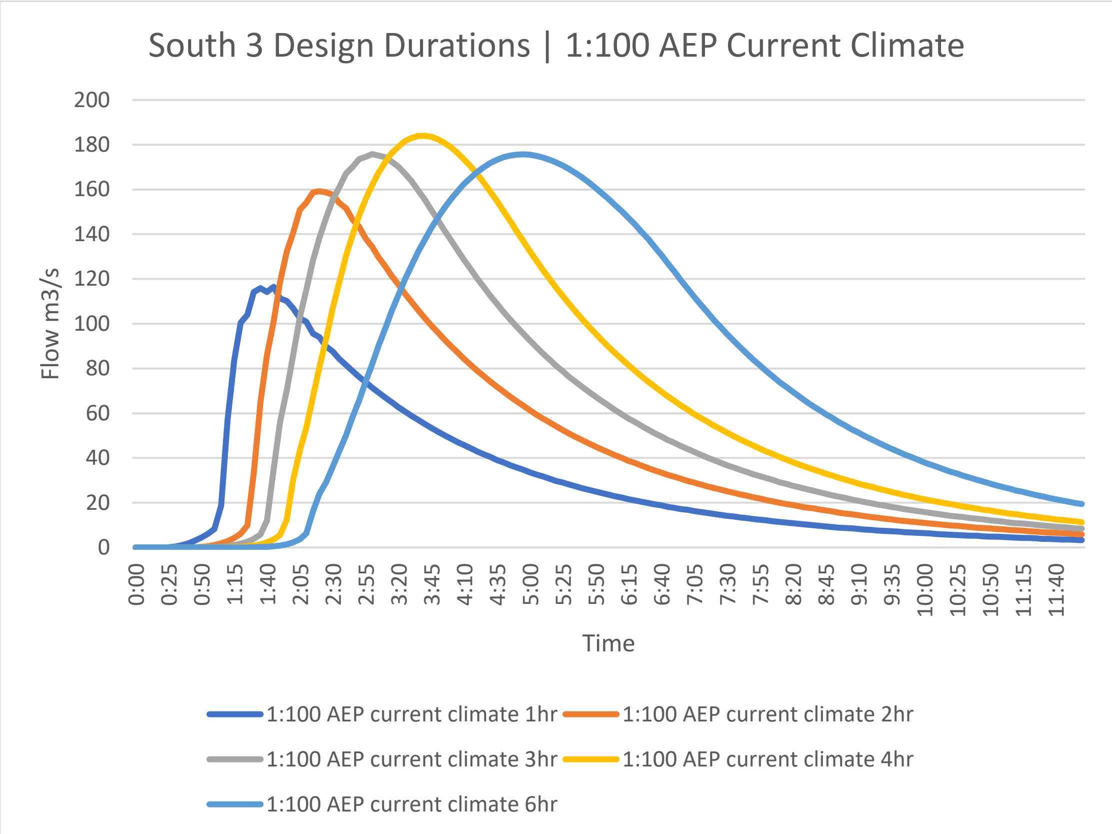


Figure 2-16: Design Durations for the South 3 (Waikawa) Catchment for 1:100 AEP Current Climate

Note that it was not required to calculate critical duration for the Ōhau River catchment, since peak flows were based on Flood Frequency Analysis (which uses peak values only). The relatively short length of the Ōhau being modelled relative to the magnitude of the peak means that selection of hydrograph shape will have minimal impact on transmission of the hydrograph shape through the modelled reach. The Ōhau hydrograph shape was adopted and scaled from Waiakwa South 3 catchment for the 4hr and 6hr storm durations, since analysis of historic data showed very similar timing response between the Ōhau and Waikawa gauges. An example historic event with a clean short duration peak is shown below, and the timings of the Ōhau and Waikawa match very well.

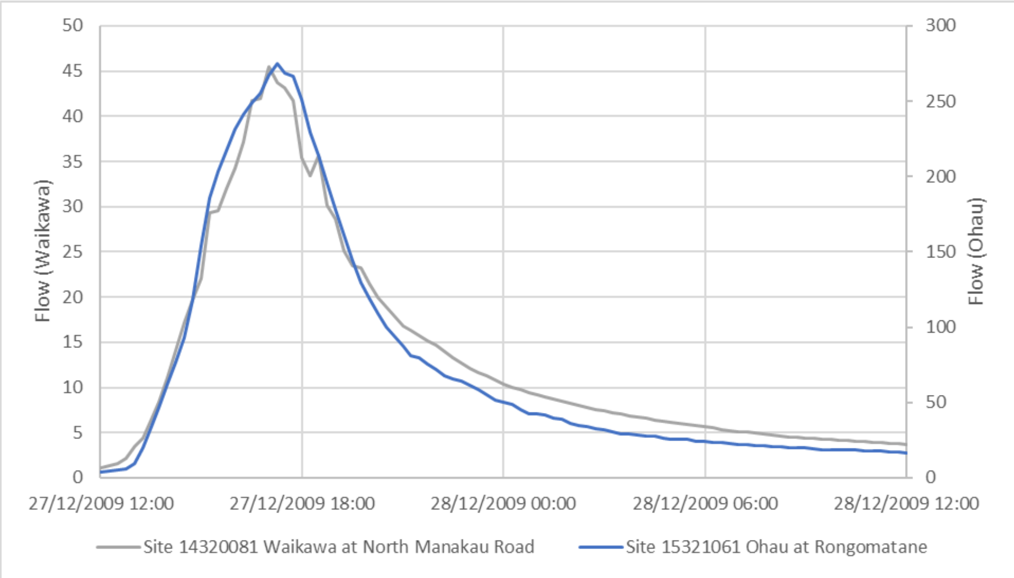


Figure 2-17: Similar observed hydrograph timing on Waikawa and Ōhau (December 2009 event)

2.5.3 Model Calibration

As described in Section 2.2, three catchments & their respective flow gauges were used to aid in the validation of the hydrological models. At least four events were selected for each gauge to increase confidence, due to some uncertainties in spatial rainfall coverage. Rainfall gauges were used where data was available for the selected events. Thiessen polygons were created in ArcGIS and were appropriately weighted when applied to sub-catchments in the model, as illustrated in Figure 2-7.

Catchments used for validation:

- The catchment to the Koputaroa at Tavistock Rd flow gauge
- The catchment of Manakau Stream at SH1 flow gauge (which incorporates South 1 and South 2 catchments)
- The Waikawa at N Manakau Rd gauge for South 3

The use of three flow gauges when calibrating the model added confidence to the validation process for the chosen model parameters. An example of recorded and modelled flow for the South 3 (Waikawa) catchment is shown in Figure 2-18. Further event charts are provided in Appendix B along with some additional site-specific and event-specific commentary.

Overall, the graphs show a reasonable match. There was a mixture of the model peak flow being higher or lower than the observed flow, and most of this error is associated with the spatial coverage of rainfall, in addition to the runoff model parameters. On balance, the consistent set of parameters applied to the models were considered suitable and were also confirmed reasonable by other checks outlined in Section 2.5.4 below.

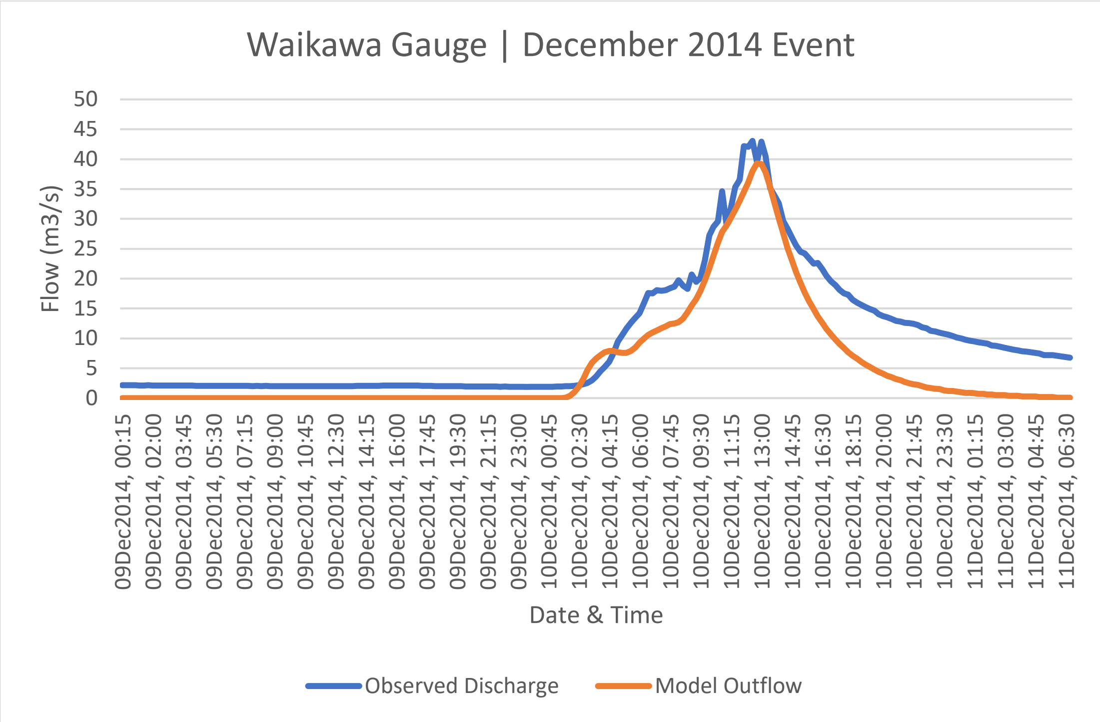


Figure 2-18: Hydrological model vs observed hydrograph at Waikawa Gauge

2.5.4 Comparison of Results versus Rational and Regional Estimates

A 1:100 AEP event rational and regional method peak flow calculation was conducted for each catchment as additional methods to compare with the outputs of the HEC-HMS models.

Table 2-7 lists the results for each catchment and shows that the hydrological model peak flows match reasonably well against these independent calculations. The Rational Method calculation usually provides most reliable flow estimates for catchments less than 10km^2, and the Regional Method (McKerchar and Pearson 1989)[2] calculation for catchments over 10km^2. However, both methods are included in the table for information purposes. The online NIWA Flood Frequency Tool (Griffiths et al)[4] was also used as another regional calculation approach but was found to give inconsistent results.

Regional Method $Q/A^{0.8}$ contour values range between 1.7 and 2.0 for the modelled catchments and all catchments had a q100 growth factor of 2.2. Regional Method results for all catchments are included in Table 2-7.

Rational Method estimates were based on the following formula:

Peak Flow (m^3/s) = C (unitless) I (mm/hr) A (m^2)/(3600*1000)

Where C is the runoff coefficient, I is the rainfall intensity for a storm duration corresponding to the catchment time of concentration (ToC) and a given AEP, and A is the catchment area. The runoff coefficient of 0.3 was estimated based on the NZ Building Code guidance – E1 Surface Water.

[2] McKerchar, A.I., Pearson, C.P. (1989) Flood Frequency in New Zealand. Publication of the Hydrology Centre, No. 20: 87.
[4] https://niwa.maps.arcgis.com/apps/webappviewer/index.html?id=933e8f24fe9140f99dfb57173087f27d

Table 2-7: Comparison of Rational & Regional Method Calculations, Flood Frequency Analysis Results and model Results for the 1:100 AEP Event (current climate)

Catchment Name	Area (km^2)	Rational method 1:100 AEP current climate (m^3/s)	Regional method 1:100 AEP current climate (m^3/s)	TIDEDA FFA 1:100 AEP current climate (m^3/s)	HEC-HMS model 1:100 AEP current climate (m^3/s)
Sth 1 (Waiauti)	7.1	27	19	-	28
Sth 2 (Manakau)	7.1	35	20	-	30
Sth 3 (Waikawa)	29.8	106	68	180	179
Sth 4 (Kuku)	7.7	32	16	-	26
North	7.5	36	20	-	23
Koputaroa	21.4	50	43	20	47

Regional Method results are consistently lower than the Rational Method which is not unexpected. The significant difference is results from these methods for the Waikawa catchment is thought to be due to the steep rainfall gradient within this catchment. Regional Method contour resolution in this area is too low to account for the change in rainfall across the catchment and therefore increased flows from the headwaters.

The North catchment is underestimated relative to the Rational Method, although it is a part of the calibrated HEC-HMS model to Koputaroa which matched well with both Rational and Regional Method. The Koputaroa Flood Frequency Analysis appears unrealistically low, possibly due to short record, low confidence in gauging station, and the use of GEV distribution (presented in section 2.4.1.1) may tend to underestimate the 1:100 AEP event.

Overall, the HEC-HMS model calibration and checks versus relevant independent Flood Frequency Analyses, Regional and Rational method calculations provides confidence that the HEC-HMS model is a suitable tool for generating design hydrographs to feed into the hydraulic model. A summary of the adopted peak flows is provided in Section 2.6.

2.6 Summary of Adopted Peak Model Flows

Based on the calibrated HEC-HMS model parameters and rainfall discussed in the preceding sections, the model was run for the 1:10 AEP, 1:25 AEP, 1:100 AEP & 1:200 AEP current climate design rainfall events. These provided the runoff hydrographs for input to the hydraulic model, whose application is discussed in Section 3.3. The peak results provided for the hydraulic model are shown in Table 2-8 below.

Table 2-8: Summary of Peak Flow Results for Each Catchment

Catchment	1:10 AEP 3h (m^3/s)	1:10 AEP 6h (m^3/s)	1:25 AEP 3h (m^3/s)	1:25 AEP 6h (m^3/s)	1:100 AEP 3h (m^3/s)	1:100 AEP 6h (m^3/s)	1:200 AEP 3h (m^3/s)	1:200 AEP 6h (m^3/s)
Sth_1 (Waiauti)	16.3	13.9	20.9	22.5	28.2	24.6	32.1	28
	1:10 AEP 4h (m^3/s)	**1:10 AEP 6h (m^3/s)**	**1:25 AEP 4h (m^3/s)**	**1:25 AEP 6h (m^3/s)**	**1:100 AEP 4h (m^3/s)**	**1:100 AEP 6h (m^3/s)**	**1:200 AEP 4h (m^3/s)**	**1:200 AEP 6h (m^3/s)**
Sth_2 (Manakau)	17.5	16	22.1	20.4	29.6	27.6	33.5	31.2
Sth_3 (Waikawa)	113.3	107.7	140.4	133.8	184	175.7	206.6	197.4
Sth_4 (Kuku)	15.2	13.6	19.4	17.6	26.3	24	29.8	27.4
Ōhau	353	353	443	443	594	594	679	679
Catch_33d	19.3	17.3	24.6	22.4	33.4	30.5	37.8	34.8
Catch_33e	21.0	18.8	26.8	24.3	36.3	33.1	41.1	37.8

Catchment 33 (Ōhau River to Muhunoa East Rd) contains two smaller sub-catchments that drain into the Ōhau downstream of Rongomatane Gauge. To account for these additional flows two additional sub-catchment inflows have

been determined (33d & 33e). South 4 (Kuku) catchment was used as a donor to generate peak flow and hydrographs using a scaling factor. The scaling factors applied: 1.27 (33d) and 1.38 (33e).

3 Hydraulic Modelling Setup

3.1 Hydraulic Modelling Approach

TUFLOW Classic/ HPC (version: 2020-10-AA) was used to build and simulate peak flood extents and levels across the Ōhau-Manakau drainage area. The software is a widely used tool for both urban and rural flooding and is designed to perform both 1D-2D unsteady and steady flow simulations for river and floodplain flow analysis.

The "Quadtree" functionality was utilised within the model build setup. Quadtree allows square grid cells to vary in cell size, so enables higher resolutions where more refined hydraulic calculations are needed, and lower resolutions where there is little variation in topography (e.g. floodplains). The approach sub-divides cells based on the nesting levels i.e. dividing a cell into four cells, then further divide those into four, and so on.

Rural or flatter terrain is represented with larger computational grid cells while main rivers and key topographical features including stopbanks have finer grid resolution. This offers the build efficiency of a standard fixed grid model with benefits of a flexible mesh approach (e.g. much improved run times for similar accuracy), especially when combined with sub-grid sampling.

Table 3-1: Grid Cell Resolution

Features	Grid Cell Size (metres)
Floodplain	24-48
Ōhau River	12
Roads/ Railways	12
Waikawa/ Manakau Channels	6-12
Narrow streams/ drainage channels	3-6
Stopbank Locations	3

The smaller cell spacing in the refinement zone and near hydraulic features allows for more detailed results through critical flows areas. Information from the 1m grid is used to inform the computational mesh calculations, providing a high degree of accuracy for the given computational cell size.

Quadtree was run in combination with sub-grid sampling (SGS). SGS stores and uses curves representing the sub 2D cell terrain data of the 1m DEMs, TINs and Z shapes used to construct the model, instead of each 2D cell and each 2D face only having one elevation value.

In respect to this assessment, catchment scale models flow more effectively when using coarser grid cell resolution without water becoming "trapped" by small obstacles (which can be represented by additional controls if required). In addition, SGS offers excellent cell size convergence at much coarser grid cell sizes. SGS offers improved flow field representation along boundaries – open channels are more accurate defined at any orientation/ cell resolution.

A 2D "rain on grid" approach was adopted within this assessment. Using SGS removed the need to explicitly model the in-channel features within a 1D domain (please note hydraulic structures have been modelled using the 1d ESTRY solver within TUFLOW). Hydrological calculations for catchment rainfall and defined hydrographs were used for input across the 2D model. TUFLOW HPC solver is applied to provide model stability and improved simulation times for the "rain on grid" approach.

3.2 2D Model Extent

The TUFLOW 2D model includes coverage of the main catchment watercourses including: Ōhau, Waikawa, Manakau and Kuku streams, from their respective inflow locations down to the sea. Coverage of the Ōhau River extends up to the Rongomatane gauge, approximately 12km upstream of State Highway 1. The Kuku, Waikawa and Manakau streams all start approximately 1km upstream of the proposed Ō2NL corridor. The model extends downstream at the tidal boundary along the Kuku Beach and Waikawa Beach.

The sand dunes and mobile river mouths have been modelled as reflected within the LiDAR DEM, without any adjustments for bathymetry in the intertidal zone. The ground levels, taken from the LiDAR data, have been used to define individual grid cell elevations. Figure 4-1 shows the general grid cell alignment at the river mouth (Ōhau River).

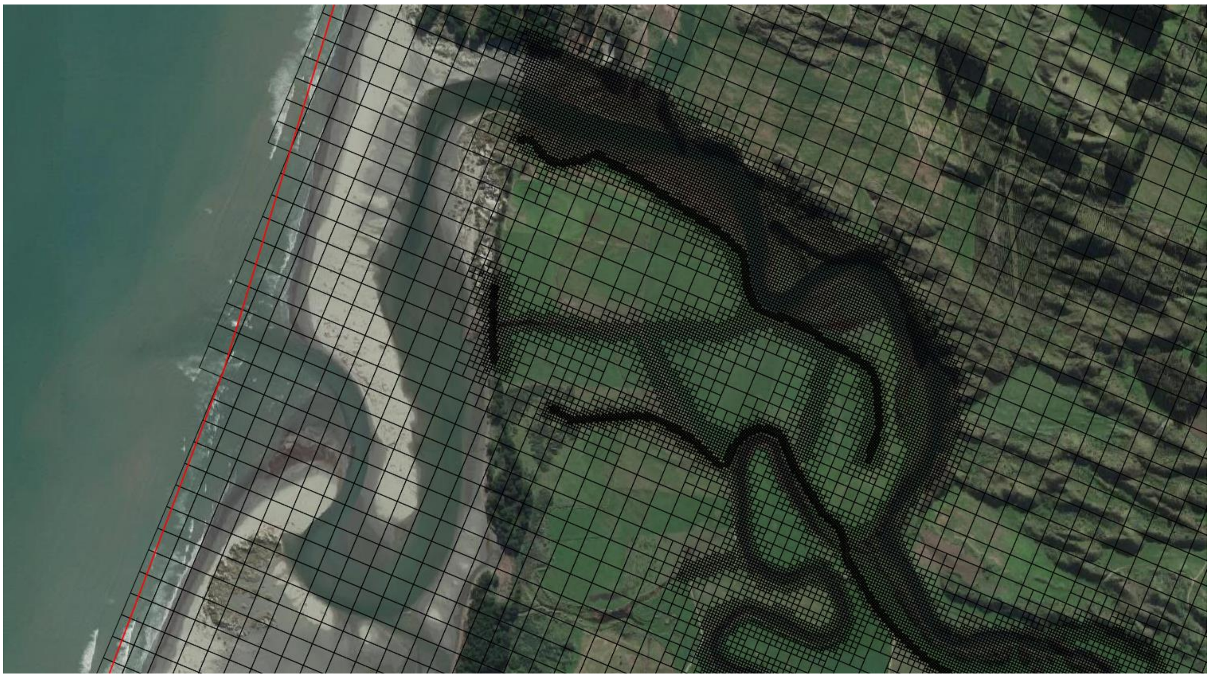


Figure 3-1: Inter-Tidal Zone - Model Grid Cell Distribution

Due to natural on-going changes to channel bathymetry within this region it is noted the channel bed elevations and profile may have changed since the LiDAR was flown. This is a limitation of the approach at this location but is not likely to have a substantial impact wider modelling results closer to the Ōhau-Manakau drainage scheme. It was deemed appropriate to model the beach and inter-tidal zone using coarser grid resolution. Towards the drainage scheme, the grid cell sizes have been reduced, therefore offering increased definition of ground profiles and elevations in the key areas.

As discussed within section 3.3.3 a constant tidal level has been applied across the full width of the downstream extent of the model between the Ōhau and Waikawa tidal outlets. This has been applied as a 2D boundary condition (shown by red line). Section 3.3.3 provides more details on the tidal levels applied within the model.

To provide stream continuity on the flow surface, the terrain model was burnt down mainly at small bridges outside the area of interest or farm access tracks where there is no information available. The burning process was applied by creating a 2D z-shape using the bounding lowest grid cell elevations. The process aimed to remove locations of high ground shown within the channel and provide flow continuity at these locations.

3.3 Boundary Conditions

3.3.1 Rainfall

The calculated rainfall depths have been incorporated into the model using 2d RF layer. The “RF” type applies a rainfall versus time boundary within the form of a hyetograph. This is subsequently converted to a hydrograph to smooth the transition from one rainfall period to another. This approach applies a rainfall depth to every cell within each rainfall region.

Figure 2-6 shows cumulative rainfall plots for each of the rain gauges across the catchment. The plots show increasing rainfall gradient with elevation, with the gauge at Tangata receiving the highest rainfall (steepest gradient) and gauges on the coastal plain showing a flatter gradient. This macro scale pattern is also reflected in the HIRDS design rainfall grid shown in Figure 2-8. The greatest rainfall gradients occur in the larger hydrological catchments (in which spatial variation of sub-catchment design rainfall depths has been taken into account). Therefore the rainfall applied in the hydraulic model only applies to the lower portion of the overall rainfall gradient.

The rainfall has been split into two separate regions across the 2D modelling domain as shown in Figure 3-2. Two separate rainfall regions have been applied due to the orographic influence between the coast and the Tararua foothills. As shown earlier from HIRDS in Figure 2-8, the downstream coastal rainfall region (0-40m elevation) receives low and relatively evenly distributed design event rainfall. The central Ōhau/Ō2NL rainfall zone (downstream of the larger catchments) is in a transition zone between low and high rainfall. Most of the land in this zone lies between 20-60m elevation. Only a few narrow ridge lines in the south east extend above this, with some reaching over 200m but comprising a very small proportion of the direct rainfall zone. Neither the spacing of rain gauges or the HIRDS rainfall grid provide an accurate rendition of rainfall within this transition zone. Therefore, two direct rainfall zones was considered reasonable for representing the coastal plains up to the foothills.

The upstream domain covers the Ō2NL model domain with the intervening area up to the inflow hydrograph locations. At these locations' hydrographs have been incorporated into the model as described in 3.3.2.

Figure 3-2: Model Rainfall Boundary Extents

3.3.2 Inflow Hydrographs

A series of inflow hydrographs have been applied to the hydraulic model. In total 7 inflows locations have been defined covering the catchments as described in section 2.6. A "QT" type has been applied within the 2D bc layer which references the specific input hydrograph. 2D BC lines have been positioned across the width of the channel and partially into adjacent floodplain at each of the key inflow locations. This approach applied flow to the lowest elevation grid cell along the width of the line.

3.3.3 Tidal Boundary

Mean Sea Level (MSL) has been applied to the baseline model for all design event simulations. The tidal level is represented within the model as a "HT" Head vs Time boundary. The constant MSL of 1.1m was calculated at the outlet of Ōhau at Waikawa Beach. The nearest secondary port locations include Manawatu River Entrance and Waiorua Bay, with a known MSL of 1.3 and 0.9m respectively (relative to Wellington 1953 datum). This difference was then calculated to the outlet at Waikawa Beach.

A constant tidal level has been applied across the full width of the downstream extent of the model between the Ōhau and Waikawa tidal outlets. This has been applied as a 2D boundary condition. The tidal influence is estimated to extend approximately 3km upstream along the Ōhau River, depending on fluvial flows and state of tide. Combinations of different tide cycles during flood events have not been evaluated within this current assessment, as agreed with HRC.

3.4 Hydraulic Structures

The key hydraulic structures across the study area were included within the model build (shown in Appendix C). The structures are modelled within the 1D domain (ESTRY) and dynamically linked back into the 2D domain (TUFLOW) using SX connectors. The connectors transfer flow and water level through the structure based on upstream/downstream conditions.

A range of hydraulic structures have been included within the model. Within the vicinity of the railway line and SH1 there are numerous openings conveying flow through these structures.

Appendix C shows location and details of the structures included within the model. This information contains structures obtained from HDC, Kiwirail and Waka Kotahi NZTA. Please note many of these were adopted from the Ō2NL model build previously undertaken, but extended to include features west of the previous Ō2NL model domain. The dimensions are also reflective within this assessment and have not been modified.

Within the Ōhau-Manakau Drainage Scheme there are numerous assets that have been included within the model. HRC provided information on these assets including culvert opening sizing (C.3). The invert elevations at each structure were unknown, therefore LiDAR has been used to determine these elevations. It is not certain if these culverts contain outlet control devices to prevent ingress of tidal/ fluvial waters from the main rivers. An assumption made within the model was to replicate these structures as uni-directional culverts. This would only allow a single flow direction to replicate the presence of a flap along the culvert outlet. Depending on sensitivity of decisions, these structures could be surveyed to provide improved confidence.

In locations where gates exist, these have been modelled as closed and the vertical/ horizontal dimensions of drop structures taken from LiDAR data. No information was provided on gate operations and opening areas within each gate.

In some locations there was insufficient information on the opening dimensions of the structures. In these instances, LiDAR has been used to model the opening through the structure. For example, the railway embankment crossing, along the Ōhau River, has been represented using the LiDAR imagery. No soffit/ deck levels have been applied at this location.

3.5 Topographical Features

3.5.1 Stop Banks

The catchment includes a number of key topographical features that will influence the extent and magnitude of flooding. The Ōhau-Manakau Drainage Scheme includes a series of HRC owned assets including stop banks.

The stop banks have been incorporated into the model using 2D Z-shapes. LiDAR was used to inform crest elevations along the top of the banks. Using the “RIDGE” option within TUFLOW this approach enforced the crest elevations onto the underlying grid.

In certain areas the GIS line missed parts of the true stop bank alignment. Adjustments were made in GIS to ensure the line followed the bank positioning based on LiDAR and aerial imagery. Spatial analysis was undertaken to identify the highest crest elevations along the stop banks at 1 meter intervals. LiDAR data was used to inform these crest elevations. These elevations were subsequently reinforced into the model using 2D Z-shapes.

A limitation of using SGS is that it allows water to flow from low point to low point within the same cell even if there is higher point in between them. Without breaklines SGS will be more likely to allow "leaks" through hydraulic controls including levees or embankment, than compared to running the model without SGS. It is recommended to use 2d z-shapes to enforce these features where crest elevations are important.

Applying the “RIDGE” option within the 2D Z-shape forces the cells to be raised to align with the stopbank crest levels. This prevents artificial low points developing when using SGS.

3.5.2 River Bed Elevations

HRC provided channel survey of the Ōhau, Manakau and Waikawa watercourses. This information has been used to refine bed invert elevations within the 2D model.

A review of bed invert elevations between the LiDAR and channel survey showed LiDAR elevations were on average 0.8 meters higher than the survey. To resolve the difference, a DEM modification (2d-z-shape feature in TUFLOW) was applied which references the bed invert level at each cross section. The average channel bed width was calculated between surveyed cross sections. This average width was applied to the z-shape width attribute and bed elevations interpolated between each surveyed cross section.

Figure 3-3 shows an example long section within the Ōhau River. The plot compares the bed elevations identified from the LiDAR imagery against the modelled bed elevations (using the survey information data provided).

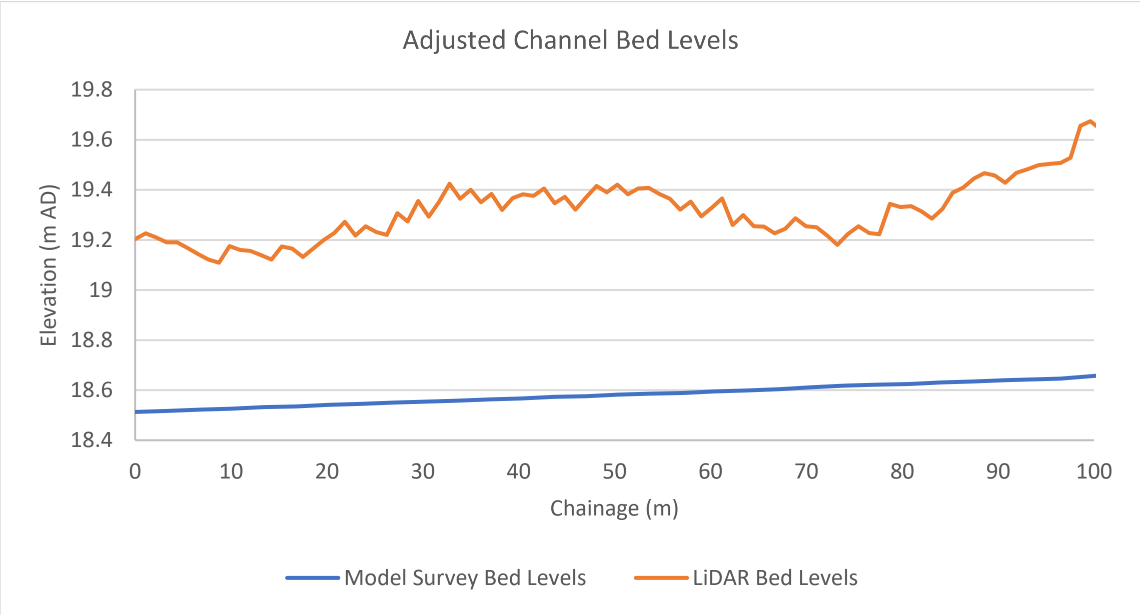


Figure 3-3: Example of Adjusted Channel Bed Levels

The intertidal zone has been represented in a simplified manner using the DEM provided. Due to the natural on-going changes to channel bathymetry within this region it is noted the channel bed elevations and profile may have changed since the LiDAR was flown. It should also be noted LiDAR cannot penetrate through the water surface to the bed profile. The supplied channel survey information was used to provide closer alignment of bed levels along the Ōhau River and Waikawa Stream.

3.6 Soil Infiltration

The hydraulic model accounts for soil infiltration through applying initial and continuing losses to the 2D domain. TUFLOW offers the ability to model the infiltration of ponded water using different methods. The Initial Loss/ Continuing Loss (ILCL) approach was chosen as this provides a quick approach to soil infiltration based on a limited set of parameters and can also be compared against the losses from the HEC-HMS models. The ILCL determines infiltration of water based on an initial amount (inmm) then at a constant rate (mm/hr) once the initial amount has been exceeded. This approach within TUFLOW allows infiltration to occur after the rainfall event has passed and thereby is more representative of the natural drainage / infiltration process within the catchment.

Table 3-2: Soil Infiltration Rates

Initial Losses (mm)	Continuing Losses (mm/hr)	Porosity (fraction)	Initial Moisture (fraction)
12	5	0.43	0.25

The ILCL rates align closely to previous works on the Ō2NL project. In addition, the porosity factor was determined using a default value for sandy soils. The initial moisture fraction of 0.25, represents an initial saturation of the underlying soils which thereby influences the overall soil capacity during the infiltration process.

A series of checks were undertaken varying the ILCL parameters applied during simulation. The values shown above provided results which aligned closely to previous historic overland flow routes and extents. In addition, checks on the overland flow hydrographs against previous modelling work (Ō2NL) provided confidence the parameters applied were sensible.

Please note the initial/ continuing losses were not applied to the rainfall data prior to use within the model. The ILCL rates are applied across the entire 2D modelling domain. Raw rainfall data has been applied to the 2D domain. Table 3-2 shows infiltration rates used within the hydraulic model.

3.7 Roughness Coefficients

3.7.1 Hydraulic Structures

Roughness coefficients were applied to the different hydraulic structures within the model. HRC supplied asset information contained details of specific culvert materials. Table 3-3 outlines the coefficients applied for each material type. Please note a number of culverts had undetermined material types. In these instances, an assumption of 0.013n was applied replicating concrete (finished) surface.

Table 3-3: Hydraulic Structures - Roughness Coefficients

Roughness coefficients (n)	Material
0.013	Concrete
0.012	Steel
0.013	Cast Iron
0.012	Plastic

3.7.2 2D Overland Topography

Roughness coefficients, including Manning's n, represents the resistance to flow within the river channel and across the open flood plains. The Land Cover Dataset (obtained from Landcare Research) was used as a basis to define individual land use polygons across the modelling domain. These were checked against aerial imagery to check position and extents were appropriate. The roughness coefficients were chosen through observing aerial imagery including Google Earth.

Table 3-4: 2D Manning's "n" Roughness Coefficients

2D Manning's "n" roughness coefficients	Land use type
0.08	High Vegetation
0.048	Open Space
0.014	Road
0.10	Urban
0.045	Water
0.10	Trees
0.07	Brush
0.035	Grass

3.8 Model Performance

A series of checks have been undertaken to assess reliability of results from the model. The model health indicators were reviewed in combination with further visual checks for consistency. It is noted the approach has used the Sub-Grid Sampling (SGS) combined with the Quadtree functionality. SGS uses the TUFLOW HPC solver, which is mass conservative therefore aims to attain volume within the model. Therefore results will need to undergo more robust review particularly along boundary inputs.

All of the model simulation outputs have been checked for consistency to ensure there are no significant erroneous/ unusual results being produced.

The 1:100 AEP (4hr) results are presented in this section. Figure 3-4 shows the mass balance output from the model log file. It indicates the model is performing within the acceptable threshold of +/- 1%.

```
Volume at Start (m3):  252851
Volume at End (m3):    6645665
Total Volume In (m3):  24217871
Total Volume Out (m3): 17829792
Volume Error (m3):     4735 or 0.0% of Volume In + Out
Final Cumulative ME:   0.01%
```

Figure 3-4: Model Log Output - Mass Balance (1:100 AEP– 4hr)

The model log shows no 1d-2d negative depths being created during the simulation. Normally indicative of repeated calculations within a single timestep. There were no repeated warnings or checks during the model simulation.

The flow within the 1d structures did not highlight any unusual/ significant changes in flow profiles. The flows appeared stable and appropriate based on opening dimensions/ boundary conditions.

The 2d results were also reviewed to identify any areas of unusual flow patterns, locations of high velocity and water depths. The results did not show any unusual results for concern. In summary the model is performing as expected and within the recommended tolerances.

3.9 Baseline Results – Validation

To provide a level of confidence within the modelling outputs the baseline results were compared against previous records of flooding within the vicinity of the Ōhau, Manakau and Waikawa watercourses. The purpose was to validate general overland flow routing and flood extents based on local knowledge within this area.

HRC supplied information regarding the January 2008 flood event. The information included GIS layers of flood extents and photographic records of the flooding during the event. The baseline modelled 1:10 AEP (6hr) selected as the most appropriate scenario to compare against, based on the magnitudes of the gauged flows in this event.

Appendix D shows a comparison of the flood event outlines compared to the modelled flood depths from the new hydraulic model. The model results within the vicinity of the Ōhau River show good correlation in respect to flood extents and identifies locations of attenuation behind the stopbank. Along the Ōhau, overtopping along the left bank leads to flooding within the area behind the defences. The model has shown to replicate this mechanism appropriately.

Along the Waikawa and Manakau confluence the model results again show good correlation with the recorded flood extents. Channel capacity is exceeded along both channels at this location. This leads to overtopping of the defences and storage within the adjacent floodplain.

The model results are shown to match key flood extents within the vicinity of the drainage scheme. This provides acceptable levels of confidence for the purposes of the LOS assessment.

Following a heavy rainfall event in June 2021 the area experienced localised flooding within the Ōhau Manakau drainage scheme boundary. HRC commissioned a topographical survey following the event. The survey identified locations of overtopping and debris lines within the scheme boundary. This information was supplied as part of this assessment and used to help further validate modelling results.

4 Overtopping Assessment

4.1 Methodology

An overtopping assessment has been carried out on the existing flood defence assets within the Ōhau Manakau drainage scheme boundary using the baseline model results This will inform a level of service (LOS) assessment by HRC, who were not able to provide a defined set of LOS parameters (e.g. freeboard, peak overtopping rate per meter or per asset, with or without consideration for duration or total volume of overtopping or receptor types behind the asset).

A high level approach was adopted for this assessment to provide HRC with an indication of the overtopping rates from the existing stop banks. The outputs can then be used to inform decision making for future resilience and asset management. Please note the analysis includes both HRC owned assets and private assets (supplied by HRC) along the Manakau and Waikawa streams. These were included as they fall within the Oahu-Manakau Scheme Boundary as shown below (Figure 4-1). HRC required these we checked to see how they performed as part of the LOS assessment.

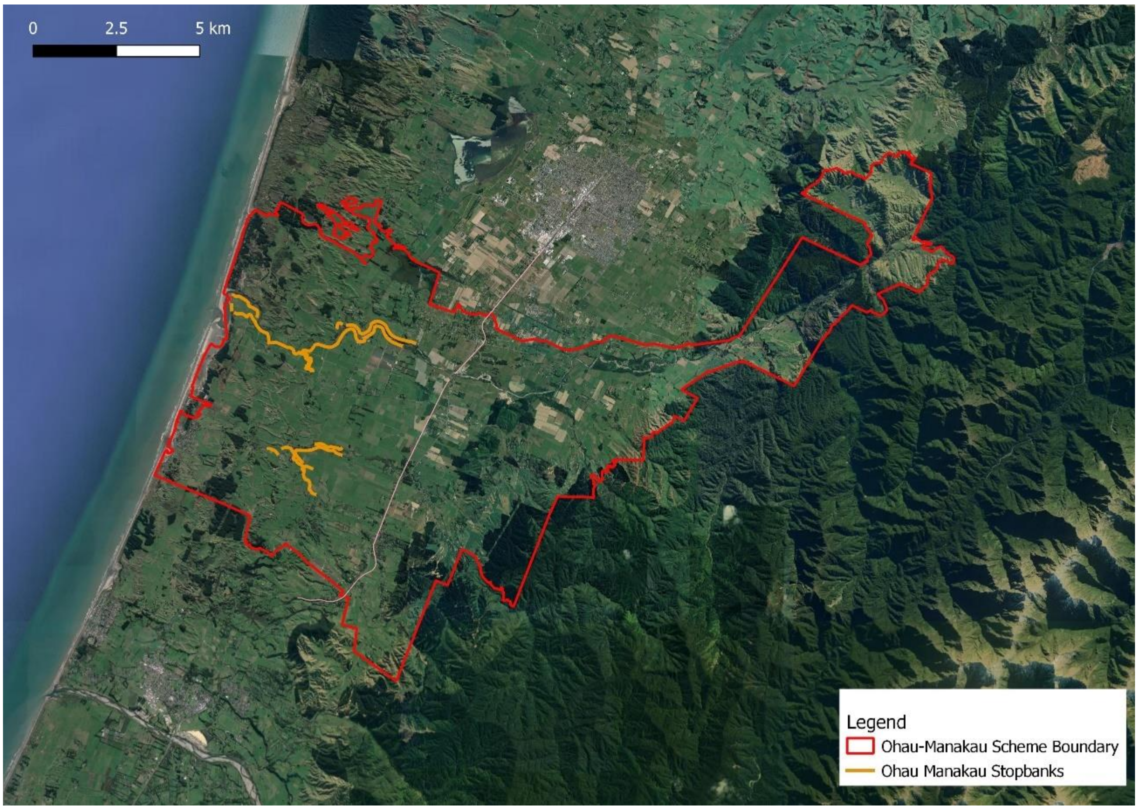


Figure 4-1: Stopbank Locations - Ōhau Manakau Scheme Boundary

TUFLOW 2D “PO lines” have been used to extract flow, water level and velocity across the length of each stopbank for the duration of the simulation. The PO Lines were positioned directly on top of the stop bank 2D Z-shapes lines (that enforced maximum levels along the stop banks from LiDAR, as discussed in section 3.5.1.

The 2D PO results were used to extract peak flow and duration of overtopping for each design event. This information was collated for all stopbanks (HRC and privately owned).

4.2 Results

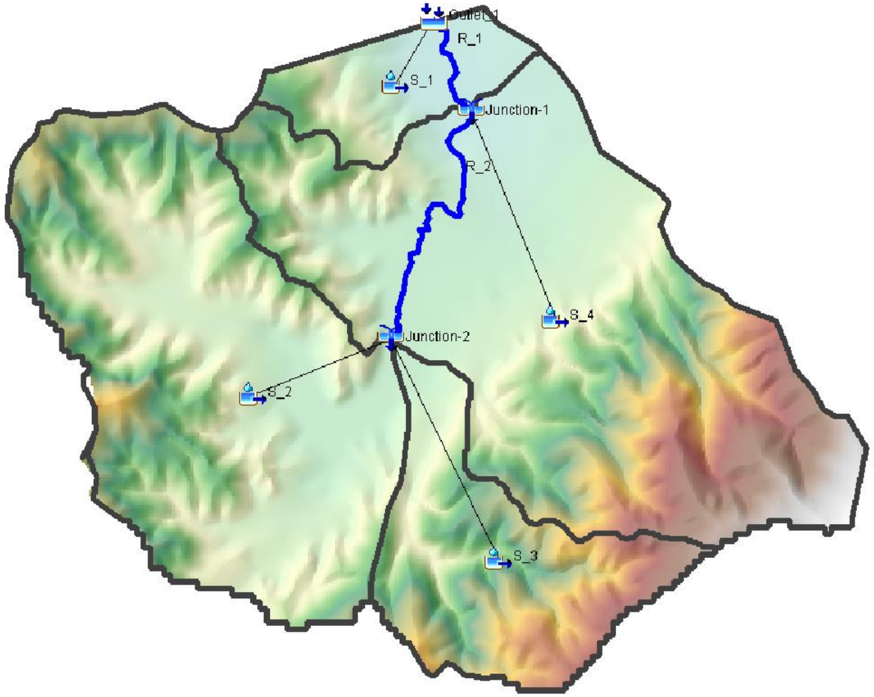
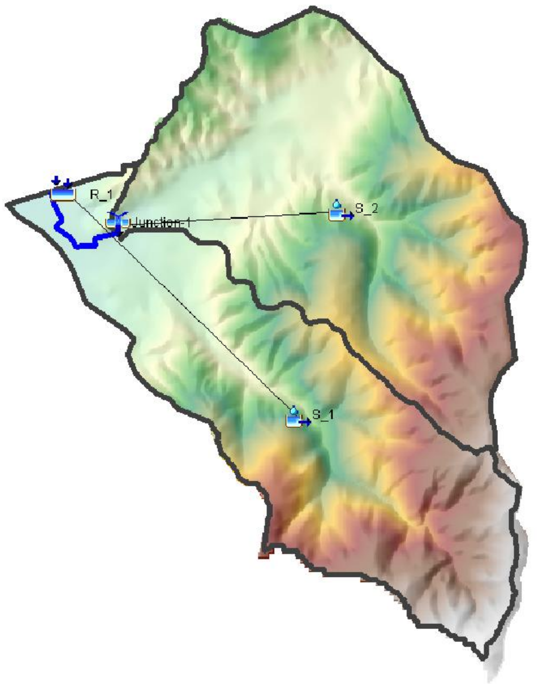
The overtopping assessment has shown a number of the HRC owned assets are overtopping at between a 1:10 - 1:200 AEP. Reviewing the results from the 1:10 AEP event several stop banks were overtopped for a short duration but high peak flow. This concentrated flow may pose a hazard in terms of the structural integrity of the bank, and will be a risk to people or crops behind the stop banks. This assessment has not yet considered the impacts or consequences of overtopping other than modelled flood depths and velocities.

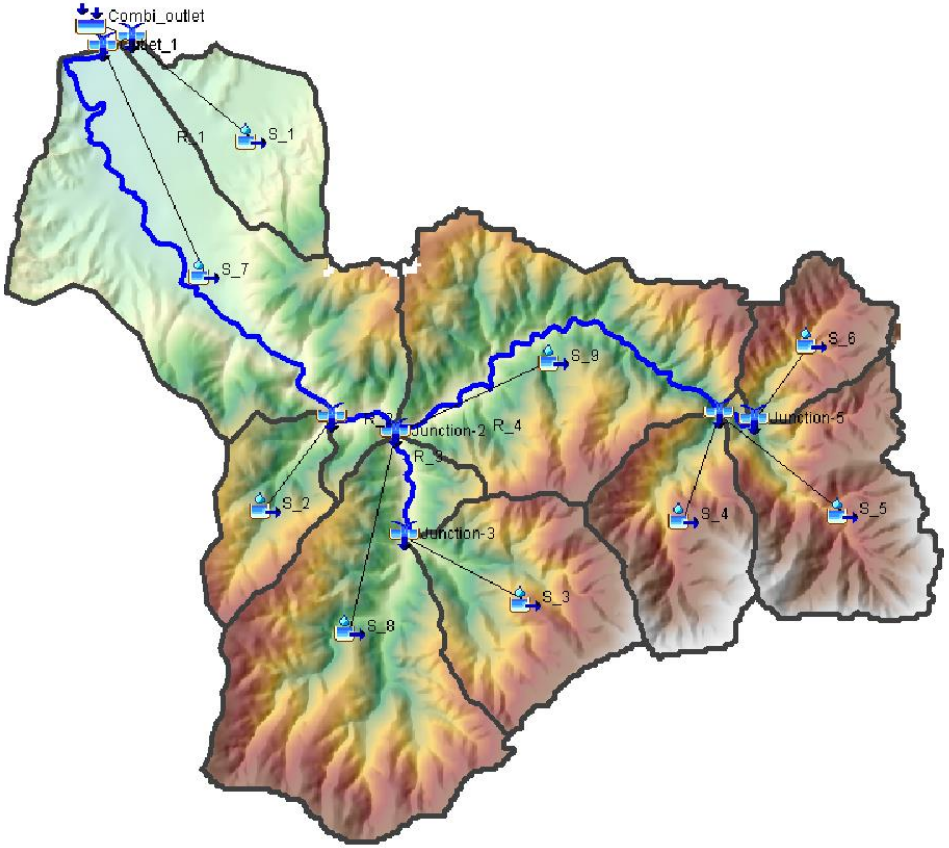
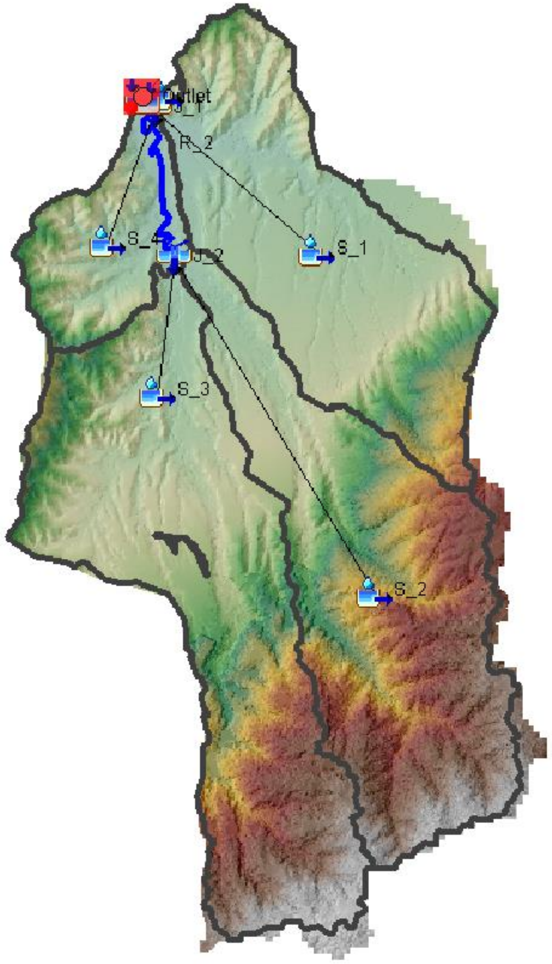
Please note the assessment has only taken in account of the flow directly from the watercourse side of the stopbank, and may not reflect other overland flow routes into some basin areas. Appendix F shows tabulated results from the overtopping assessment.

Appendices

We design with community in mind

Appendix A HEC – HMS Model Schematics

South 1 (Waiauti)	**South 2 (Manakau)**
	

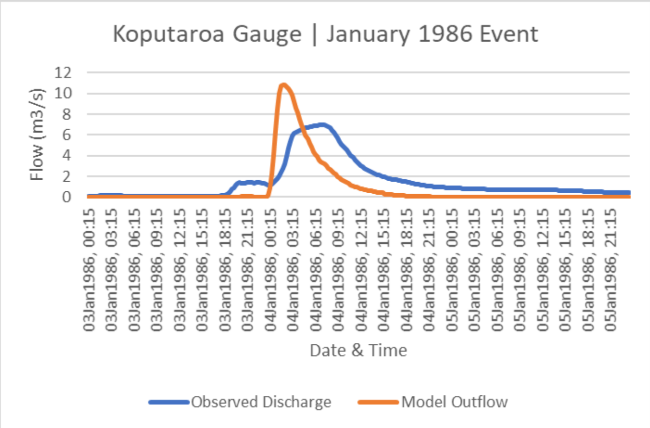
South 3 (Waikawa)	South 4 (Kuku)
	

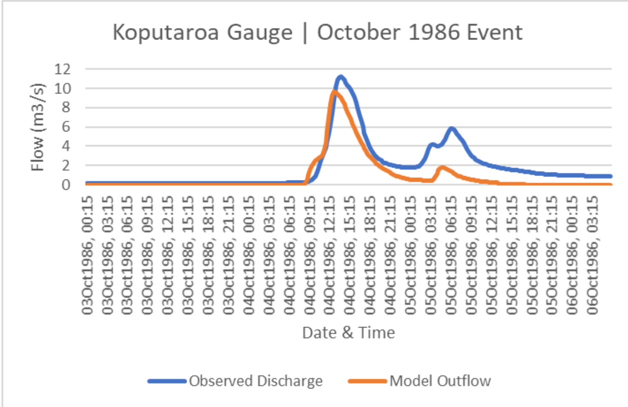
Appendix B HEC – HMS Validation Graphs

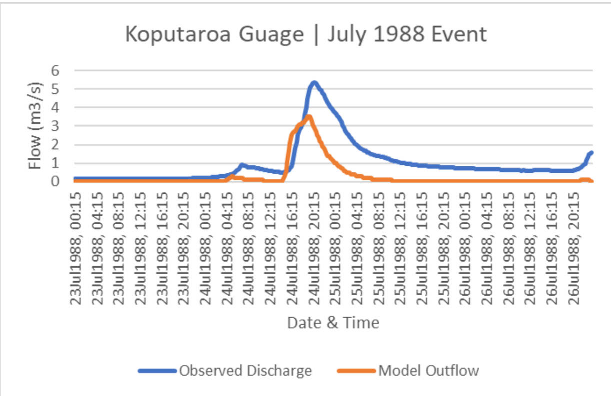
Refer to Section 2.5.3.

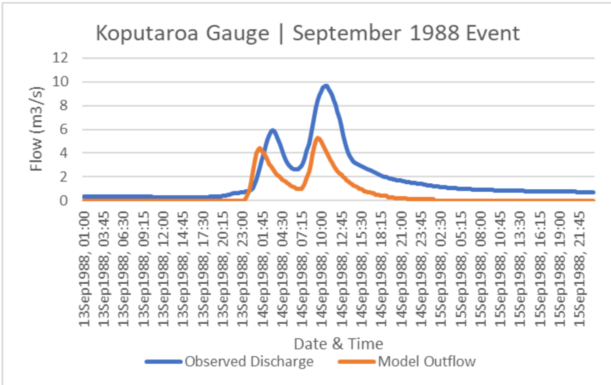
The first table contains four separate events simulated on the Koputaroa gauge at Tavistock Rd (which had s shorter record from 1974-1989).

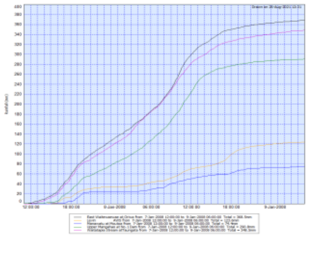
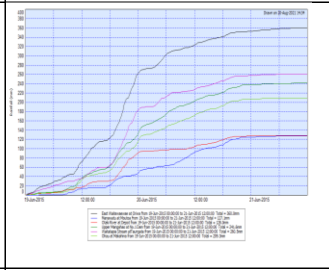
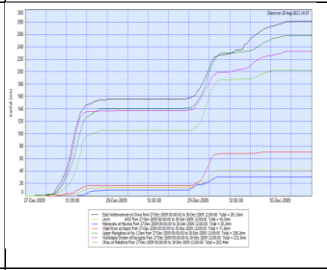
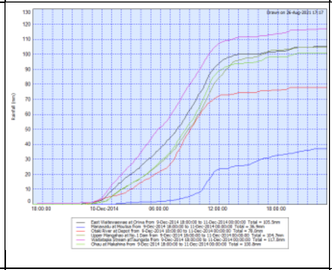
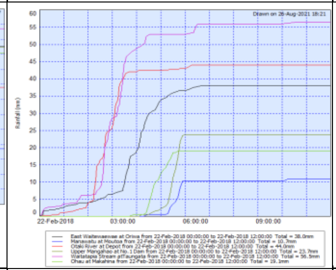
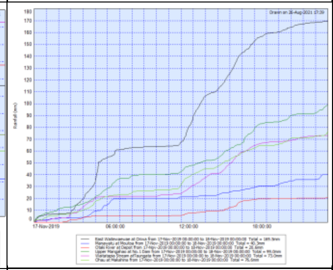
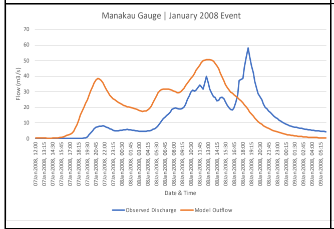
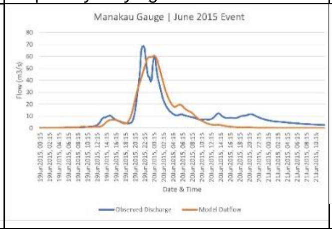
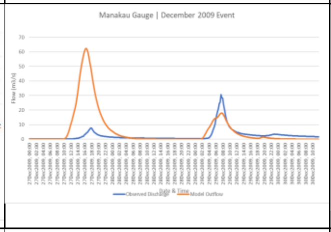
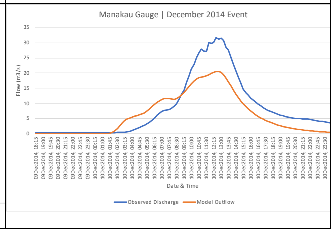
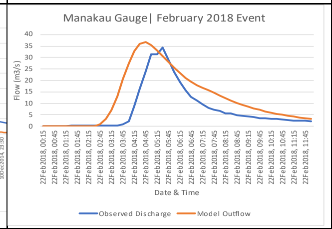
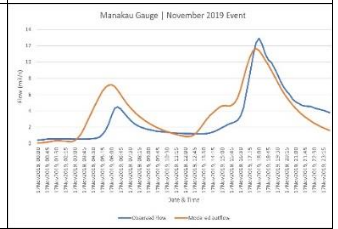
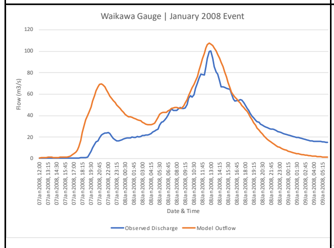
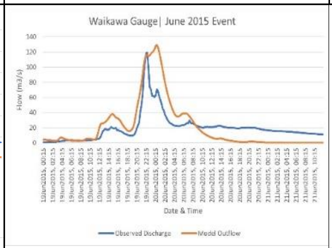
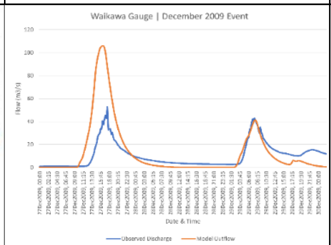
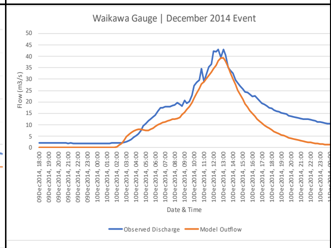
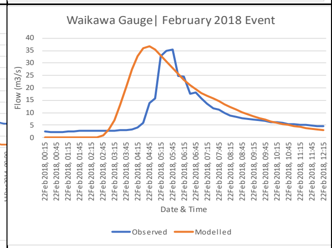
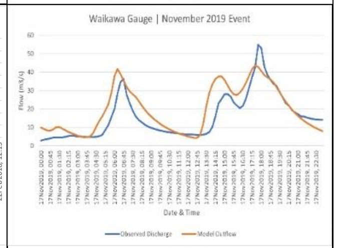
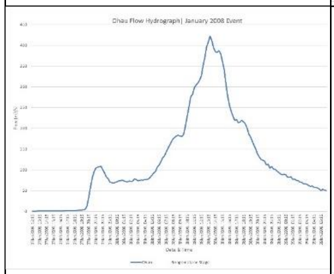
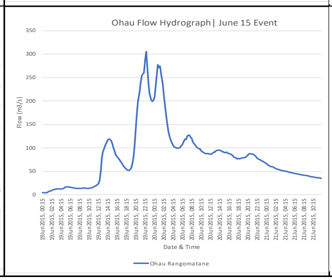
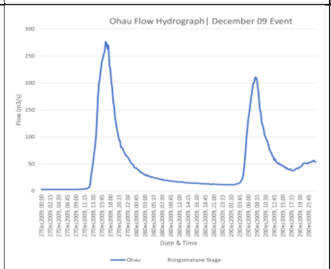
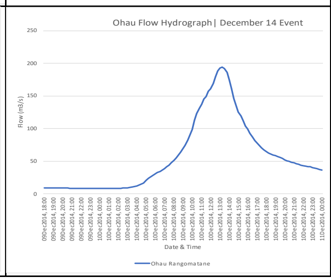
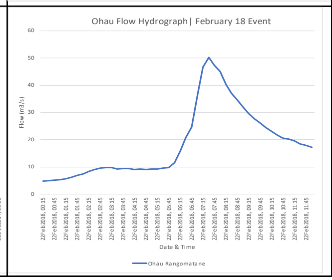
The first table is followed by a more detailed assessment for Manakau and Waikawa hydrological models. A very small layout is used deliberately to highlight patterns across rainfall plus Manakau and Waikawa on the same screen. Zooming in allows more detail to be seen. Ōhau hydrographs also shown to support discussion on hydrograph shape for some events.







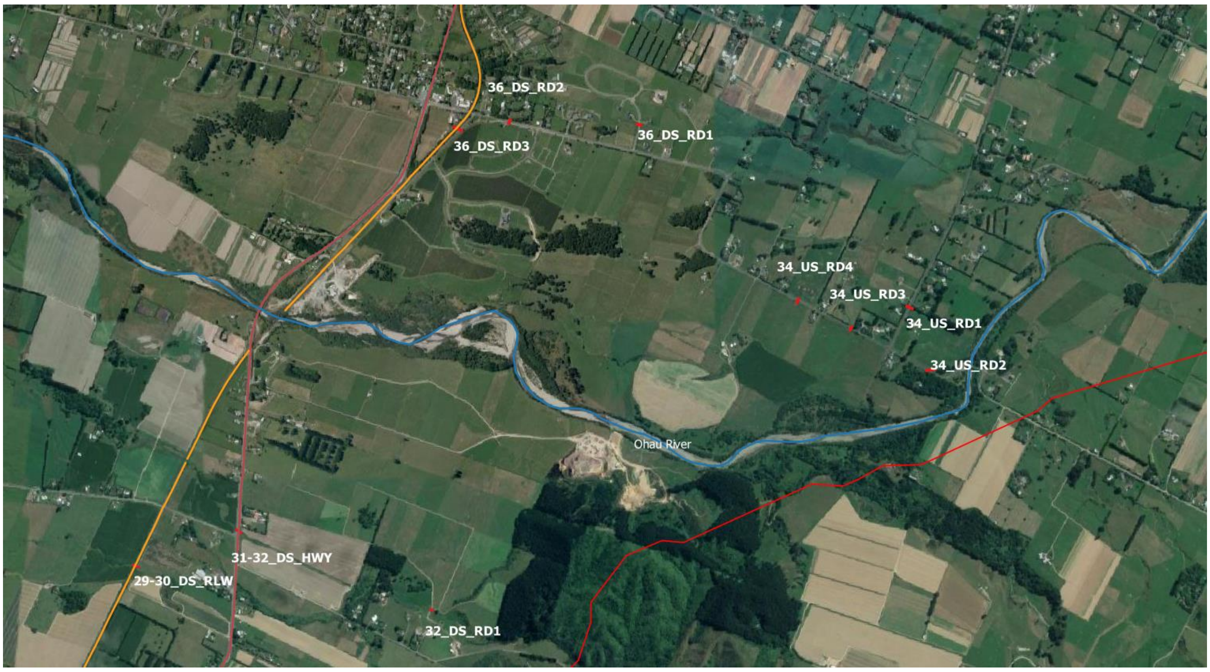


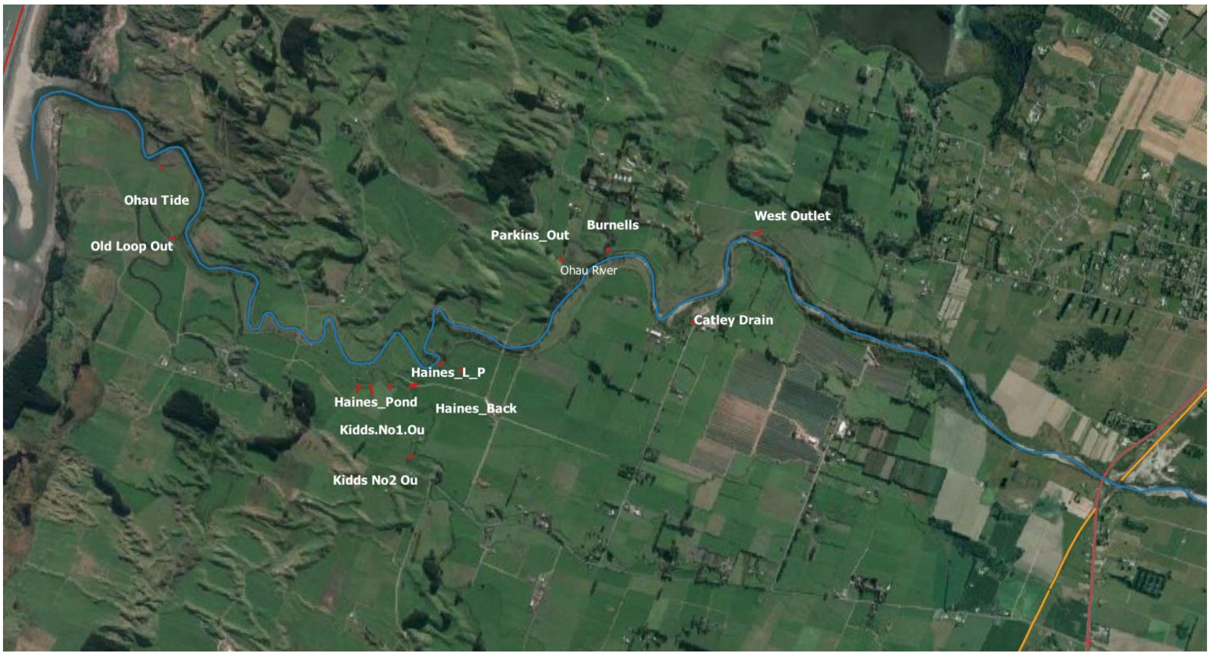
<table>
<tr><th>Jan 2008</th><th>Jun 2015</th><th>Dec 2009</th><th>Dec 2014</th><th>Feb 2018</th><th>Nov 2019</th></tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Large event circa 1:10, rain spatially variable
1st peak over predicted at both sites, 2nd peak over at Manakau but good at Waikawa, 3rd peak observed at Manakau but not observed at Waikawa or Ōhau or most raingauges, hence would be difficult to match in model. Note Otaki rainfall no event data.</td>
<td>Large event circa 1:10, rain spatially variable and two peaks close together. 2nd peak observed at Manakau and Ōhau but hardly visible at Waikawa. Overall fit of peak magnitude at both sites is good, although model attenuation results in the two peaks mixing together, partly also a function of spatially varying rainfall.</td>
<td>Small double event, rain spatially variable, 1st peak way over at both Mankau & Waikawa although note the very high first hit of rainfall in the hills so would be difficult to get better model with such high rainfall.
2nd peak fits better at both sites although Manakau under.</td>
<td>Small event, rain spatially variable, low at Manakau, good fit at Waikawa</td>
<td>Small event, rain TIMING VERY variable, peak values are good at both sites although early due to the use of some high/early raingauge data</td>
<td>Small event, rain variable, fit reasonable (mix of over and under)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</table>

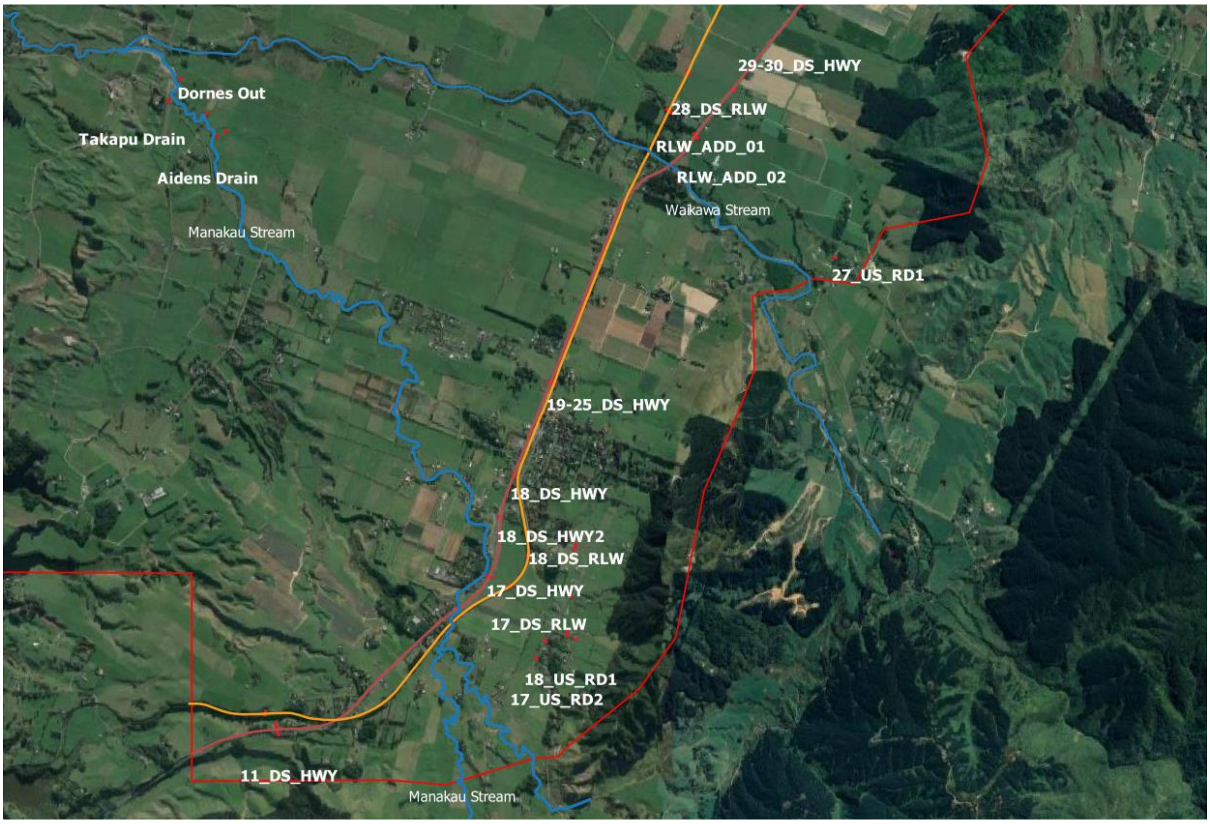
Appendix C Hydraulic Structures

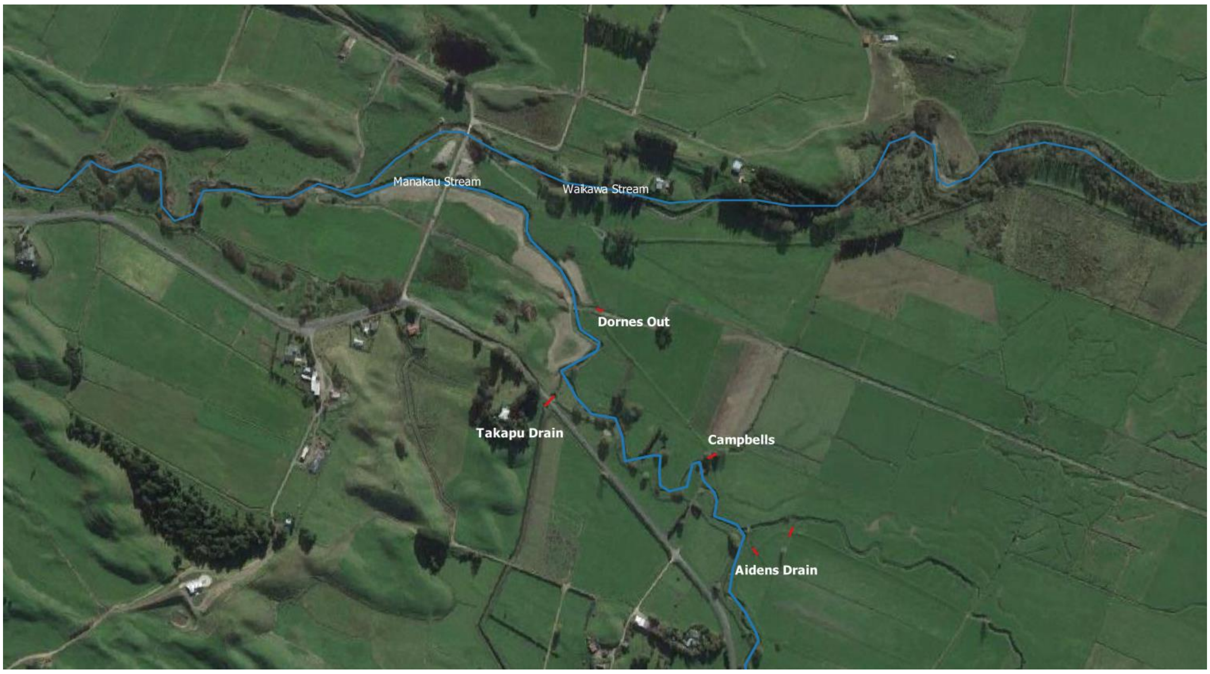
C.1 Structure Locations

The following images show the locations of individual structures applied within the hydraulic model.






29-30_DS_HWY
28_DS_RLW
RLW_ADD_01
RLW_ADD_02
Waikawa Stream
Dornes Out
Takapu Drain
Aidens Drain
Manakau Stream
27_US_RD1
19-25_DS_HWY
18_DS_HWY
18_DS_HWY2
18_DS_RLW
17_DS_HWY
17_DS_RLW
18_US_RD1
17_US_RD2
11_DS_HWY
Manakau Stream


Manakau Stream
Waikawa Stream
Dornes Out
Takapu Drain
Campbells
Aidens Drain

C.2 Structure Information

Information on hydraulic structures obtained from HDC, Kiwirail and Waka Kotahi NZTA. Please note highlighted cells indicate assumptions made on estimated values at the structure.

Culvert Name	No Culverts	Source	Diameter (m)	Shape	Length (m)	Invert Levels (us/ds, m)
11_DS_HWY	1	Highway	1.2	Circular	72.3	35.3/33.66
17_DS_HWY	1	Highway	0.6	Circular	69.4	34.24/34.24
17_DS_RLW	1	KiwiRail	0.45	Circular	28.6	35.46/35.31
17_US_RD1	1	HDC	0.6	Circular	15.0	45.78/44.37
17_US_RD2	1	HDC	0.6	Circular	14.0	45.78/45.44
18_DS_HWY	1	Highway	0.6	Circular	22.3	25.86/25.86
18_DS_RLW	1	KiwiRail	W 1.22 X H 0.92	Rectangular	42.6	33.22/33.26
18_US_HWY	2	HDC	1.05	Circular	17.2	42.93/42.57
18_US_RD1	1	ASSUMED	0.6	Circular	15.0	49.87/49.87
18_US_RD2	1	HDC	0.6	Circular	15.0	52.92/52.92
18_DS_HWY2	1	Highway	0.45	Circular	22.5	28.9/30.11
19-25_DS_RLW	1	KiwiRail	1.4	Circular	21.5	27.36/27.36
19-25_DS_HWY	1	Highway	1.05	Circular	18.1	27.38/27.38
19_DS_RD1	1	HDC	0.6	Circular	15.0	43.04/42.98
27_US_RD1	1	HDC	0.6	Circular	15.0	66.2/66.93
28_DS_RLW	1	KiwiRail	0.45	Circular	10.0	39.72/39.32
28_DS_HWY	1	Highway	0.375	Circular	24.0	44.71/44.19
29-30_DS_RLW	1	KiwiRail	1.75	Circular	10.0	24.34/23.93
29-30_DS_HWY	1	Highway	1.05	Circular	20.9	37.9/38.9
32_DS_RD1	1	ASSUMED	0.6	Circular	15.0	33.15/33.15
34_US_RD1	*1*	HDC	0.3	Circular	9.0	48.87/48.67
34_US_RD2	*1*	HDC	0.6	Circular	20.0	49.29/49.12
34_US_RD3	*1*	HDC	0.6	Circular	20.0	46.42/46.1
34_US_RD4	*1*	ASSUMED	W 3.42 x H 2.0	Rectangular	12.0	45.02/44.94
36_DS_RD1	*1*	HDC	0.75	Circular	11.9	41.5/41.29
36_DS_RD2	*1*	HDC	0.45	Circular	10.0	35.27.35.02
36_DS_RD3	*1*	HDC	0.45	Circular	10.0	33.13/33.13
11_DS_RLW	3	KiwiRail	0.6	Circular	32.0	37.56/38.7

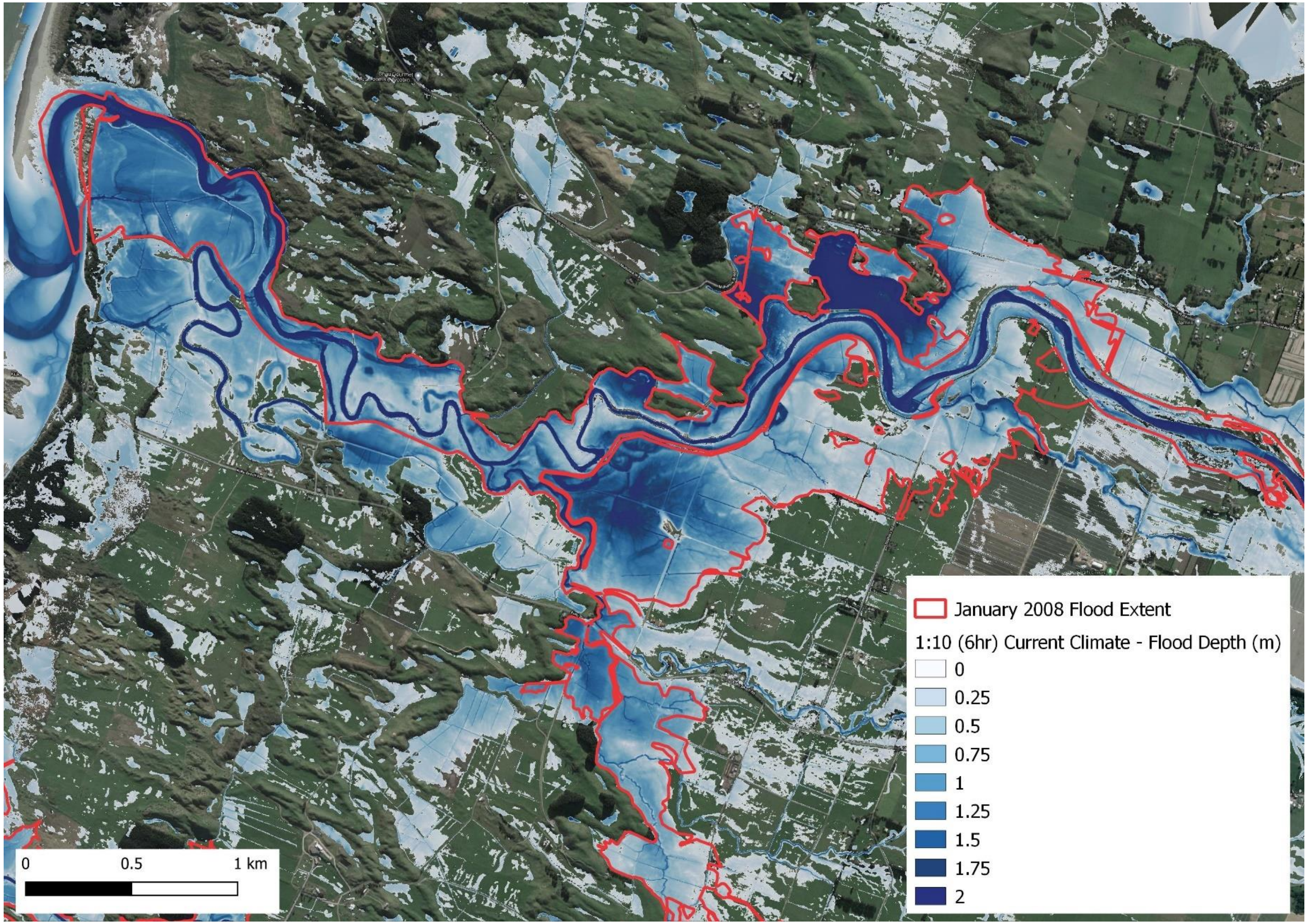
C.3 HRC Scheme Assets

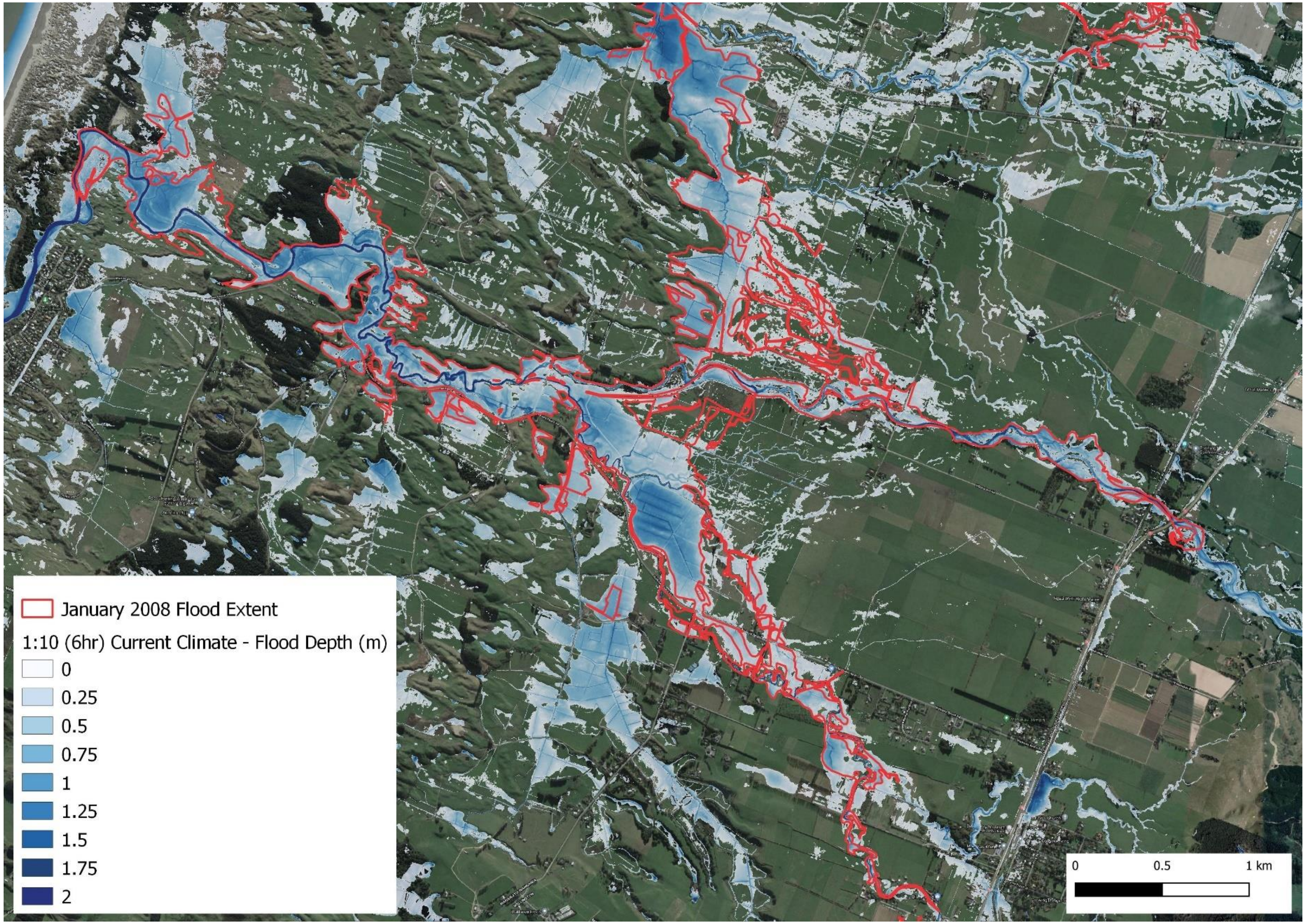
Information on hydraulic structures within the Ōhau Manakau Drainage Scheme Boundary obtained from HRC. Please note highlighted cells indicate assumptions made on estimated values at the structure.

Many of the structures are circular pipes, therefore no horizontal diameter has been applied.

Asset Number	Asset Name	Vert dim or pipe dia (m)	Horizontal dim (m) if different	Number (no.)	Length (m)	Modelled	Comments
837100	Aidens Drainage Outlet	0.6	-	1	Assumed	Y	Invert levels estimated (LiDAR)
837130	Aidens Outlet	0.6	-	1	Assumed	Y	Invert levels estimated
837060	Burnells Outlet	0.9	-	1	Assumed	Y	Invert levels estimated
837160	Campbells	0.9	-	1	Assumed	Y	Invert levels estimated
837030	Catley Drain Outlet	0.9	-	1	Assumed	Y	Invert levels estimated
837140	Dornes Outlet	0.3	-	1	Assumed	Y	Invert levels estimated
837170	Haines backflow	0.75	-	1	Assumed	Y	Invert levels estimated
837040	Haines Drain Outlet	1.2	-	1	Assumed	Y	Invert levels estimated
837150	Haines Drop Structure	1	3	1	n/a	N	LiDAR used to replicate
837570	Haines drop structure no.2	1	12.4	2	n/a	N	LiDAR used to replicate
837051	Haines large ponding outlet	1.2	22	1	Assumed	Y	Invert levels estimated
837050	Haines pond Outlet	0.45	-	1	Assumed	Y	Invert levels estimated
837180	Haines pumping gate	0.45	-	1	n/a	N	
837010	Kidds No 2 Outlet	0.3	-	1	Assumed	Y	Invert levels estimated
837000	Kidds No.1 Outlet	0.25	-	1	Assumed	Y	Invert levels estimated
837001	Kidds No.1a	0.3	-	1	Assumed	Y	Invert levels estimated
837002	Kidds No.1b	0.3	-	1	Assumed	Y	Invert levels estimated
837190	Ōhau tide bank gate	0.9	-	1	7.2	Y	Invert levels estimated
837120	Old Loop Outlet	1.2	-	2	Assumed	Y	Invert levels estimated
837580	Parkins Drop Gates	1	6.18	1	n/a	N	LiDAR used to replicate
837080	Parkins Outlet	0.6	-	1	Assumed	Y	Invert levels estimated
837020	Tahamata Outlet	1.2	-	1	Assumed	Y	Invert levels estimated
837110	Takapu Drain Outlet	1.05	-	2	Assumed	Y	Invert levels estimated
837070	West Outlet	0.6	-	1	Assumed	Y	Invert levels estimated

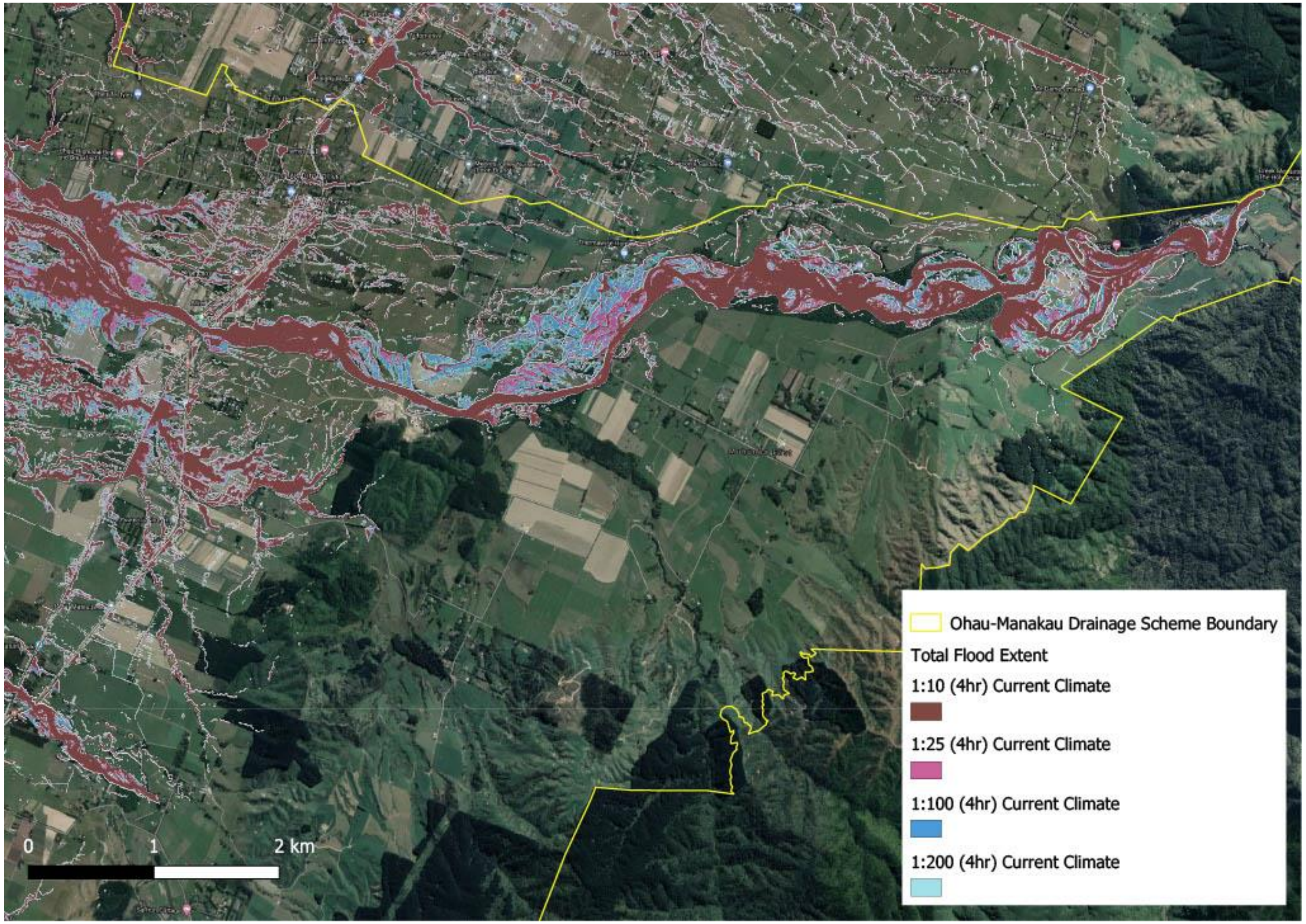
Appendix D Model Validation – January 2008 Flood Event

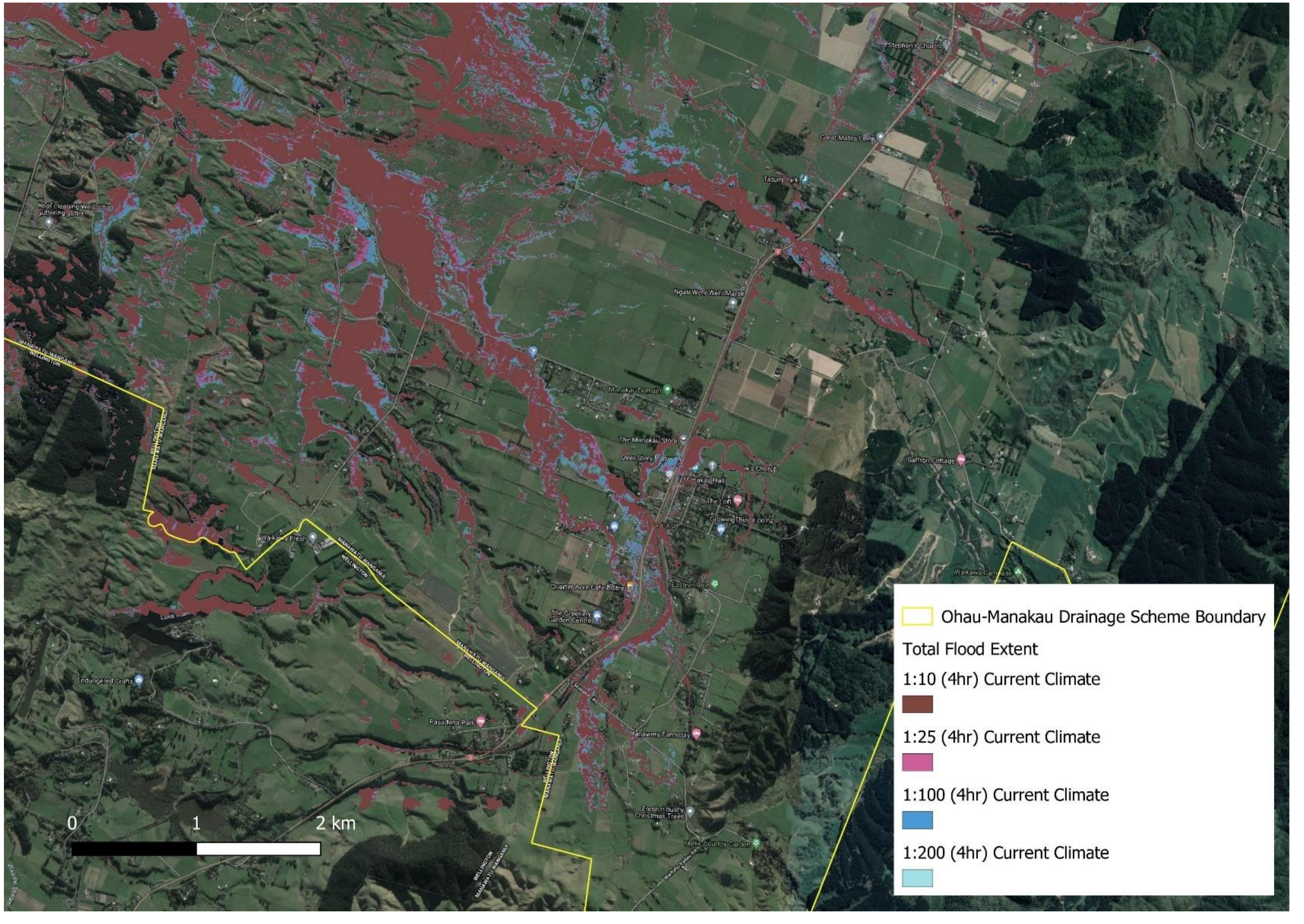



January 2008 Flood Extent
1:10 (6hr) Current Climate - Flood Depth (m)
0
0.25
0.5
0.75
1
1.25
1.5
1.75
2
0
0.5
1 km

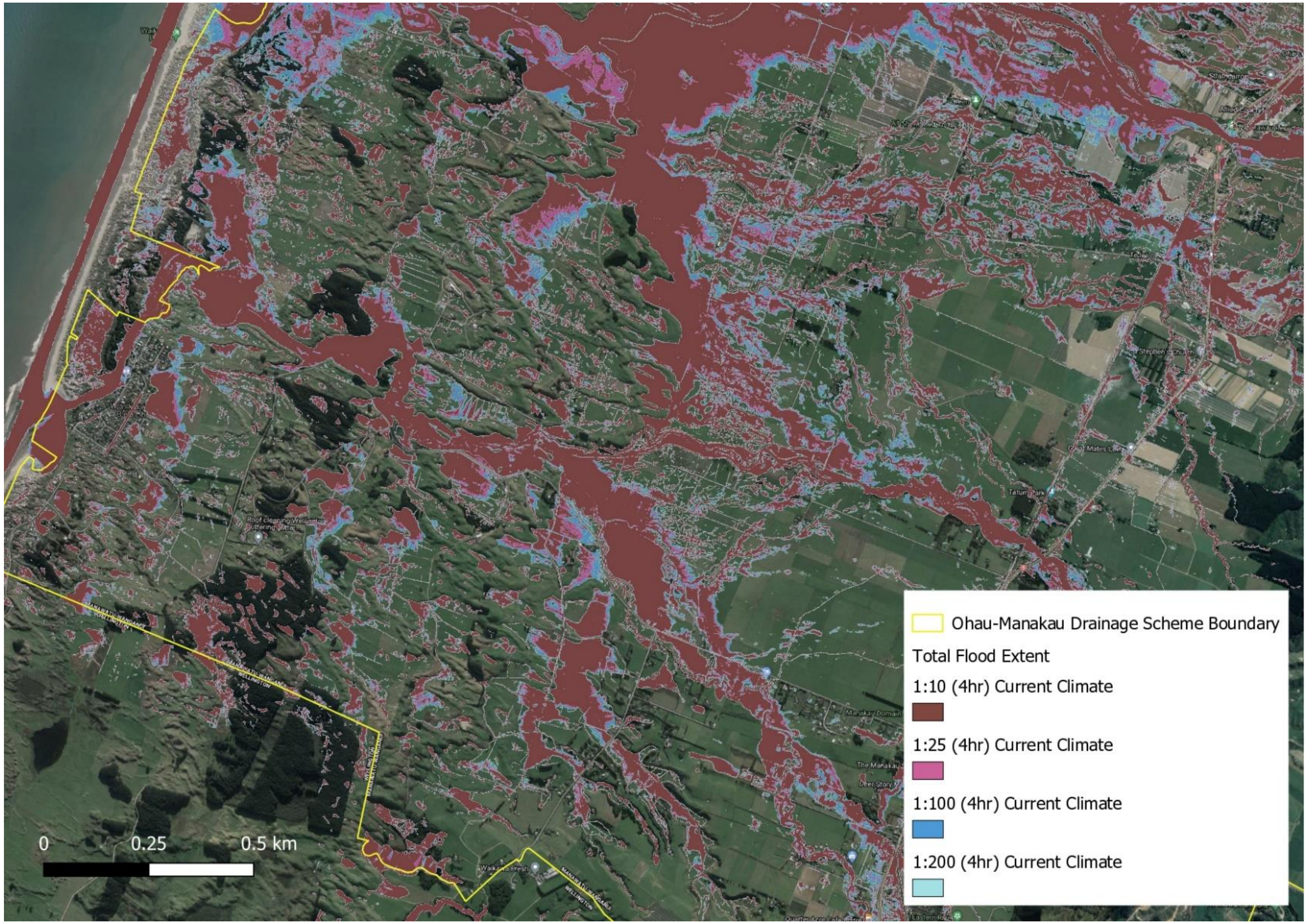
Appendix E Flood Extents - Design Events

E.1 Maximum Flood Extents – Storm Duration (4 hours)

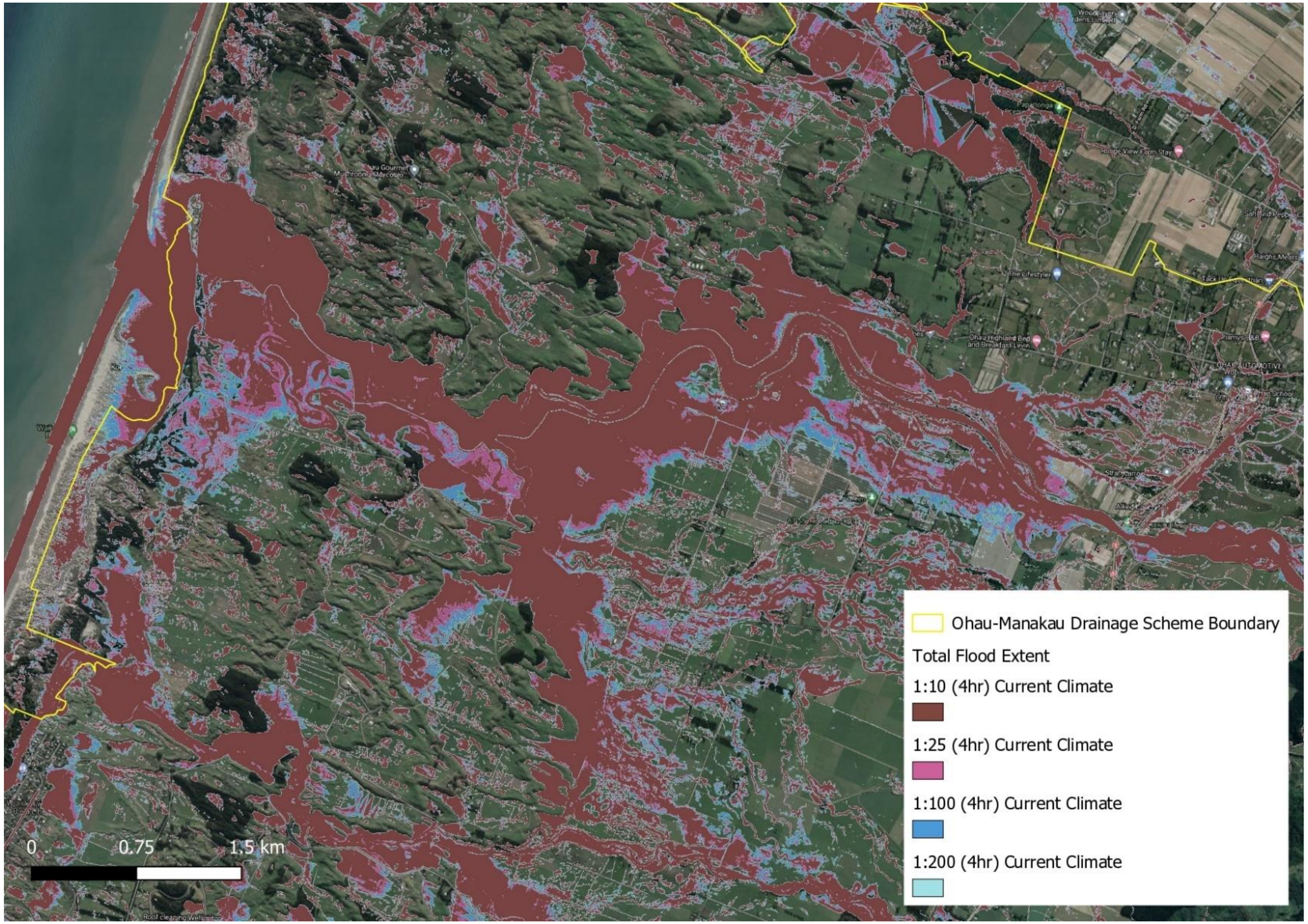




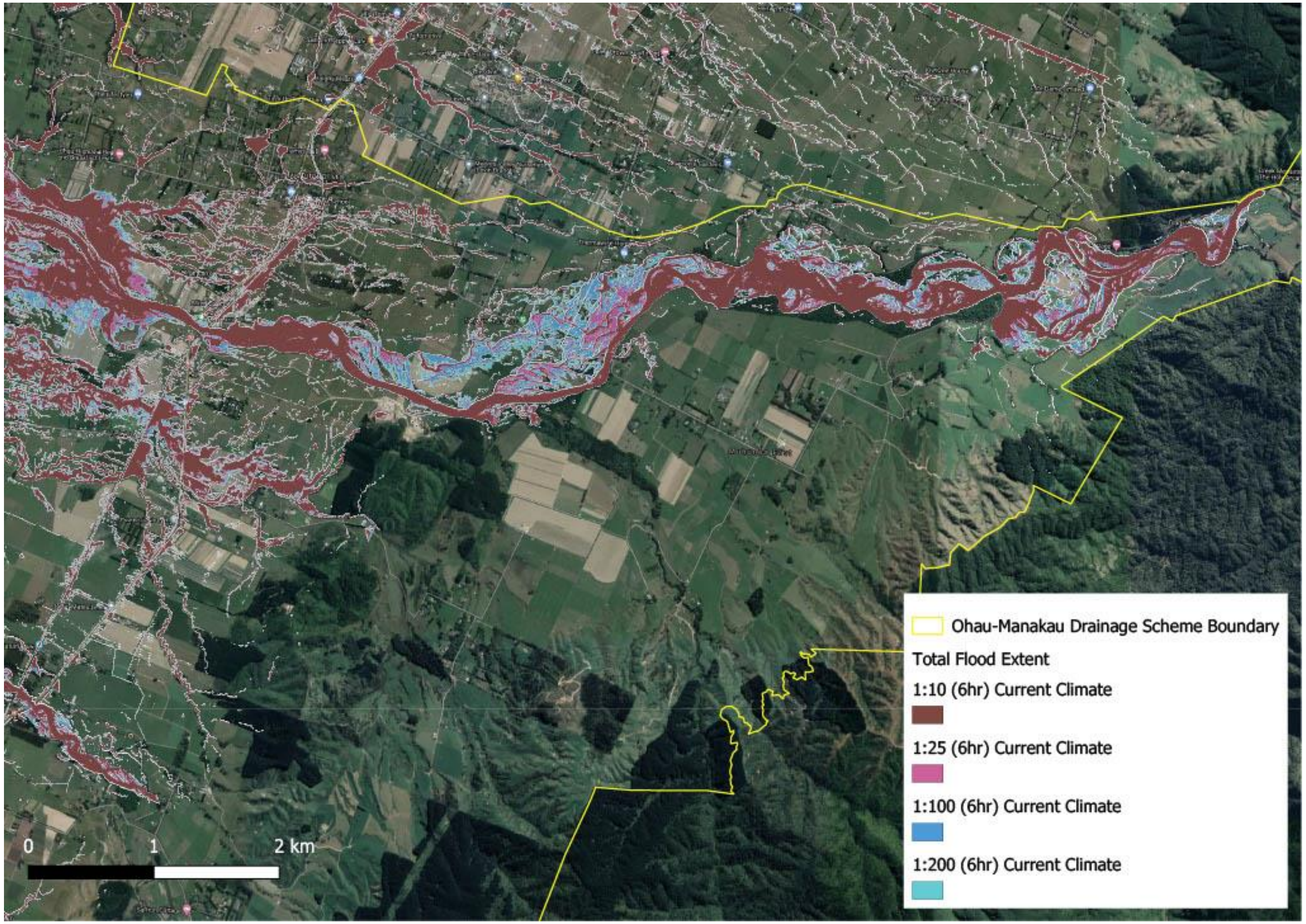
Ohau-Manakau Drainage Scheme Boundary
Total Flood Extent
1:10 (4hr) Current Climate
1:25 (4hr) Current Climate
1:100 (4hr) Current Climate
1:200 (4hr) Current Climate
0
1
2 km

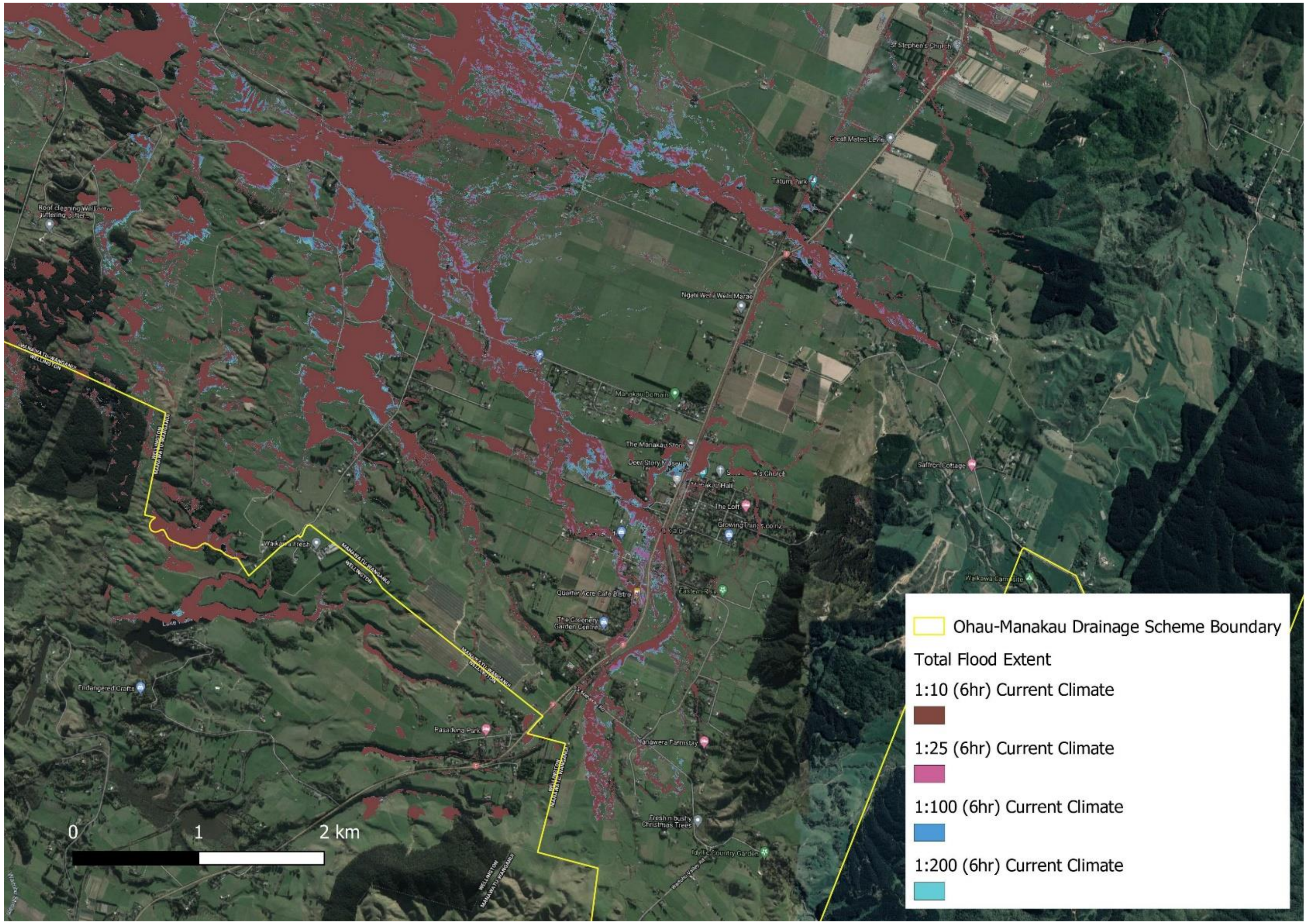


Ohau-Manakau Drainage Scheme Boundary
Total Flood Extent
1:10 (4hr) Current Climate
1:25 (4hr) Current Climate
1:100 (4hr) Current Climate
1:200 (4hr) Current Climate
0
0.25
0.5 km

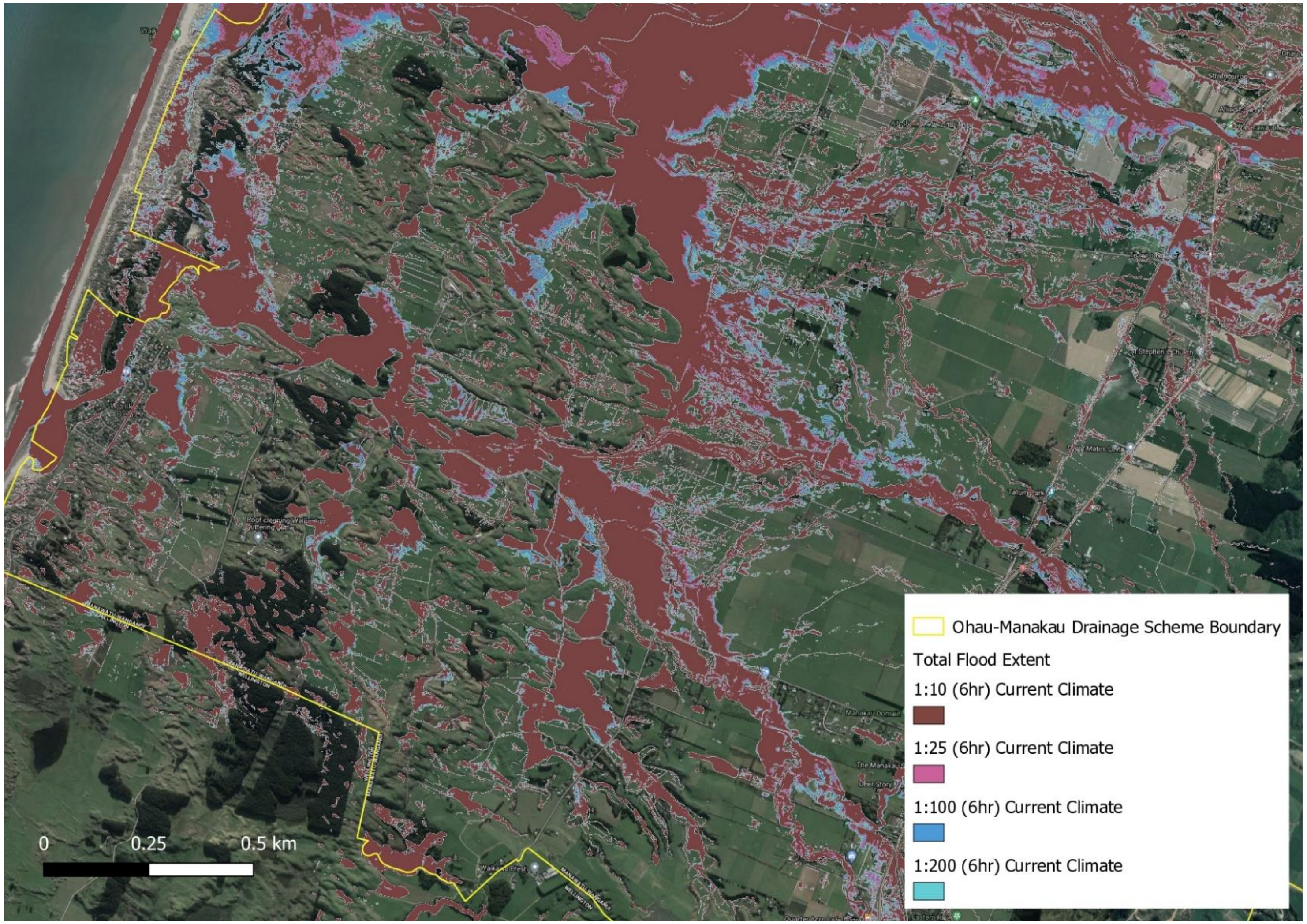

Ohau-Manakau Drainage Scheme Boundary
Total Flood Extent
1:10 (4hr) Current Climate
1:25 (4hr) Current Climate
1:100 (4hr) Current Climate
1:200 (4hr) Current Climate
0
0.75
1.5 km

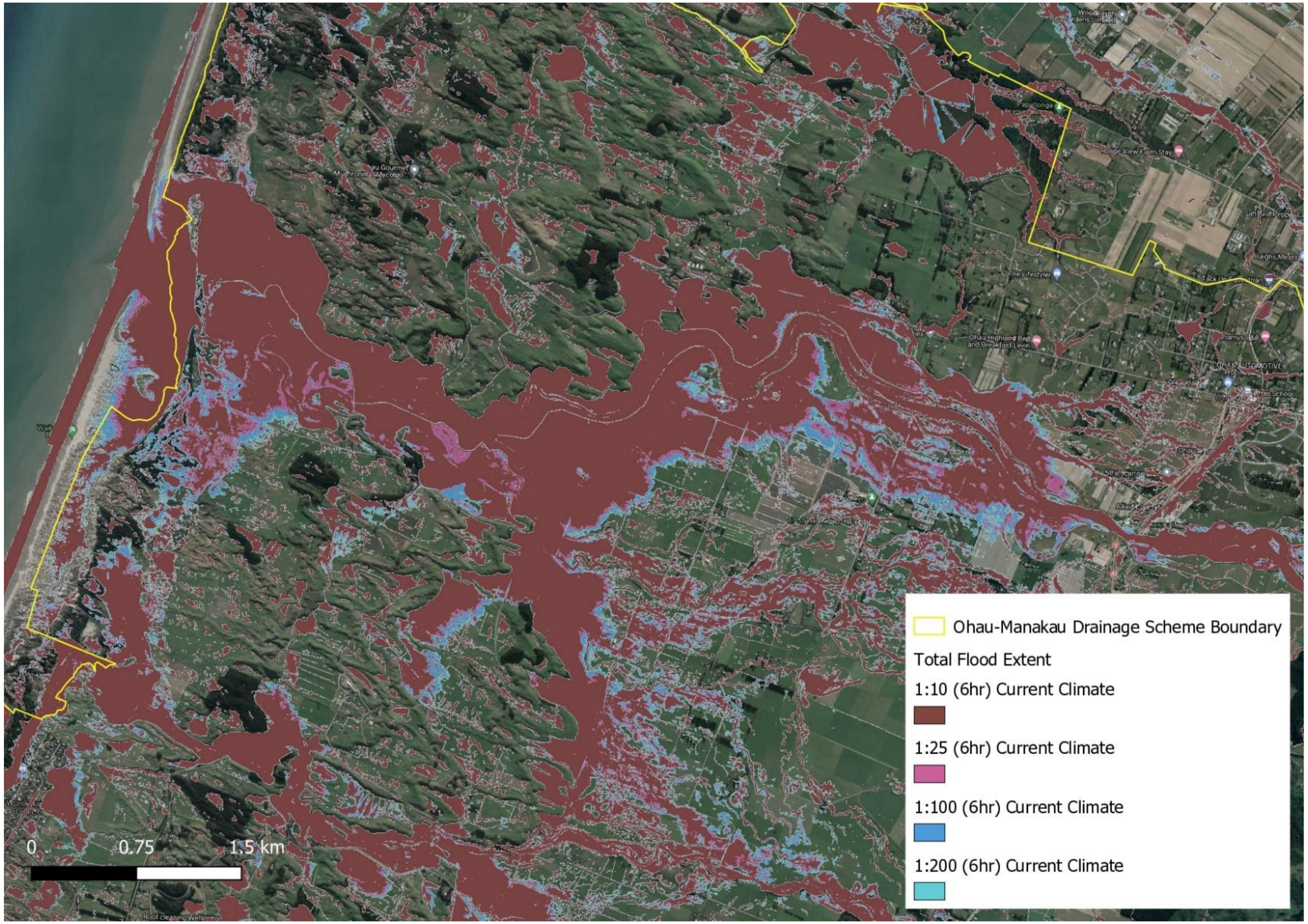
E.2 Maximum Flood Extents – Storm Duration (6 hours)





Ohau-Manakau Drainage Scheme Boundary
Total Flood Extent
1:10 (6hr) Current Climate
1:25 (6hr) Current Climate
1:100 (6hr) Current Climate
1:200 (6hr) Current Climate
0
1
2 km


Ohau-Manakau Drainage Scheme Boundary
Total Flood Extent
1:10 (6hr) Current Climate
1:25 (6hr) Current Climate
1:100 (6hr) Current Climate
1:200 (6hr) Current Climate
0
0.25
0.5 km


Ohau-Manakau Drainage Scheme Boundary
Total Flood Extent
1:10 (6hr) Current Climate
1:25 (6hr) Current Climate
1:100 (6hr) Current Climate
1:200 (6hr) Current Climate
0
0.75
1.5 km

Appendix F Overtopping Assessment

Name	Asset ID	Q10 - 4hr			Q10 - 6hr			Q25 - 4hr			Q25 - 6hr		
		Peak Overtopping Flow (m3/s)	Duration of Overtopping (hrs)	Overtopping Volume (m3)	Peak Overtopping Flow (m3/s)	Duration of Overtopping (hrs)	Overtopping Volume (m3)	Peak Overtopping Flow (m3/s)	Duration of Overtopping (hrs)	Overtopping Volume (m3)	Peak Overtopping Flow (m3/s)	Duration of Overtopping (hrs)	Overtopping Volume (m3)
Ohau stopbank L_no2	834001	0.00	0.00	0	0.00	0.00	0	0.29	1.00	882	0.90	1.00	2164
Kuku stopbank L	834020	9.07	5.00	124695	36.36	6.25	341887	61.95	6.75	463203	103.24	7.50	939879
Ohau stopbank L	834002	28.59	4.25	244404	36.04	5.50	441609	42.65	5.00	479043	55.67	7.50	733788
Ohau stopbank L	834003	15.41	3.50	102753	26.15	4.75	236478	37.95	4.50	310050	48.82	5.75	549270
Ohau stopbank L	834004	0.00	0.00	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00	0
Ohau stopbank R_no1	834010	0.00	0.00	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00	0
Ohau stopbank R	834011	0.00	0.00	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00	0
Ohau stopbank R	834008	27.00	1.00	79875	28.03	1.25	78298	35.80	1.25	87282	35.27	1.25	82872
Ohau stopbank L_no2	834000	1.01	4.25	6669	2.37	4.50	21614	2.96	5.25	25047	3.52	5.50	37080
Ohau stopbank L_no1	834001	0.00	0.00	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00	0
Ohau stopbank L	834008	1.35	3.50	8181	4.68	4.00	39032	6.30	5.00	50787	10.48	5.25	107181
Ohau stopbank R_no2	834010	0.00	0.00	0	2.83	2.00	11803	4.68	2.25	20754	14.83	4.25	90783
Ohau stopbank L_no1	834000	0.00	0.00	0	0.00	0.00	0	2.23	2.00	7695	9.34	3.25	56151
Kuku stopbank R	834030	22.19	5.25	109917	83.99	6.00	594268	127.81	6.75	883620	177.37	8.25	1688589
Ohau stopbank R	834012	0.00	0.00	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00	0
Manakau stopbank R_no1	n/a	19.75	11.50	189090	31.39	11.50	391698	34.60	11.50	359676	46.72	11.75	538650
Manakau Stopbank L_no1	n/a	0.00	0.00	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00	0
Manakau stopbank R_no2	n/a	7.77	6.00	56961	12.58	6.50	133401	14.04	7.00	127269	16.33	8.25	190188
Manakau Stopbank L_no2	n/a	0.00	0.00	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00	0
Manakau Stopbank L_no3	n/a	0.00	0.00	0	1.51	1.50	6479	2.52	2.00	8928	2.92	3.25	20241
Manakau Stopbank L_no4	n/a	18.90	4.50	136377	28.16	4.75	300024	31.54	5.25	286128	38.08	6.50	424503
Waikawa stopbank R_01	n/a	0.00	0.00	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00	0
Waikawa stopbank R_02	n/a	0.00	0.00	0	1.52	1.25	5537	2.29	1.75	7245	3.55	2.50	16389
Waikawa stopbank L	n/a	2.43	1.00	5214	2.87	1.00	5987	2.97	1.00	6598	2.55	1.50	9180

Name	Asset ID	Q100 - 4hr			Q100 - 6hr			Q200 - 4hr			Q200 - 6hr		
		Peak Overtopping Flow (m3/s)	Duration of Overtopping (hrs)	Overtopping Volume (m3)	Peak Overtopping Flow (m3/s)	Duration of Overtopping (hrs)	Overtopping Volume (m3)	Peak Overtopping Flow (m3/s)	Duration of Overtopping (hrs)	Overtopping Volume (m3)	Peak Overtopping Flow (m3/s)	Duration of Overtopping (hrs)	Overtopping Volume (m3)
Ohau stopbank L_no2	834001	2.87	1.00	2945	3.01	1.00	3125	3.13	1.00	2934	4.42	1.00	4497
Kuku stopbank L	834020	202.15	8.25	1770408	268.53	9.25	2877417	295.78	9.50	2710377	363.70	9.75	4191732
Ohau stopbank L	834002	78.17	6.50	929457	92.72	7.75	1306863	97.99	7.00	1184814	111.34	8.00	1634366
Ohau stopbank L	834003	82.97	5.75	833067	106.87	7.00	1306863	114.62	6.25	1162251	138.49	7.50	1709410
Ohau stopbank L	834004	0.00	0.00	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00	0
Ohau stopbank R_no1	834010	0.00	0.00	0	0.00	0.00	0	0.00	0.00	0	0.19	1.25	490
Ohau stopbank R	834011	0.00	0.00	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00	0
Ohau stopbank R	834008	47.07	1.50	89766	51.80	1.50	89100	50.88	1.75	101106	53.81	1.75	119453
Ohau stopbank L_no2	834000	3.35	6.50	27405	3.06	7.50	24372	2.43	7.00	20421	2.90	7.50	20304
Ohau stopbank L_no1	834001	0.00	0.00	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00	0
Ohau stopbank L	834008	17.59	6.50	175014	24.17	7.50	288774	24.74	6.75	261045	31.96	7.75	399354
Ohau stopbank R_no2	834010	36.37	4.50	221643	53.21	5.50	438813	59.87	5.00	403866	76.23	6.25	706699
Ohau stopbank L_no1	834000	44.75	3.75	261297	84.55	5.00	638127	95.49	4.00	616833	152.76	5.75	1268299
Kuku stopbank R	834030	291.87	8.50	2769993	362.81	9.25	4236345	391.84	10.00	3954762	463.53	9.75	5799900
Ohau stopbank R	834012	0.00	0.00	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00	0
Manakau stopbank R_no1	n/a	61.60	11.75	676458	65.82	10.75	4236345	75.03	11.75	852624	78.17	10.75	1064569
Manakau Stopbank L_no1	n/a	0.00	0.00	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00	0
Manakau stopbank R_no2	n/a	18.90	8.50	227907	20.16	9.00	284787	22.09	8.50	276687	23.31	9.50	344226
Manakau Stopbank L_no2	n/a	0.93	1.00	2592	1.66	2.25	7038	3.61	1.75	13401	4.85	2.25	25210
Manakau Stopbank L_no3	n/a	4.87	3.50	34434	5.39	4.00	49887	6.53	3.75	50184	6.93	4.50	70548
Manakau Stopbank L_no4	n/a	49.06	6.50	538992	52.99	7.50	691668	56.74	6.75	669024	60.43	7.75	845501
Waikawa stopbank R_01	n/a	0.00	0.00	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00	0
Waikawa stopbank R_02	n/a	4.95	3.25	30375	5.50	3.50	45801	6.46	3.50	47601	7.59	4.25	70869
Waikawa stopbank L	n/a	3.52	2.75	11548	3.09	3.00	10548	3.98	3.25	13256	3.58	3.25	12145

CREATING COMMUNITIES

Communities are fundamental. Whether around the corner or across the globe, they provide a foundation, a sense of belonging. That's why at Stantec, we always **design with community in mind**.

We care about the communities we serve—because they're our communities too. We're designers, engineers, scientists, and project managers, innovating together at the intersection of community, creativity, and client relationships. Balancing these priorities results in projects that advance the quality of life in communities across the globe.

New Zealand offices:
Alexandra, Auckland, Balclutha, Christchurch, Dunedin, Gisborne, Greymouth, Hamilton, Hastings, Napier, Nelson, Palmerston North, Queenstown, Tauranga, Wellington, Whangārei

Stantec
Level 15, 10 Brandon Street, Wellington, 6011
PO Box 13-052, Armagh, Christchurch, 8141
New Zealand: +64 4 381 6700 | www.stantec.com