REPORT

Raupo Drainage Scheme – Flood Hazard Impact Analysis

Northland Regional Council

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EXECUTIVE SUMMARY

Ruawai, a small township located in the Raupo region of the North Island of New Zealand, is situated on the banks of the Wairoa River. The Wairoa River is known to be vulnerable to coastal inundation and riverine flooding during large storm events, which can have detrimental effects on both the infrastructure and residents of the region. The location of the township on the eastern bank of the Wairoa River makes it particularly vulnerable to flood hazards, and it is therefore important to be proactive in understanding these risks to protect the community and their assets.

The assessment of the potential flooding impacts on the surrounding Raupo region has been undertaken using industry-standard hydraulic models. These computer-based models simulate the flow of water through the catchment, and have been utilised to predict the potential impact of flooding on the built environment, infrastructure, and communities. The hydraulic assessment has been prepared using TUFLOW HPC modelling software, a high-performance computing model used extensively in floodplain, coastal, and stormwater management. The TUFLOW HPC model developed for this study is able to identify the potential flooding extents, depths and velocities that can be used to assess the impact on the built environment, infrastructure, and community as well as, subsequently, aid in the development of effective mitigation measures.

Throughout the model development, Iain Beattie – Chair of the Raupo Drainage Board – provided on-ground local knowledge to ensure the model flood outputs reflected what was experienced on the ground. This iterative process ensured that there was a level of confidence in the model results. Additionally, the model was peer-reviewed by Hugh MacMurray, to ensure it was technically sound and fit-for-purpose.

A TUFLOW hydraulic model has been developed to simulate flood response across the Raupo Drainage Scheme in Kaipara District. This includes the town of Ruawai and surrounds, which are protected from the Wairoa River with a series of stopbanks and floodgates. These structures were included in the model, which was simulated for design events including the 1%, 2%, 10% and 20% AEP, as well as the 1% AEP with Climate Change using a rainfall-on-grid approach.

Additional Costal Hazard scenarios were simulated without rainfall, to present the implications of sea level rise on the district.

Flood maps, including depth, velocity and hazard, are provided in the Appendix B.

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1 INTRODUCTION

1.1 Background

Ruawai, a small township located in the Raupo region of the North Island of New Zealand, is situated on the banks of the Wairoa River. The Wairoa River is known to be vulnerable to coastal inundation and riverine flooding during large storm events, which can have detrimental effects on both the infrastructure and residents of the region. The location of the township on the eastern bank of the Wairoa River makes it particularly vulnerable to flood hazards, and it is therefore important to be proactive in understanding these risks to protect the community and their assets. Most notably, much of the town and surrounding farmland sits near sea level, and a series of protective stopbanks and pumps are crucial to managing both stormwater runoff from the local catchment, and encroaching tidal waters.

One of the major impacts of flooding on Ruawai and surrounding areas across the Raupo region is the damage to private property and infrastructure, including farmland. Coastal and riverine floodwaters can inundate homes and businesses, causing extensive damage to buildings, land, and other property and infrastructure. Specifically, roads, bridges, and other critical transportation infrastructure may be inundated, washed away, or severely damaged during large events, making it difficult for residents to travel and for emergency services to access the area. In large events, homes are evacuated, and valuable agricultural land and crops are destroyed. The recent events in early 2023, with extreme wind, rainfall and combined with a significant storm surge raising levels in the Wairoa River, disrupted the kumura season, occurring at the start of the harvesting season. This results in a material loss of kumura yield and financial hardship on local farmers[1].

A similarly significant impact of flooding on Ruawai is the disruption to essential services - Flooding can result in power outages, disrupt water and sewage systems, and make it difficult for emergency services to respond to the needs of the community. Coastal and riverine flooding can also have significant economic implications for Ruawai. The damage to property and infrastructure can lead to a decrease in property values and a decrease in economic activity as agricultural businesses struggle to recover. In addition, the disruption to essential services can lead to a loss of productivity and income for residents. The recent Cyclone Gabrielle was an example of how disruptive flooding and extreme weather can be for the region.

In light of the potential coastal and riverine flooding risks faced across the region, Northland Regional Council has taken the initiative to update the hydraulic modelling for the locality. The revised modelling will inform an updated drainage scheme and hazard impact analysis. This analysis is aimed at informing a comprehensive assessment of coastal flooding mitigation options. This action taken by the Northland Regional Council represents a significant step towards addressing the known vulnerability of the township, and the updated study is an important part of the overall coastal, flooding, and stormwater management strategy for the region. Council can subsequently use the outcomes of this study to separately identify recommendations for coastal flooding and stormwater management responses that can be tailored to the specific needs of the community. This will play a vital role in increasing overall resilience and reducing the impact of flooding on the wider community.

The assessment of the potential flooding impacts on the surrounding Raupo region has been undertaken using industry-standard hydraulic models. These computer-based models simulate the flow of water through the catchment, and have been utilised to predict the potential impact of flooding on the built environment, infrastructure, and communities. The hydraulic assessment has been prepared using TUFLOW HPC modelling software, a high-performance computing model used extensively in floodplain, coastal, and stormwater management . The TUFLOW HPC model developed for this study is able to identify the potential flooding

[1] Personal communication with Iain Beattie and Joseph Camuzo

extents, depths and velocities that can be used to assess the impact on the built environment, infrastructure, and community as well as, subsequently, aid in the development of effective mitigation measures.

1.2 Purpose and Intent

This report provides detailed technical documentation associated with the development of the hydraulic model for the Raupo coastal hazard impact analysis and provision of mitigation strategies. The TUFLOW model development and validation process is thoroughly documented in the report, including information on the software and tools used, the data sources and input parameters, and the procedures followed to ensure the model is accurate and reliable.

The report also includes a detailed description of the data sources and inputs used to develop the model, such as topography, land use, and gauge-derived design Intensity-Duration-Frequency (IDF) rainfall data. It also includes a description of the procedures followed to ensure the model is accurate and reliable, such as model validation and sensitivity analysis.

The report also quantifies the estimates for a suite of Annual Exceedance Probability (AEP) design events for the greater Raupo catchment area, including the estimated depths, flows, and water levels. This information is critical for Northland Regional Council to understand the level of flood risk in the catchment area and to develop appropriate management strategies to mitigate those risks. It will be a valuable resource for Northland Regional Council and other stakeholders to understand the level of risk in the catchment area and to demonstrate the importance of the suggested mitigation options.

In relation to this, the study provides Northland Regional Council with the necessary data and information to make informed decisions about flood and stormwater management. Uses of the data may include; land use planning, development control, emergency response planning and community engagement. The study outcomes can be used to support Council in their efforts to minimise flood risk and promote community resilience. The study outputs can be used to provide an understanding of the flood hazard and risk in the Raupo area, which will inform future planning decisions and development control decisions by providing information about the flood hazard and risk in specific areas. This aims to ensure that new developments are located in areas that are less prone to coastal, riverine, or stormwater inundation and new developments are designed to minimise the risk of flooding.

Finally, the study outcomes can be used to support Council in their efforts to promote community resilience. The information from the study can be used to educate the community about flood hazard and risk in the area and to raise awareness about the importance of severe stormwater inundation, flood preparedness and resilience, and further use the study to identify areas where additional investment in flood protection measures is needed and to work with the community to develop community-based stormwater and flood risk management plans.

1.3 Overview of Study Objectives and Methodology

The objectives for the Raupo coastal hazard impact analysis, as stated in the project brief and extensively documented in this report, are summarised briefly as follows:

- Derivation of New Flood Model: The report describes the process of deriving a new direct rainfall hydraulic model for the Raupo locality and overall catchment area. The new model has been developed using TUFLOW HPC hydraulic modelling software.
- Calibration / Verification: The model has been validated to ensure that the hydraulic modelling outputs are representative of historical observations and can be used to reliably inform the assessment of a range of storm events.
- Design Event Modelling: The hydraulic model has been used to define stormwater and flood risk and likelihood across a full range of AEP design storm events, from the frequent to rare events, to quantify existing and future flood risk. This information can be used to identify areas of high risk and to guide future planning decisions. Outputs for each AEP design flood event, include flood depths, flows, and water levels, which are critical for the Council to understand the level of stormwater and flood risk in the catchment area.
- Technical Documentation and Flood Mapping: The report provides technical documentation and updated inundation mapping and digital datasets. These materials will be used to inform any future management initiatives for land use planning, development control, and community engagement, and will support the council in their efforts to minimise overall flood risk and promote community resilience. Reports and flood risk maps will also be a valuable resource for other organisations or researchers who wish to use or replicate the model in the future.

1.4 Study Area and Locality

Ruawai is located 30 km south of Dargaville and is the main township in the southern Raupo region of Northland. It is situated in a rural area and primarily serves the outlying farming community, which is mainly composed of cattle farming and kumara growing. The community is known to be vulnerable to coastal flooding from Kaipara Harbour, particularly in the low-lying areas. The township is also home to important infrastructure assets, such as roads, bridges, and residential properties, which are at risk of flooding from the Wairoa River.

The Kaipara Harbour and Wairoa River play a vital role in Ruawai. The Kaipara Harbour, being one of the largest harbours in New Zealand, is a significant coastal feature that provides many important ecological, cultural, and economic benefits to the local community. The Kaipara Harbour is an ecological haven for a wide range of marine life, including shellfish, and seabirds, and is an important breeding ground for many species of fish - it is therefore a popular destination for recreational fishing. The harbour plays a significant economic role for the Ruawai township, acting as a major transportation hub for the region and a popular tourist destination supporting boating, fishing, and sightseeing.

The Wairoa River is an important waterway that flows into the Kaipara Harbour and provides including irrigation water to the local farmers. The river also supports a wide range of aquatic life, including fish, eels, and waterfowl, and additionally provides opportunities for recreational activities. The river is dominated by tidal influences, even beyond Dargaville, with a series of flood-gates and stopbanks to protect riverside communities.

Due to Ruawai's proximity to these water sources, the township is vulnerable to coastal and riverine flooding, mostly due to tidal surge and heavy rainfall in the local and Wairoa River catchments.

2 AVAILABLE DATA

2.1 Previous Study Documentation

This current study builds upon previous research and analysis which has been prepared for the Raupo region. The data provided in the previous work used as a foundation to inform updates and improvements to the understanding of the coastal inundation and flood risk across the region. The following technical reports have been prepared to assess stormwater and flooding across Raupo and the Kaipara Harbour for Northland Regional Council, between 2017 and 2021:

2.1.1 Water Technology Regional Flood Modelling 'Catchment M10' (2021)

NRC commissioned Water Technology to conduct a region-wide flood modelling study in the Northland region of New Zealand. The study area covered over 12,500 km², excluding offshore islands. The aim of the project was to map riverine flood hazard zones across the region and update existing flood intelligence. The project used a 2D Direct Rainfall (Rain on Grid) approach with TUFLOW software adopted for the modelling.

The study modelled 19 catchments, 9 of which were calibrated against recent and historic flood events. The relevant catchment (Pouto Peninsula, M10) was not directly calibrated, but its model parameters were adopted based on adjacent calibrated catchments. The design modelling of this catchment consisted of four storm durations (1-hour, 6-hour, 12-hour, and 24-hour) for each design AEP (1%, 2%, and 10%). The modelled design flows were verified against several design flood estimation methods, including SCS, Rational Method and the NIWZ River Flood Statistics portal and provided a reasonable fit. Essentially, the modelling results were considered fit for use and could be used to identify flood hazard and potential flood risk, inform planning decisions, and provide a basis for emergency management exercises at a catchment scale.

This model considered local catchment runoff as well as the impact of the tidal boundary, however the stopbank and floodgates were not accurately modelled given the catchment scale of the model.

2.1.2 DHI Coastal Inundation Modelling for Northern Kaipara Harbour (2019, 2021)

A coastal flood model was developed by DHI and commissioned by NRC. MIKE Flexible Mesh modelling software was used. The goal of these simulations was to assess peak flood inundation levels in the northern part of the harbour due to coastal storm surge and/or sea level rise for different scenarios. The scenarios that were assessed include: present day mean high water spring level (MHWS), a present day 1% AEP storm event with wave set up allowance, a 2% AEP storm event with wave set up allowance and 0.6 m sea level rise, a 1% AEP storm event with wave set up allowance and 1.2 m sea level rise, a 1% AEP storm event with wave set up allowance and 1.5 m sea level rise, mean high water spring and 0.6 m sea level rise, and mean high water spring and 1.2 m sea level rise.

The model was developed using a new LiDAR survey dataset and was calibrated against observed water levels at the Helensville and Dargaville water level gauges. The model was also calibrated and validated for storm surge events when river flows were not significantly elevated. The report summarises that the model was calibrated at the Dargaville water level gauge for a significant storm-tide event that occurred in June 2012, and then validated for an event that occurred in September 2006.

2.1.3 eCoast Coastal Flood Modelling of Ruawai, Kaihu-Dargaville, and Awanui (2017)

This study focused on the areas of Ruawai, Kaihu-Dargaville, and Awanui. Prior to this study, "bathtub" derived flood extents for various Coastal Flood Hazard Zone (CFHZ) areas were used and generally considered conservative. Subsequent desktop analyses found that overtopping volumes could likely exceed bathtub volumes for future extreme events but may be less for current extreme events.

The simulations used CFHZ levels derived by Tonkin and Taylor in 2016 to model extreme static water level scenarios that correspond to different AEP events for different water levels. The scenarios were used to derive storm surge boundary conditions for each of the model domains. The simulations were carried out using the HEC-RAS version 5.0 modelling suite. The results showed less inundation compared to previous studies, mostly due to the implementation of spatially varying roughness in the model. The study suggested that hydrodynamic modelling could be used to better understand the coastal flood extents for lower, more frequent flood events and to provide information on flood depths/velocities to inform damage assessments and assist in prioritising stop bank upgrades.

2.2 Summary

The previous hydraulic modelling found that the stopbank is overtopped in a number of locations for events with a return period greater than 50 years (2% AEP). The current level of service for the stopbank is unknown but believed to be around a 20 year return period. It is also important to note that the previous DHI and eCoast modelling only considered the flood risk from coastal inundation and the Wairoa River, and did not consider flooding from local catchment areas behind the stopbank. Those models do not consider any potential flooding from local catchment runoff.

As a result, the updated hydraulic modelling in this project has been prepared to specifically model local catchment runoff through the use of a direct rainfall modelling methodology, aimed at filling the knowledge gaps not previously explored in the abovementioned studies.

2.3 Topographic Data

Elevation data is an essential component of the hydraulic model and informs flood mapping for the overall Raupo study. The elevation data for the study was based on 1 m resolution Light Detection and Ranging (LiDAR) elevation data provided by NRC in 2021 and captured between December 2018 and February 2020. LiDAR is a remote sensing technology providing highly accurate elevation data. The LiDAR data was collected at a high horizontal resolution of 1 m, providing detailed information on the topography of the catchment. Reported accuracies are ±0.2m vertical and ±1.0m horizontal.

Bathymetric data of the harbour and Wairoa River was obtained from previous models as well as harbour maps.

The complex topography of the Kaipara district is critical to represent accurately. Much of the irrigation area is very flat, lying between 0.0 and 2.0 m NZVD. The northern half of the study area gradually rises to 4.0 m NZVD over the course of 3-5 km. Beyond this is a ring of steep peaks, including Tokatoka in the northwest, enclosing the district. The model extends to these peaks, as they form the upper limit of the catchment. Rainfall is applied across the whole catchment, with runoff from these hills naturally flowing south and west to the outlets along the Wairoa River.

The model was set up in NZVD, noting the offset to OTP varies from +0.117 – +0.122 m across the model domain.

The applied topography is presented in Figure 2-1

2.4 Survey Data

It was crucial to accurately survey key hydraulic structures across the catchment area, including dimensions and inverts. These structures, such as bridges, culverts, floodgates and stopbanks, play a vital role in controlling and directing the flow of water in the catchment area. An accurate understanding of the location and condition of these structures is needed to effectively model the behaviour of water in the catchment. Most notably, the stopbanks and floodgates were all surveyed to be represented in detail within the model.

Due to the sheer number of minor flood structures (typically small culverts at driveways or road-sides), not all structures were surveyed. Those that were not surveyed were either assumed based on up- or down-stream structure arrangement, or assessed from other sources (e.g. Google Street View). Finally, where these minor structures were found to have an influence on flood behaviour or levels, the dimensions were confirmed with a site visit.

A map of surveyed structures is presented later in this document as part of the model build (as discussed in Section 3.6).

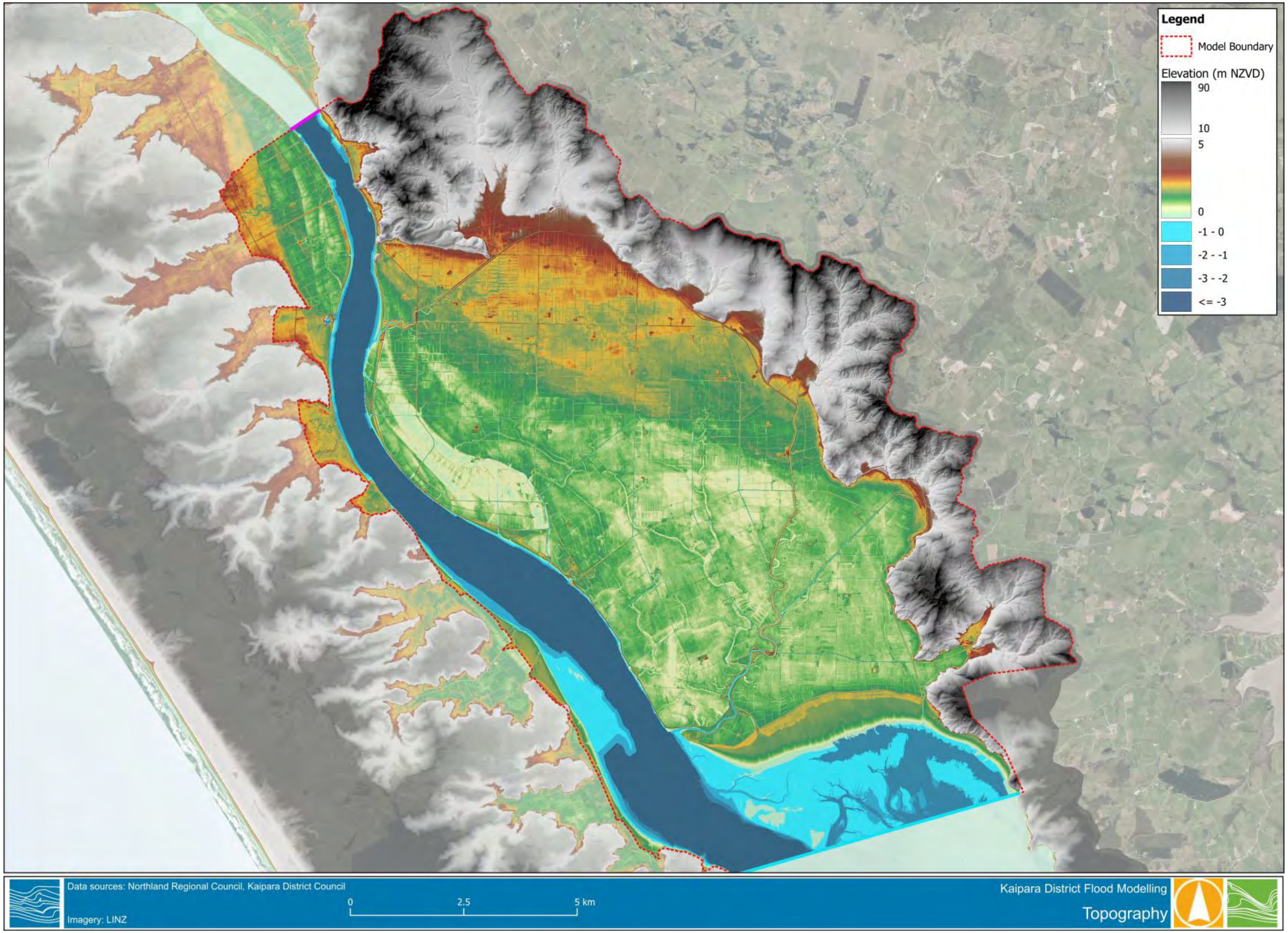

Figure 2-1 Model Topography

2.5 Provided Survey and Other GIS Datasets

2.5.1 Stop Banks

A key component of the updated hydraulic modelling is the inclusion of the stopbanks along the Wairoa River. Surveyed levels of each of these embankments, captured in 2018 and again in 2022, were provided via Kaipara District Council.

The 2022 feature survey also included the banks along K and G Canal, which have a strong influence on water levels behind the stop banks. These canals are also mostly below sea level, so banks and any structures through them are, for some areas, the only protection from tidal inundation.

2.5.2 Road Drainage and System Outlets

This study also builds upon the previous understanding of flooding across the region by including minor road and channel cross-culverts. This is provides a more comprehensive representation of coastal flooding and stormwater inundation across the region, with specific consideration for the drainage conditions throughout the catchment. This also includes flood gates or pipes that may intersect the stopbanks. Many of these are one-way flap gates, and correctly modelling their operation is crucial to accurately represent flood behaviour.

An overview of the surveyed culverts and floodgates are presented in Figure 2-2 and Figure 2-3, respectively. Appendix C shows the tabular culvert information, as provided by Kaipara District Council.

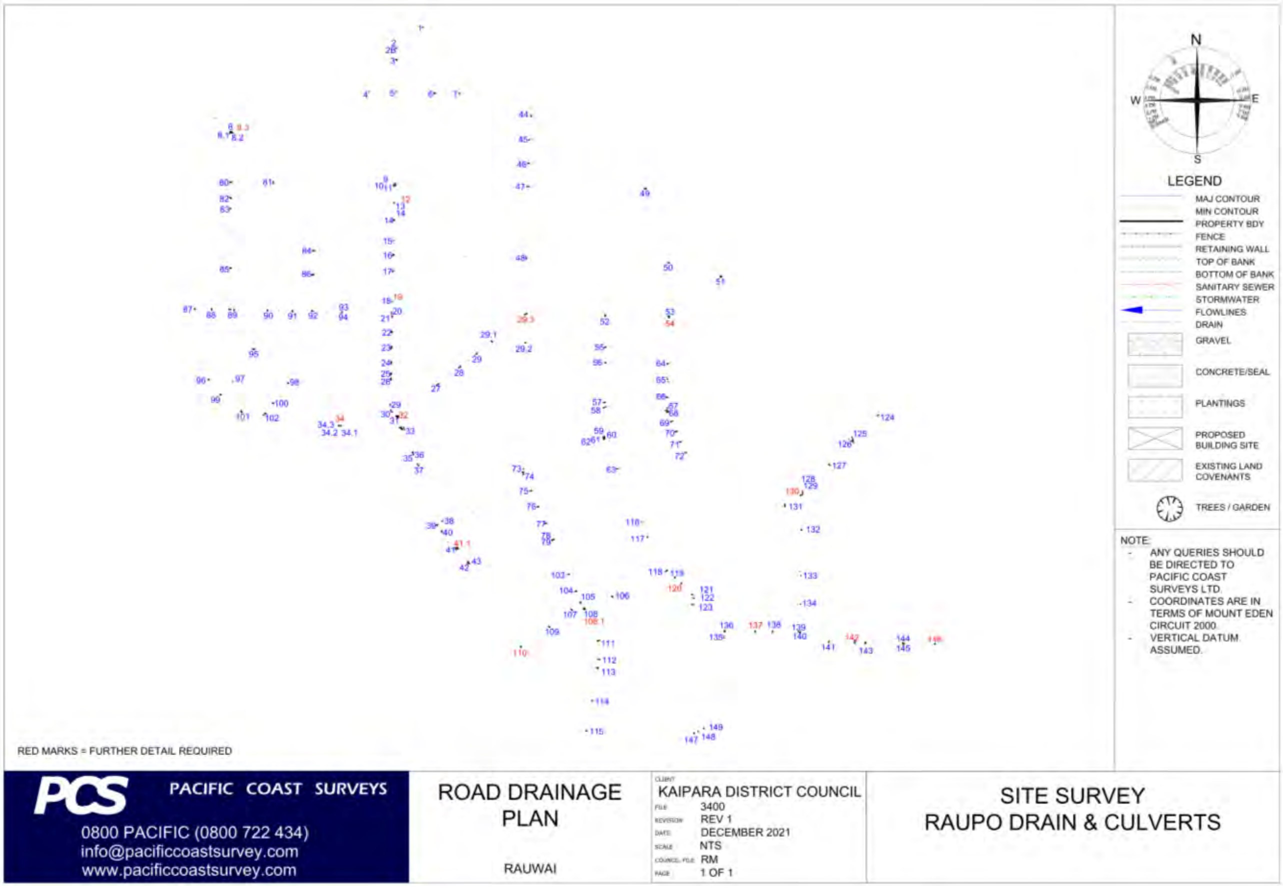

Figure 2-2 Road Drainage Plan – Raupo Drains and Culvert Locations

Figure 2-3 Raupo Floodgate Locations

3 HYDRAULIC MODEL SUMMARY

3.1 Overview

TUFLOW is a widely used software for simulating hydrodynamic and water quality processes in open channels, estuaries, and coastal waters. TUFLOW is capable of simulating a variety of hydrodynamic processes, including steady and unsteady flows, steady and unsteady water quality, and sediment transport. One of the key advantages of TUFLOW is its ability to simulate both steady and unsteady flow conditions. Steady state flow conditions refer to when the water level and flow rate remain constant over time, while unsteady flow conditions refer to when the water level and flow rate are changing over time.

The hydraulic model prepared for this study utilised a linked 1D-2D version of the TUFLOW HPC (Heavily Parallelised Computing) model. This version of TUFLOW allows for the use of Graphical Processor Unit (GPU) technology to run simulations on a relatively fine grid scale while maintaining practical simulation run times. With this fine resolution, open channels can be fully represented in 2D with sufficient cells across the waterway. Culverts are represented in 1D. The GPU technology performs computation intensive tasks significantly faster than traditional CPU based systems which can save a lot of time during the modelling process. The 2D component of the simulations provide information about riverine and coastal flood behaviour, while the 1D component is used for the structures including floodgates and culverts. These are 'linked' such that momentum is conserved between the model engines, producing more accurate results. The 1D-2D linked version allows for a more detailed representation of the catchment area, which can lead to more accurate predictions of flood risk, in the context of this study.

3.2 Model Layout and Extents

The TUFLOW model developed for this study covers an area of approximately 200 km², with a grid size of 6 m. The grid size refers to the spatial resolution of the model, which determines the level of detail that can be represented in the simulation. A smaller grid size allows for a more detailed representation of the catchment area, but also requires more computational resources and longer simulation run times. The 6 m grid size results in approximately 5 million active cells, with simulations taking 2 to 6 hours depending on storm duration.

A single TUFLOW model was developed to inform the hydraulic assessment of the Raupo catchment area. The model extents were developed to encompass the full catchment area including backwater extents for each of the respective local tributaries. The downstream model extent was also selected to align with previous studies and to ensure suitable representation of any tailwater conditions from the Wairoa River which might influence inundation levels across the lower reaches of the catchment.

The layout of the model, including boundaries and material zones, is shown in Figure 3-1.

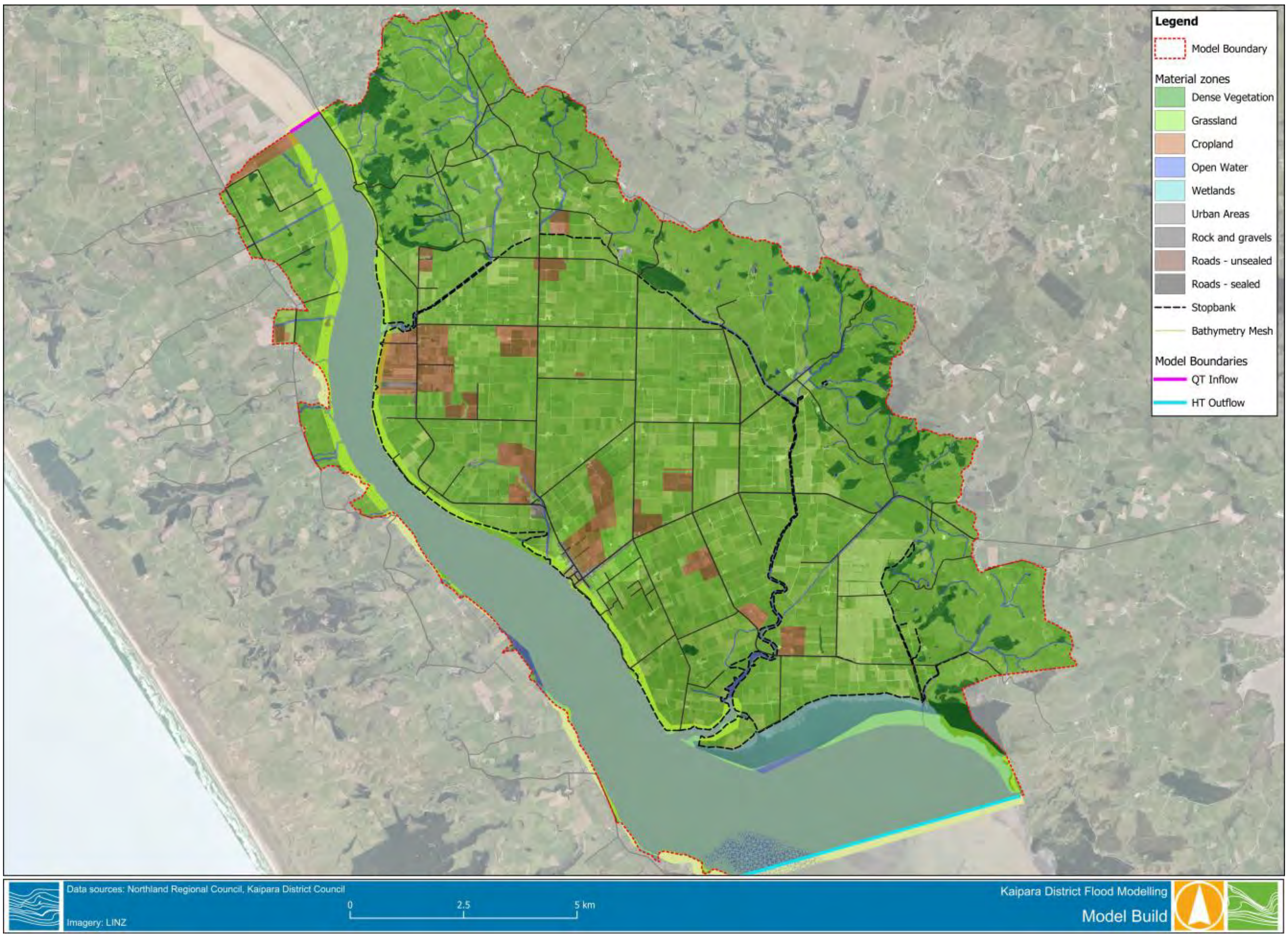

Figure 3-1 TUFLOW Model Build

Table 3-1 summarises the adopted parameters for roughness, initial loss and continuing loss. As per the agreed scope of work, they are as per the Region-wide Model (catchment M10). It should be noted these parameters were adopted based on the calibration to a historic event where streamflow gauges were present in an adjacent Kaipara District catchment (i.e. M08). We note that there were comments from the peer reviewer that some of the adopted values may be high, including:

- Initial Loss for *Dense Vegetation*, *Grassland* and *Cropland Annual*; and
- Roughness coefficient for *Dense Vegetation* and *Grassland.*

It was however, not part of the scope of work to review the in-built modelled hydrology, as it had been derived as part of the peer-reviewed Region-wide Modelling project (by Beca). Additionally, we note that the adopted values were found to be a good match to SCS and NIWA estimates across this catchment.

Table 3-1 Design Model Parameters (as per the Region-wide model, 2021)

Hydrological areas	Land use types	Manning's n	Initial loss (IL) – mm	Continuing loss (CL) – mm/hr
Entire M10 catchment	Forest	0.18	42	1.5
	Grassland	0.15	42	1.5
	Cropland – perennial	0.06	20	1
	Cropland – annual	0.06	20	1
	Wetland – open water	0.04	0	0
	Wetland – vegetated	0.05	10	1
	Urban areas	0.10	5	1.5
	Waterways	0.08	0	0
	Other	0.06	15	1.5

3.3 Sub-Grid Sampling (SGS)

Sub-grid sampling is a method that allows 2D hydraulic models to utilise high-resolution digital elevation models (DEMs) even when the model grid cell size is much larger than the DEM cell size. It enables the model to more accurately represent the topography of the area being modelled, including storage and conveyance in the system, without the need for smaller grid cell sizes which can be computationally demanding and increase model simulation time significantly. This approach allows for faster processing times and the ability to use hydraulic models in near real-time for flood emergency planning.

For the purpose of this study, the hydraulic model has been simulated with a grid cell size of 6 m and a SGS sample cell size of 2 m. This sample distance was selected based on memory requirement, and, crucially, to provide a suitable representation of the conveyance capacity of channels and drains.

3.4 Inflow Boundary

In addition to rainfall applied across the catchment, a direct inflow also enters the model in the Wairoa River, near Tokatoka. Initial iterations of the model applied a constant flow here, based on an average of flow measured upstream at Dargaville.

This region of the Wairoa River is tidally dominated and is better represented using a dynamic boundary. Further, the model begins downstream of the confluence with the Kaihu River, where the Dargaville streamflow gauge is upstream of this junction. Observations from this gauge can therefore not be directly applied without scaling to account for the influence of the Kaihu.

The previous DHI MIKE model however includes the Kaihu River catchment, as well as observed flows along the Wairoa River. It also extends down to the Kaipara harbour past the commencement of the Kaipara model. This model was thus interrogated to extract river flows in various tidal scenarios, for application into the TUFLOW model as an upstream boundary. These flows are shown on Figure 3-2 alongside DHI's present-day Mean High Water Spring (MHWS) tidal boundary at Pouto Point for reference. This MHWS level was derived by NIWA and represents a $MHWS_{10}$, i.e. a tide level exceeded 10% of the time. As discussed in the following section, DHI ran scenarios with higher sea-level conditions (+60cm and +120cm respectively), these are also shown in the figure below. Flows from these models as well as those with different tailwater conditions were extracted at Tokatoka and applied to the hydraulic model.

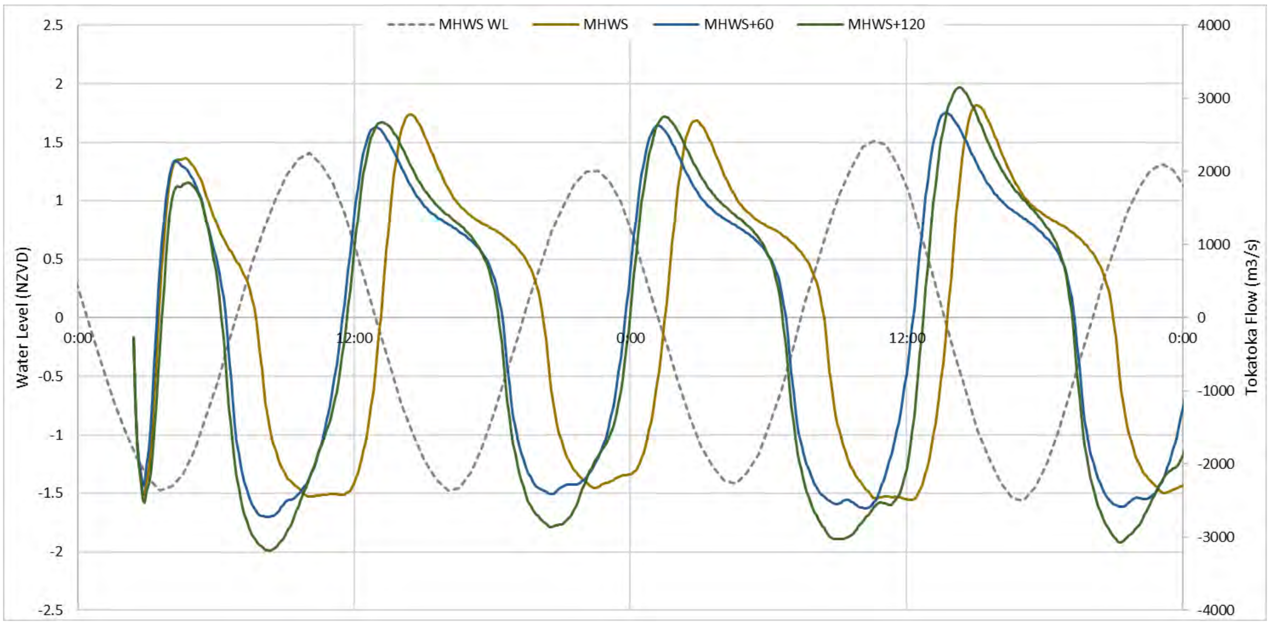

Figure 3-2 Extracted Wairoa River discharge at Tokatoka from DHI MIKE model

3.5 Tailwater Boundaries

As Raupo and much of the irrigation district are vulnerable to inundation from the Wairoa River, the representation of the tidal boundary was also determined dynamically, rather than assumed as a static peak.

Tonkin and Taylor (2016) developed coastal flood hazard tidal boundaries for the Kaipara harbour for various scenarios. These were built upon in the eCoast work, and used by DHI and others in recent modelling.

Agreed tailwater boundaries were supplied by NRC from the DHI modelling. The Coastal Hazard scenarios are comprised of both Storm Surge and Sea Level Rise, as summarised in Table 3-2.

Table 3-2 Coastal Flood Hazard scenarios from DHI

Scenario Label	Includes	Plus	Wave setup (m)	Sea Level Rise (m)
CFHZ0	MHWS	1% AEP Surge	0.18	-
CFHZ1	MHWS	2% AEP Surge	0.10	0.60
CFHZ2	MHWS	1% AEP Surge	0.20	1.20
CFHZ3	MHWS	1% AEP Surge	0.20	1.50*
MHWS	MHWS	-	-	-
MHWS+0.6	MHWS	-	-	0.60
MHWS+1.2	MHWS	-	-	1.20

*This was increased to 1.66 m for this modelling. Other values were retained from the DHI study.

An extract of each of these scenarios is plotted in Figure 3-3. Hydrographs were adjusted to account for the tidal travel time between the gauge location and the model boundary.

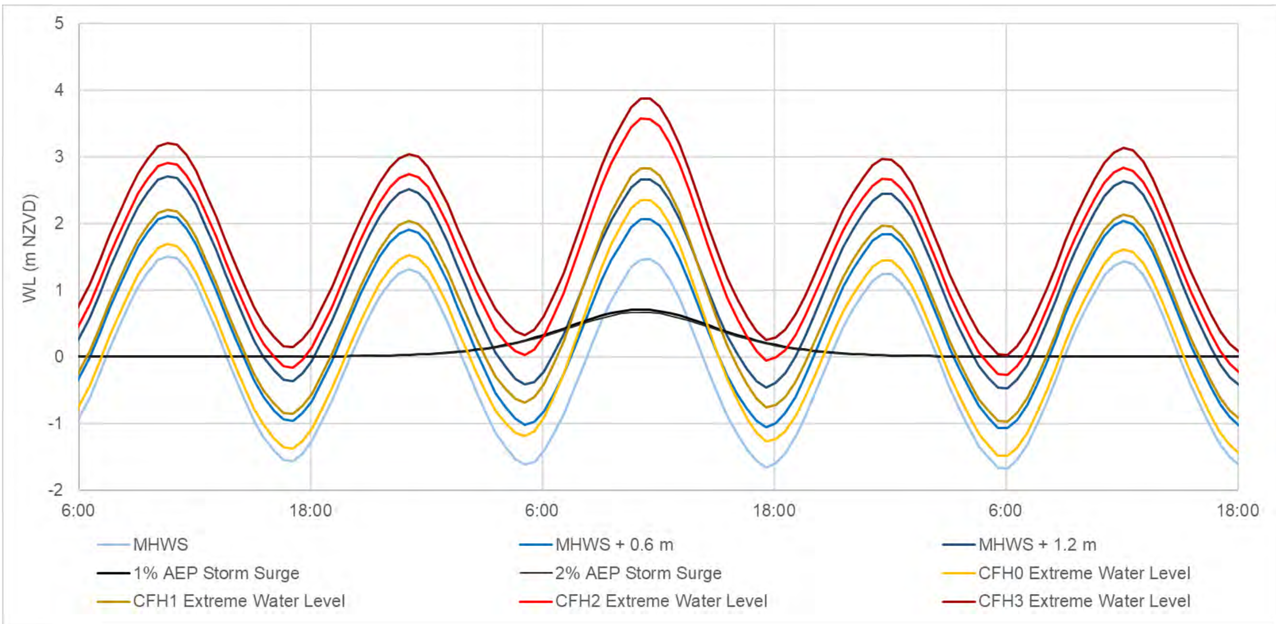

Figure 3-3 Extract of tailwater boundary scenarios at Pouto Point

3.6 Hydraulic Structures

Bridges and culverts were included as 1D structures in the hydraulic model. The representation in 1D assumes that the flow is primarily in one direction and the water level is relatively uniform across the structure's width.

The structure data for the hydraulic model was based on a combination of sources, including the stormwater network GIS database and survey provided by Northland Regional Council and Kaipara District Council. The inclusion of the hydraulic structures in the model allows for a more accurate representation of the hydrodynamic processes in the catchment area during a flood event. The model can simulate the effect of these structures on the flow and water level and can help to identify any potential bottlenecks or areas of high flood risk in the catchment area.

A total of 201 culverts and 73 floodgates were included within the model domain, with 149 culverts and 50 floodgates surveyed and the remainder assumed or confirmed by site visit. Culverts of unknown size were assumed based on known assets up- or down-stream, or typical sizes for the area. Numerous bridge structures and larger crossings were removed from the DEM by editing the topography. The contraction of the waterway cross-section is maintained where the opening was known or visible in the DEM. This allows flow through the model but does assume these large structures are not blocked in a flood event. Included hydraulic structures are presented in Figure 3-4, with assumed structures labelled as unverified.

TUFLOW files showing exact location of modelled structures have been provided to NRC and could be provided, upon request.

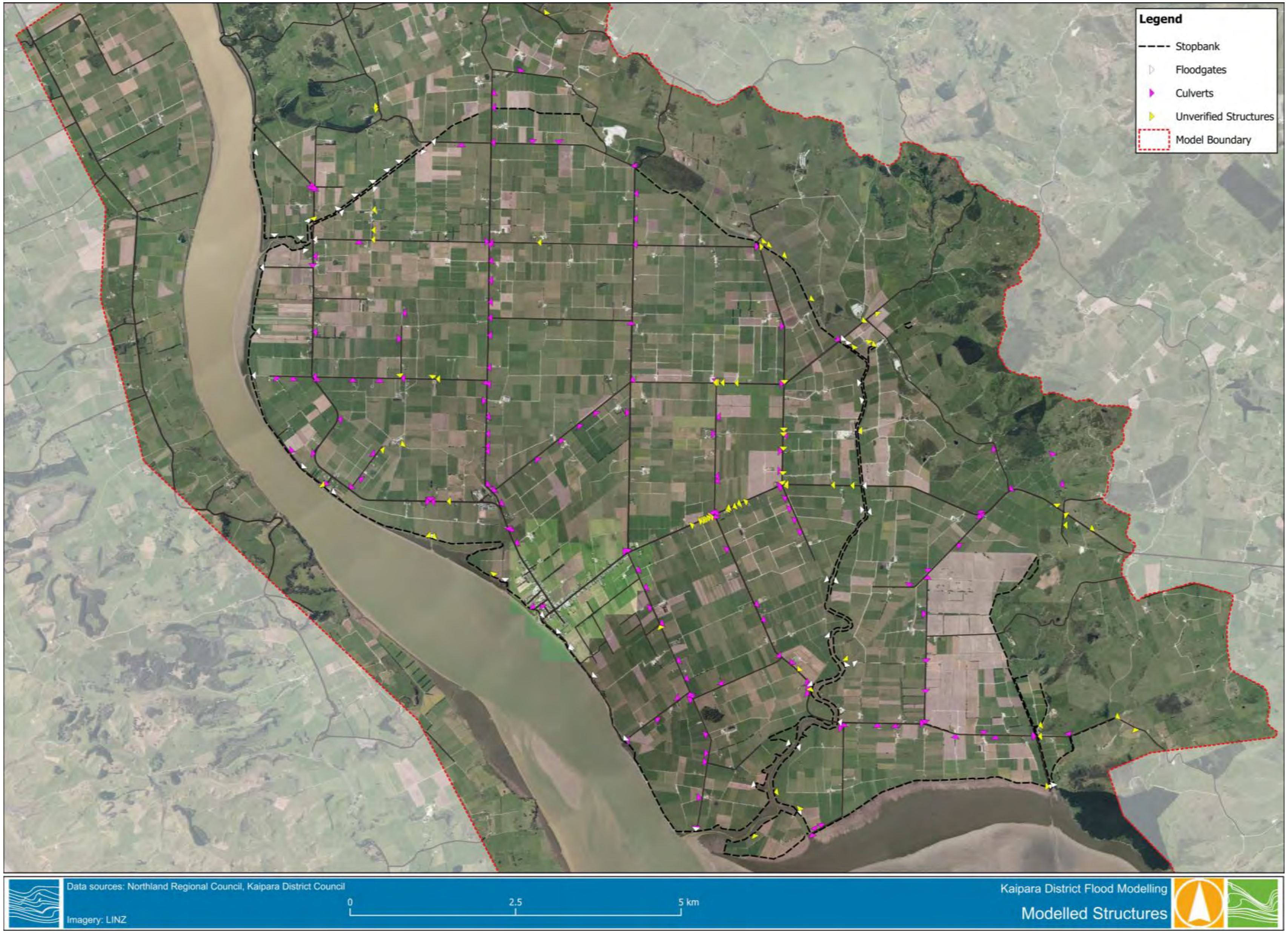

Figure 3-4 Modelled Hydraulic Structures

3.7 Floodplain Hydraulic Roughness and Rainfall Losses

Hydraulic roughness is an important parameter in the TUFLOW model, as it represents the resistance to flow that is caused by the surface features of the land, such as vegetation, buildings, and other human-made structures. The value of the roughness coefficient can affect flow behaviour and water levels in the model, and thus, must be accurately represented.

The hydraulic roughness for the TUFLOW model was based on high-resolution imagery and land use information, as well as available GIS datasets. Imagery can be used to identify and map different land cover classes, such as buildings, roads, and vegetation, in the catchment area. By using high-resolution imagery, it is possible to obtain a detailed representation of the hydraulic roughness for the TUFLOW model domain. This allows the simulation of water flow more accurately and generally produces more accurate water levels and flood extents.

It's important to note that the roughness coefficient is not constant and can change over time due to natural and anthropogenic factors, such as changes in land use, urbanisation, and vegetation patterns. Floodplain roughness for the TUFLOW model has been prepared based on a Manning's 'n' Roughness. Table 3-3 provides a summary of the floodplain roughness values and rainfall loss values for the land use types adopted and applied for this study. Loss values for the study area were developed as part of the Northland Regional Council 2021 Regional Flood Modelling Study. A map of these zones is presented in Figure 3-5.

Table 3-3 Floodplain Hydraulic Roughness and Rainfall Losses

Land Use Type	Material ID	Hydraulic Roughness (Manning's 'n')	Initial Loss (mm)	Continuing Loss (mm/hour)
Dense Vegetation	71	0.18	42	1.5
Grassland	74	0.15	42	1.5
Cropland Annual	78	0.06	20	1.0
Open Water and waterways	79	0.04	0	0.0
Vegetated wetland	80	0.05	10	1.0
Urban Areas	81	0.10	5	1.5
Rock and gravels	82	0.06	15	1.5
Roads – Unsealed	84	0.04	5	1.0
Roads – Sealed	85	0.02	3	0.5

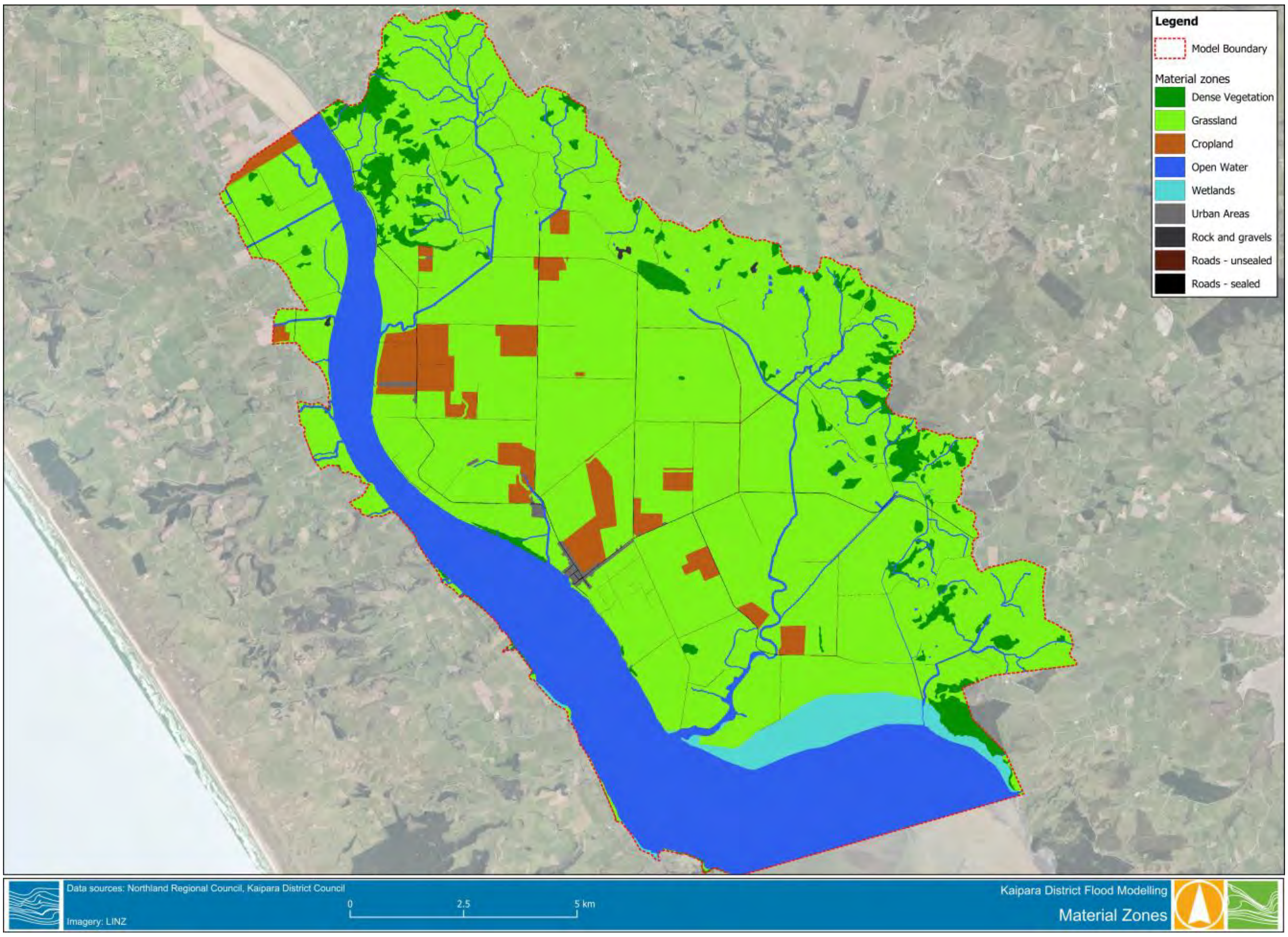

Figure 3-5 Material Zones Applied in Hydraulic Model

3.8 Hydraulic Model Validation

Material roughness and loss values were calibrated as part of the 2021 Regional Flood Modelling Study. These values produced good fits at streamflow gauges in neighbouring catchments and were considered suitable to retain for this study. The lack of any streamflow gauges within the model area precludes further calibration.

It is important to note that the model was developed collaboratively with Iain Beattie, chairman of the Raupo Drainage Board. involved regularly meetings and liaison, part of which was to gauge Iain Beattie's opinion on the veracity of the model results. Iain Beattie also liaised with other local residents, to validate model outputs against the wider community experience.

During the study, a storm event occurred in the catchment approximating a 10% AEP. Inundation in and around Ruawai was observed to closely match modelled extents, as advised by Iain Beattie.

Several iterations were necessary to obtain Iain Beattie's approval. Further ground-truthing and capture of peak flood levels during a future flood event is recommended to further refine model parameters.

4 DESIGN EVENT MODELLING

4.1 Overview

Following the updates to the hydraulic model discussed above, design scenarios were simulated in agreement with NRC. These included catchment based rainfall events, as well as the coastal hazard scenarios earlier discussed. Design modelling was conducted to simulate the catchment's response to overland flow from both the local catchment as well as the the Wairoa River, including the performance of the stopbanks and floodgates.

4.2 Design Event Rainfall

The hydraulic modelling methodology for this study involves simulating the flow of water in the catchment based on design rainfall data. This process involves applying rainfall depths onto each active grid cell across the modelling domain (the catchment). The water inundation and flow direction in the model are then determined based on the model topography and floodplain hydraulic roughness, among other minor model variables.

The rainfall depths applied to the model have been sourced from Intensity-Frequency-Duration (IFD) curves produced in alignment with data received from nearby rainfall gauges. IFD curves are statistical relationships that describe the relationship between the rainfall intensity, duration, and frequency for a specific location.

HIRDS v4 publishes design rainfalls and intensities for numerous rainfall gauges, allowing rainfall to be applied as a grid across the domain.

Gauges used included Ruawai (A64101) and Awaroa (641010) within the model domain, and Ruawai Claren Brae (A64112), Arapohue (A63091), Pouto RAWS (O00902) and Pukehau (A64224) from outside the domain, informing rainfall across the periphery of the model. As an example, design rainfall depths at Ruawai (A64101) (the most dominant gauge for the model area) are provided in Table 4-1. Other gauges are typically within ±10% of these values. 12 hour, 1% AEP gridded totals are shown alongside the gauge locations in Figure 4-1.

Table 4-1 Rainfall Depth at Ruawai (Gauge A64101)

AEP \ Duration	1 hr	6 hr	12 hr	24 hr
20%	27.3	59.7	78.3	100.0
10%	32.1	70.2	92.2	117.8
2%	43.4	95.4	124.8	160.3
1%	48.4	106.2	140.4	179.0
1% Climate Change (2081-2100 RCP 8.5)	65.4	138.0	176.4	218.9

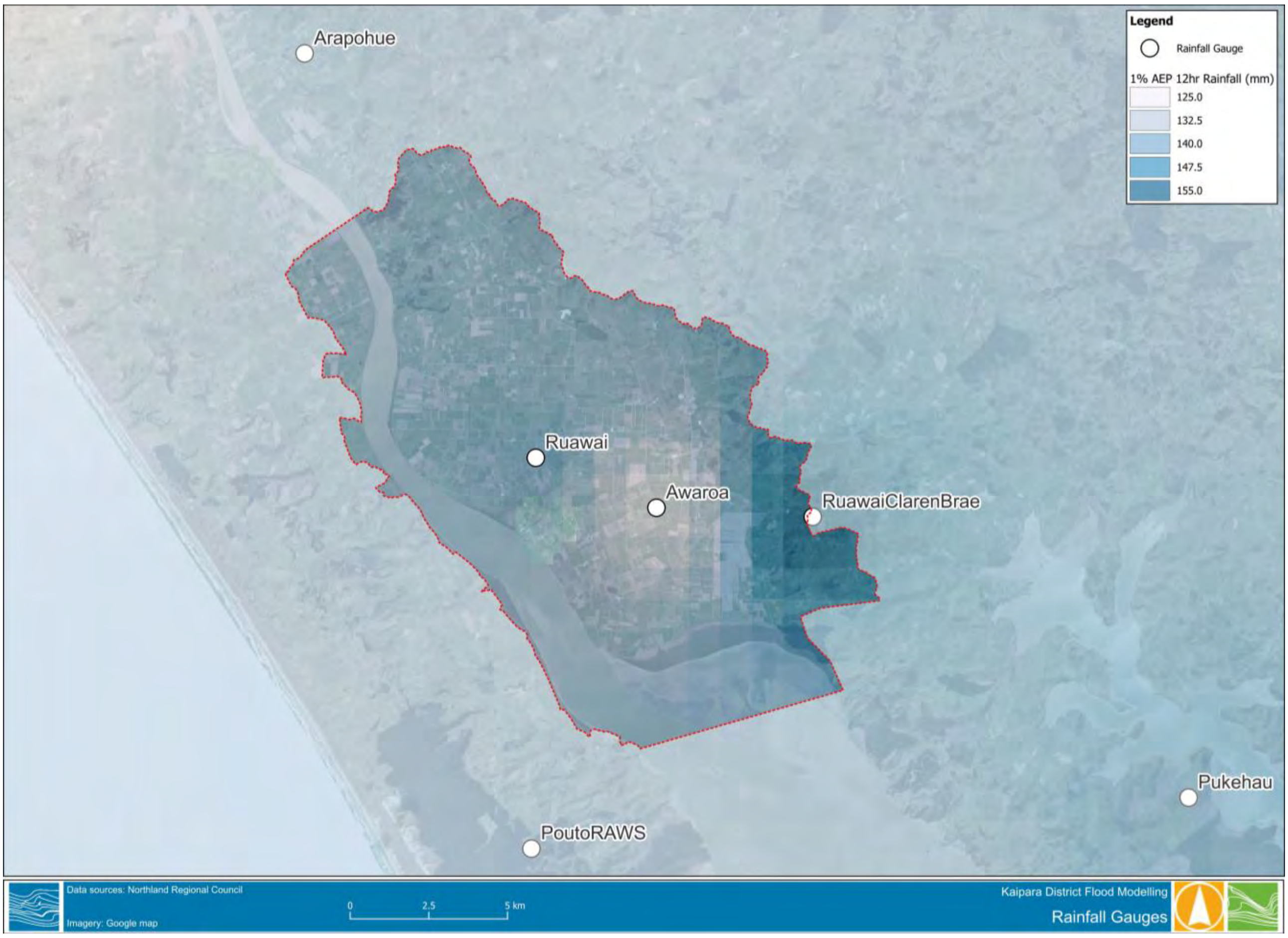

Figure 4-1 Gridded rainfall (1% AEP 12 hr) and gauges applied to the model

4.3 Hydraulic Simulations and Scenarios

The hydraulic model was simulated for each of the design event and storm duration combinations as indicated in Table 4-2 below.

Table 4-2 Hydraulically Assessed Design Event and Duration Combinations

Design Rainfall Event	Tidal Boundary	Storm Duration			
		1-Hour	6-Hour	12-Hour	24-Hour
20% AEP	MHWS	✓	✓	✓	✓
10% AEP	MHWS	✓	✓	✓	✓
2% AEP	MHWS	✓	✓	✓	✓
1% AEP	MHWS	✓	✓	✓	✓
1% AEP + Climate Change (2081-2100 RCP 8.5)	MHWS	✓	✓	✓	✓
	MHWS + 0.6 m	✓	✓	✓	✓
	MHWS + 1.2 m	✓	✓	✓	✓

Additionally, the scenarios in Table 4-3 were also simulated without any direct rainfall. These can be used to investigate the impact of the tidal boundary alone, as well as Sea Level Rise implications outside of any runoff from the catchment.

Table 4-3 Additional Modelled Scenarios (no storm applied)

Scenario	Tidal Boundary
MHWS	MHWS
MHWS + 0.6 m	MHWS + 0.6 m
MHWS + 1.2 m	MHWS + 1.2 m
CFHZ0	1% AEP Surge
CFHZ1	2% AEP Surge + 0.6 m
CFHZ2	1% AEP Surge + 1.2 m
CFHZ3	1% AEP Surge + 1.66 m

4.4 Post-Processing

Post-processing of the hydraulic model results is an important step in the analysis of flood simulations, as it allows to quantify various parameters such as water depths, water levels, velocities, and flood hazards. In this study, the post-processing procedure adopted to prepare the final grid output is as follows:

- For each AEP event, the maximum water level at each grid cell was calculated across the four durations modelled. This is used to identify the worst-case scenario of flood occurrence for each AEP.
- These results were then resampled to a higher resolution (‘remapped’) by subtracting the underlying DEM from the modelled water surface. As the raw model outputs are exported at 6 m grid cell resolution, they were resampled over a 2 m resolution DEM. Importantly, this 2 m resolution DEM was used by the model in the calculations.
- Puddles less than 100 m² and depths less than 0.10 m were filtered out of the direct rainfall results. All outputs (depth, velocity, water level and flood hazard) were then clipped to these final results for each AEP. This is a vital step for Rain on Grid results, as water can pool in small dips and drains across the topography within the model and remain unconnected to the ‘real’ flood extent. As rainfall is applied to every cell across the model, ridgelines and highpoints can show a small depth of water when maximum depths are plotted.

Post-processing was undertaken in GIS software (ArcGIS and QGIS) using the ensemble of results from the TUFLOW modelling.

The procedure of analysing multiple storm durations is key as it allows the consideration of the variability of flooding and to identify the maximum possible flood extent and its potential impact on the area of study. Due to the size of the catchment, some areas are more ‘critical’ under shorter durations (e.g. the upper catchment) compared to the lower areas nearer the drain outlets into the Wairoa River where the critical duration (peak flood levels) is much longer. Due to this effect, the presented results do not portray an extent that is likely to occur in one moment in time, rather it is the statistical depth at each cell in such an event.

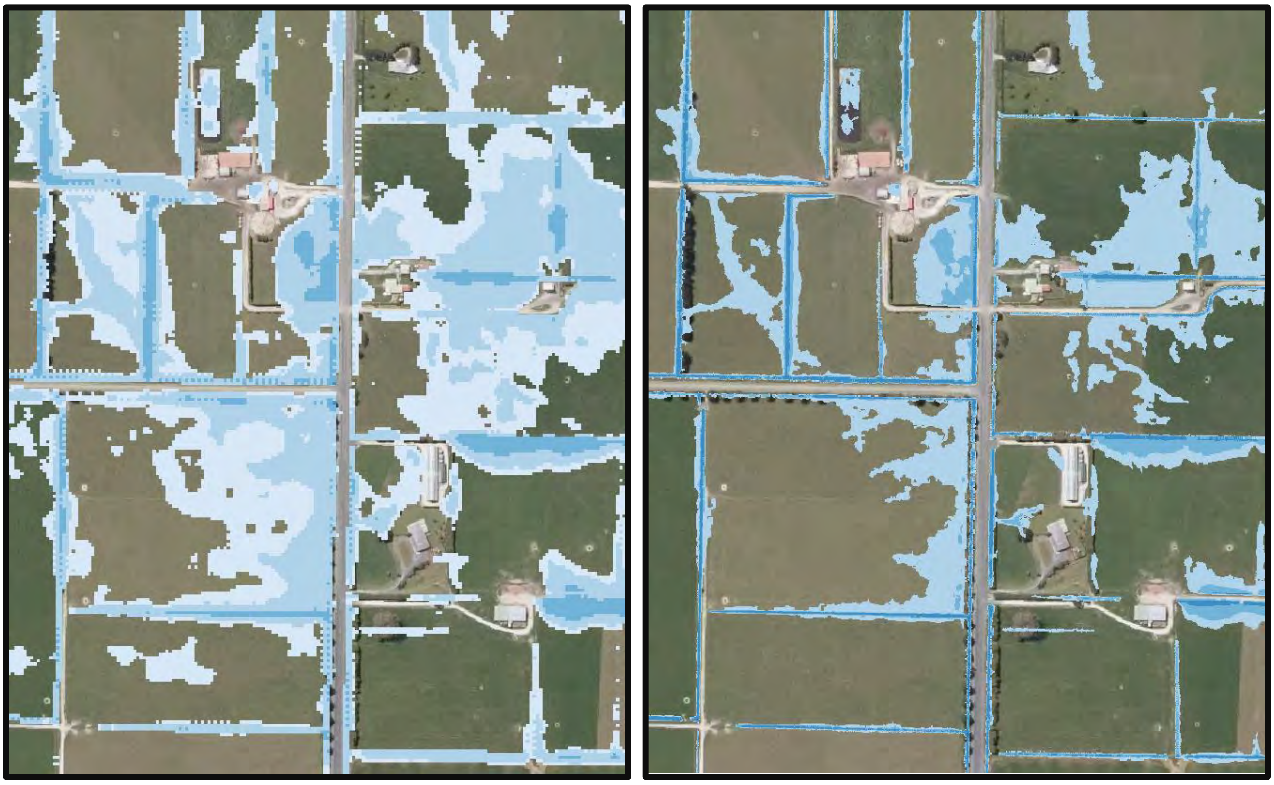

Figure 4-2 Comparison of raw (left) and filtered/processed (right) 10% AEP depth extent

4.5 Sensitivity Analysis

4.5.1 Sea Level Rise

Sea level rise is one of the main drivers of coastal flooding and erosion in the study area, and it is projected to continue to increase in the future due to changing climate conditions. Given this, it is crucial to evaluate various sea level rise projections to gain a more comprehensive understanding of the potential impacts on the township. This study has considered three separate sea level rise scenarios, being; 0.6m, 1.2m, and 1.66m. Each of these provides insight into the regions vulnerability to coastal inundation over time and under different sea level rise scenarios. The outcomes of this sensitivity analysis will be used to determine the overarching effects of sea level rise on the Raupo region and subsequently inform the coastal hazard mitigation options assessment.

4.5.2 Boundaries

Variations of the model were run with static, rather than dynamic, tailwater boundaries. These were set to the peak of the tidal event (e.g. MHWS). Similarly, scenarios were run with constant river inflow, or an event based inflow (e.g. the 1% AEP river flow).

These were shown to have little impact behind the stopbanks. Some differences were noted, particularly around the ability of the floodgates to operate under the constant high tailwater conditions. In typical conditions, these structures drain during the low tide, and close up in the high tide. With a static boundary or high Wairoa River inflow, they remain closed for the duration of the simulation. This sensitivity analysis can be quite useful, e.g. to show the impacts of a storm at a high-tide coinciding with a large rainfall storm event in the local catchment.

4.6 Hydraulic Modelling Peer Review

Throughout the model development, Iain Beattie – Chair of the Raupo Drainage Board – provided on-ground local knowledge to ensure the model flood outputs reflected what was experienced on the ground. This iterative process ensured that there was a level of confidence in the model results. Additionally, the model was peer-reviewed by Hugh MacMurray, to ensure it was technically sound and fit-for-purpose.

4.6.1 Peer Review

The TUFLOW hydraulic model was peer reviewed by Barnett and MacMurray Ltd (BM), an organisation specialising in river, stormwater, and coastal hydraulics. The peer review process involved a comprehensive review of Water Technology's hydraulic model at various stages throughout the project timeline, including prior to the delivery of this final report. Main modelling items refined as a result of the peer review included:

- Culverts were modified to reduce localised instabilities
- Adjustment to how the Wairoa River was modelled:
  - Bathymetry from the DHI model was incorporated into the model, and adjusted near floodgates;
  - Roughness values of the Wairoa River were adjusted;
  - Upstream boundary conditions were changed to match flows at Tokatoka from the DHI study

Additional details are provided in Appendix A.

Hugh MacMurray closed out his comments on 1 February 2023, which suggests the model is now fit-for-purpose.

5 SUMMARY OF RESULTS

5.1 Overview

For each scenario modelled, maximum depth, velocity, water elevation and flood hazard outputs were mapped. These are presented in Appendix B. As an example, a peak depth plot is presented in Figure 5-1 for the coastal flood hazard scenario CFHZ1.

Flood Depth results were also uploaded to an ArcGIS Online web portal for stakeholder comment. This featured a 'swipe' tool to compare any two different result datasets from the suite of simulations.

Flood hazard was determined as a function of depth and velocity at any one point. This can be further classified with peak depth and velocity into hazardous zones as shown in Table 5-1. Peak hazard (as D*V) is presented for CFHZ1 in Figure 5-2.

Table 5-1 Typical Flood Hazard Classification

Class	Depth x Velocity
Low	≤ 0.2
Low to Moderate	0.2 – 0.4
Moderate	0.4 – 0.6
Moderate to High	0.6 – 0.84
High	> 0.84

Figure 5-1 Peak Flood Depth – CFHZ1

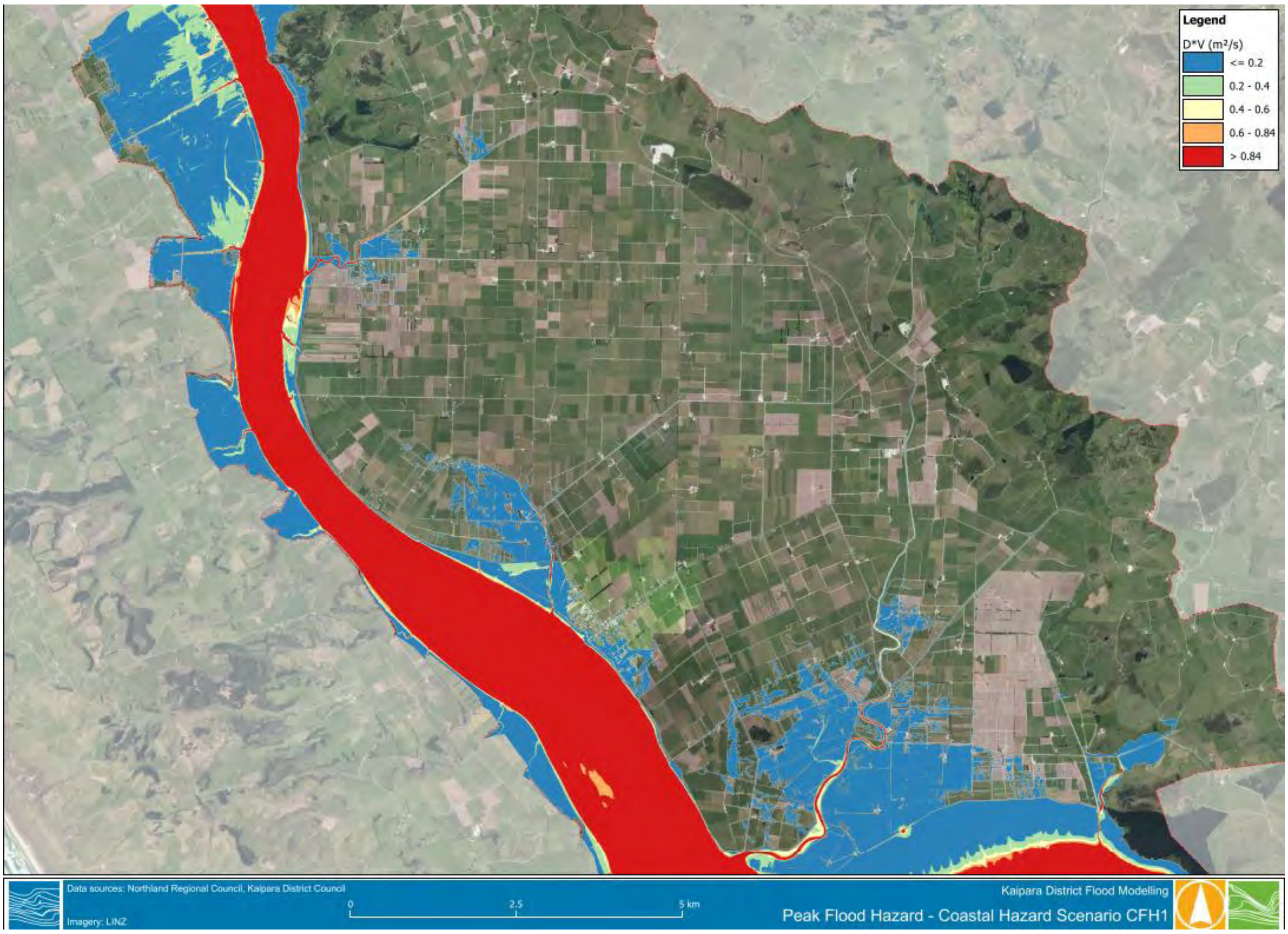

Figure 5-2 Peak Flood Hazard – CFHZ1

6 HYDRAULIC MODELLING AND OTHER STUDY LIMITATIONS

The Raupo coastal hazard impact analysis study represents the most comprehensive hydrologic and hydraulic modelling assessment undertaken for the catchment to date. Within this context, due regard should be given to the limitations and constraints involved in the derivation of model outputs. Future users of the information developed during this flood study need to consider the limitations of the modelling to correctly interpret the outcomes and outputs from this study. The following points summarise the main limitations and uncertainties associated with this study include:

- LiDAR is a remote sensing technology that uses laser pulses to measure the distance between the sensor and the ground surface. LiDAR is commonly used to create high-resolution digital elevation models (DEMs), which are used as inputs for hydrologic and hydraulic modelling. However, LiDAR has some limitations that need to be considered when using it for flood studies. One of these limitations is that LiDAR cannot penetrate dense vegetation or water, which means that the elevations of areas covered by these features may not be accurately represented in the LiDAR-derived DEM.

  Therefore, inaccuracies in the LiDAR-derived DEM can affect the accuracy of the hydraulic model results especially when focusing on in-channel flows. There are errors in LiDAR accuracy which should be considered assessing design flood levels and design planning levels. Furthermore, if these areas are not accurately represented in the LiDAR topography, it can affect the assessment of flood risk, flood extents, and flood depths in the study area. It is important to be aware of these limitations when interpreting the outcomes and outputs of the flood study.

- When simulating flood scenarios using a hydraulic model, it is important to consider how different factors can impact the accuracy of the results. One of these factors is the potential for blockages at hydraulic structures, such as bridges, culverts, and dams. This can affect the flow and behaviour of water in a flood event. The hydraulic model used in this study assumes that hydraulic structures within the study area were included as 1D structures and no blockages will occur. This assumption may lead to an underestimation of the potential flood hazards in areas upstream of where blockages are likely to occur, especially if there are limited or no provisions for these events in the area. It is noted that the flat landscape with many fences reduce the likelihood of blockages in the irrigation district culverts. Major road culverts and floodgates could become blocked by debris in large events and should be monitored.

- The hydraulic model used in this study has been developed using industry standard input parameter values and techniques, and has been validated at adjacent catchments using observed flood data. While this aims to minimise uncertainties in the model, it is important to note that uncertainties may still exist. The potential sources of uncertainty include the accuracy of the parameter values, the choice of discretization scheme, and the assumptions made about the physical processes taking place. These uncertainties can affect the results of the model, which could lead to over or underestimating of the flood hazard. It is therefore important to keep these limitations in mind when interpreting and using the model results.

- It is important to understand that the models and results are based on the best available data at the time of the study and represent a snapshot in time. Therefore, it is important to revisit or rework the study if significant changes occur in the catchment area that may affect the outcomes of the study. Some examples of such changes could include impacts to topography as the result of major flood events, changes in design rainfalls estimates, increased certainty on the effects of climate change, advancements in modelling techniques, and large-scale infrastructure developments such as dams or levees.

APPENDIX A
MODEL PEER REVIEW

APPENDIX A
MODEL PEER REVIEW

Bertrand F. Salmi

From: Hugh MacMurray <hugh.macmurray@riversandfloods.co.nz>
Sent: Tuesday, 24 January 2023 5:19 PM
To: Bertrand F. Salmi
Cc: Vicki Henderson
Subject: Raupo review

Caution: External Email.

Hi Berti,
I've had a look at the new model version and results.
I'm happy to close out my comments on the model build and the results that I've seen.
There remains a review of the report on the study.
Do you want something formal from me now, or can I leave it until after I see the report?
Cheers,
Hugh

Hugh MacMurray CPEng
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Upper Moutere 7144
69 Russell Street
Nelson 7010
Tel 07 855 9659
Mob 021 136 9487
hugh.macmurray@riversandfloods.co.nz

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Phone +64-7-855-9659
Email info@riversandfloods.co.nz

Your ref:
Our ref: BM1-555
20 July 2022

Water Technology
15 Business Park Drive
Notting Hill
Victoria
Australia 3168

Attention: Bertrand Salmi

Dear Bertrand,

<u>Peer review of Raupo catchment modelling – Stage 1</u>

The purpose of this letter is to provide the first stage of the Raupo Drainage Scheme Hydraulic Model Review. The comments provided are based on Tuflow model files provided in June 2022. Further stages of the review will be carried out as set out in the agreement covering our services signed in October 2021.

The review record attached to this letter uses the following system for category of comments and status with regard to resolution.

Category level	Status level
C1: Critical Issue (to be resolved	S1: resolve before proceeding with next stage of work
C2: Important Issue (request change)	S2: Update during next stage of work
C3: Discussion Item (potential change needed)	S3: Consider during next stage of work
C4: Note (for consideration – no change needed)	S4: Closed

We look forward to your responses and to resolving the matters raised.

Regards,

Hugh MacMurray
Barnett & MacMurray Ltd

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Review Record

Review Revisions:
A 28 June 2022

Item	Rev	Reference	Review comment	Category	Water Technology response	Status
1	A	2d_zsh_Kaipara_Banks_06_R	I can't see any objects in the model area. Where are they?	C3		S3
2	A	2d_zsh_Kaipara_Banks_03_L&P	Spot check on one element. The bank at about 1699650, 5997740 has only one point snapped to the line. Looking in DEM_Z_flt, it's not clear that the whole line is set to the level specified in the _P file.	C3		S3
3	A	Kaipara_01.tmf	Manning n for grassland seems high, that for cropland seems low. Initial losses seem high.	C3		S3
4	A	Kaipara_100yr_6h_MHWS_TS_v06B_DEM_Z.flt	Bed level in the Northern Wairoa river seems to be -1.58m nearly everywhere. How was that selected? I suspect it is not realistic, because a typical low tide at Dargaville is about -1.5m OTP.	C2		S2
5	A	M18_100yr_6h_output.csv	How was the Northern Wairoa River flow determined? And how does 650m3/s compare	C3		S3

			with a frequency analysis if available (at Tangiteroria perhaps)?			
6	A	2d_mat_M10_R	Most of Northern Wairoa River has n=0.08 and the lower reach has n=0.15. That can't be realistic.	C1		S1
7	A	2d_bc_Kaipara_01	A tide level is specified at the downstream boundary, and a discharge near Tokatoka. The discharge boundary condition together with the very high Manning n and the (I suspect) rather high river bed, mean that the tidal water level variation along the river is quite unrealistic. A typical low tide at Dargaville is -1.5m (OTP, I don't know how that relates to NZVD in this area, but can be found on the LINZ website). Mulgor Consulting did a sea level analysis at Dargaville and found that the average mean sea level anomaly for July (when it was greatest) was about 0.07m, with the range of mean sea level anomaly for July -0.2 to 0.25. Mulgor commented that the sea level anomaly at Dargaville is probably river flow related. But it is clearly not so great as to dominate the tidal signal. To put it crudely, there is nearly always a tidal water level variation and reversing flow at Dargaville (and that is even true well up the Kaihu valley). Although I have not modelled it, I think the Northern Wairoa in the reach of interest is estuarine in character, and tidal flows nearly always dominate river flows. I think to do the job properly there should be a long reach of	C1		S1

			the river included in the model, say up to Tangiteroria, with some allowance made for the tidal prism of major tributaries like the Kaihu and the Manganui. Alternatively you could just assume that the tidal water level variation is the same all the way up to Tokatoka and neglect any influence of the Northern Wairoa river flow. That would be more realistic than the current model.			
8	A	Kaipara_100yr_6h_MHWS_TS_v06B.xmdf	The water level at in the Northern Wairoa at Tokatoka rises steadily to about 2m. The Northern Wairoa river inflow according to M18_100yr_6h_output.csv peaks at about 650m3/s. My guess is that would be nowhere near enough flow to wash out the tidal signal. This means that the water levels on the river side of the floodgates are not realistic (see also notes above about Manning n and river bed bathymetry).	C1		S1
9	A	1d_nwk_Kaipara_Culverts_06_L	Some culverts specified in this file don't appear in the 1d results. Kaipara_010yr_6h_MHWS_TS_v06B.tpc. For example Surv_109. Ignore is set to True in the file for quite a few culverts. Why was that done?	C3		S3
10	A	Kaipara_010yr_6h_MHWS_TS_v06B.tpc	Quite a few culvert flows are unstable, and the amount of flow is significant and could affect the overall accuracy of the simulation.	C2		S2
11	A	1d_nwk_Kaipara_assumed_01_L	The nodes linking these culverts to the 2d domain are in 1d_nwk_Kaipara_Culverts_06_P. Not wrong but confusing.	C4		S3

12	A	1d_nwk_Kaipara_assumed_01_L	Quite a few of the unstable culverts are in this file. In many cases the unstable culverts do not have inlet and outlet loss values assigned (StockCross1, Naumai1, Blong1, Blong2, Greenhill1, Greenhill3). Table 5-3 in the manual does not seem to cover the case of null values in the inlet and outlet loss fields. This could be tried as a cure for the instabilities.	C2		S2

WATER TECHNOLOGY
WATER, COASTAL & ENVIRONMENTAL CONSULTANTS

APPENDIX B
MAPPED RESULTS

APPENDIX C
SURVEYED CULVERT

22010005_R01_V02

UNIQUE ID	NORTHINGS	EASTINGS	IL	TOP	
1	6008537.02	1691585.15	2.68	5.12	BOX CULVERT
	6008545.91	1691587.21	2.66	5.19	
2	6008215.40	1691170.23	1.80	3.10	
	6008208.15	1691158.63	1.80	3.09	
2B	6008213.68	1691170.37	1.79	3.05	
	6008206.53	1691158.63	1.76	3.06	
3	6008014.56	1691155.07	1.44	3.33	
	6008014.47	1691167.16	1.41	3.27	
4	6007482.44	1690707.72	1.37	1.81	
	6007494.86	1690707.84	1.19	1.56	
5	6007489.11	1691143.42	0.90	2.01	
	6007488.82	1691160.99	0.82	2.08	
6	6007475.76	1691781.92	1.58	1.91	
	6007462.76	1691781.58	1.42	1.75	
7	6007457.41	1692181.37	1.92	2.35	
	6007469.32	1692181.28	1.73	2.21	
8	6006848.88	1688479.00	0.60	0.91	
	6006842.68	1688478.81	0.58	0.86	
8.1	6006824.03	1688449.45	0.69	1.24	
	6006835.92	1688462.24	0.59	1.29	
8.2	6006822.32	1688495.96	0.83	1.45	
	6006817.25	1688495.54	0.98	1.49	
8.3	6006827.56	1688478.25	0.71	1.48	
9	6005990.79	1691117.97	0.14	1.50	
	6005990.19	1691135.39	0.01	1.98	
10	6005971.96	1691112.75	1.09	1.57	
	6005969.25	1691116.86	1.43	1.67	
11	6005968.44	1691120.58	0.89	1.52	
	6005969.50	1691135.01	0.54	1.39	
12					
	6005690.72	1691114.17	0.58	1.36	
13	6005688.38	1691128.26	0.77	1.08	
	6005682.94	1691115.48	0.70	1.16	
14	6005406.97	1691126.16	0.24	1.46	HEADWALL
	6005407.57	1691109.60	0.18	1.40	
15	6005078.95	1691117.04	0.21	0.63	
	6005078.45	1691104.22	0.14	0.60	
16	6004840.72	1691114.10	0.21	1.45	
	6004841.24	1691100.80	0.20	1.35	
17	6004577.71	1691108.10	0.19	0.83	

UNIQUE ID	NORTHINGS	EASTINGS	IL	TOP	
	6004578.32	1691095.63	0.10	0.70	
18	6004084.69	1691086.25	-0.06	0.53	
	6004084.52	1691098.75	-0.04	0.66	
19	6004086.91	1691099.32	-0.05	1.22	
20	6003900.09	1691081.75	-0.24	1.88	BOX CULVERT
	6003893.90	1691081.39	-0.25	1.80	
21	6003835.98	1691095.03	-0.17	0.40	
	6003836.44	1691080.56	-0.32	0.42	
22	6003587.32	1691076.75	0.00	0.50	
	6003587.72	1691091.45	-0.17	0.17	
23	6003334.86	1691085.89	0.09	0.50	
	6003331.29	1691071.36	-0.10	0.30	
24	6003087.52	1691067.55	-0.35	0.38	
	6003086.96	1691082.01	-0.23	0.32	
25	6002904.73	1691077.46	-0.32	0.10	
	6002904.94	1691063.58	-0.50	-0.13	
26	6002824.13	1691077.14	-0.04	0.67	
	6002823.93	1691062.22	-0.17	0.50	
27	6002725.27	1691831.30	-0.11	0.45	
	6002734.69	1691823.05	-0.31	0.25	
28	6003008.04	1692187.70	-0.33	0.19	
	6003018.27	1692179.29	-0.38	0.16	
29	6003229.51	1692467.99	-0.39	0.16	
	6003239.20	1692459.55	-0.64	0.07	
29.1	6003437.20	1692707.74	-0.63	-0.01	
	6003426.66	1692715.65	-0.53	0.14	
29.2	6003408.98	1693258.97	-0.14	0.34	
	6003408.87	1693243.31	-0.39	0.30	
29.3	6003875.65	1693256.64	-0.53	2.08	BOX CULVERT
	6003882.85	1693266.85	-0.53	2.04	
30	6002301.60	1691083.06	-0.40	0.17	
	6002288.27	1691067.66	-0.52	0.04	
31	6002209.35	1691184.91	-0.31	0.83	
	6002198.17	1691170.70	-0.38	0.59	
32	6002216.76	1691168.42	-1.11	1.99	BOX CULVERT / BRIDGE
	6002211.64	1691162.60	-1.12	1.85	
33	6002020.58	1691287.19	-0.44	0.06	
	6002014.34	1691272.99	-0.60	-0.20	
34	6002069.60	1690238.20	-0.70	1.36	BOX CULVERT / BRIDGE
	6002059.37	1690239.03	-0.72	1.35	

UNIQUE ID	NORTHINGS	EASTINGS	IL	TOP	
34.1	6002056.77	1690249.23	-0.58	0.19	
	6002057.19	1690243.33	-0.67	-0.02	
34.2	6002057.11	1690230.63	-0.66	-0.10	
	6002057.04	1690235.62	-0.82	-0.16	
34.3	6002072.17	1690229.51	-0.43	0.25	
	6002072.00	1690235.53	-0.60	0.33	
35	6001619.87	1691437.02	-0.80	0.11	
	6001607.87	1691421.32	-0.97	0.05	
36	6001613.48	1691438.79	-0.03	0.34	
	6001617.92	1691437.30	-0.05	0.36	
37	6001417.70	1691500.82	-0.80	-0.30	
	6001426.88	1691522.70	-0.84	-0.22	
38	6000519.53	1691905.10	0.76	0.99	
	6000508.87	1691912.71	0.82	1.29	
39	6000448.34	1691816.14	-0.38	0.90	
	6000442.62	1691824.53	-0.59	0.71	
40	6000343.80	1691901.51	-0.87	1.59	BOX CULVERT
	6000339.74	1691889.80	-1.20	2.72	
41	6000077.98	1692153.35	-0.63	0.09	BOX CULVERT
	6000049.56	1692128.83	-1.04	-0.24	
41.1	6000084.37	1692147.29	-0.56	-0.16	
42	5999835.89	1692328.79	-0.83	0.29	
	5999823.01	1692312.25	-0.87	0.19	
43	5999842.53	1692337.29	-0.52	0.16	
	5999837.84	1692330.88	-0.79	-0.01	
44	6007107.80	1693344.74	2.52	3.71	
	6007098.15	1693349.37	2.39	3.58	
45	6006715.28	1693321.47	1.26	1.87	
	6006713.42	1693304.88	0.96	1.47	
46	6006333.68	1693315.31	0.80	1.39	
	6006333.44	1693298.66	0.55	1.00	
47	6005950.32	1693307.77	0.68	1.75	
	6005950.91	1693289.98	0.46	1.45	
48	6004801.09	1693269.63	0.66	1.86	
	6004786.84	1693269.84	0.56	1.81	
49	6005916.13	1695212.06	1.09	1.79	
	6005916.21	1695199.26	1.02	1.98	
50	6004712.00	1695580.41	0.50	1.32	
	6004711.88	1695592.70	0.46	1.31	
51	6004487.79	1696427.08	0.20	3.25	BRIDGE

UNIQUE ID	NORTHINGS	EASTINGS	IL	TOP	
	6004493.62	1696420.13	0.11	3.31	
52	6003846.39	1694553.07	0.04	1.09	
	6003861.54	1694553.08	0.03	1.17	
53	6003843.98	1695572.63	0.43	0.64	
	6003844.38	1695588.81	0.01	1.22	
54	6003828.27	1695589.30	-0.04	1.17	
55	6003341.62	1694547.26	-0.37	0.23	
	6003341.13	1694560.72	-0.41	0.31	
56	6003084.62	1694543.61	0.28	0.64	
	6003084.64	1694557.40	-0.28	0.33	
57	6002442.18	1694542.92	0.31	0.56	
	6002441.57	1694530.66	0.04	0.55	
58	6002364.67	1694544.72	-0.57	-0.09	
	6002361.19	1694530.68	-0.46	0.04	
59	6001872.82	1694535.00	0.33	0.35	
	6001867.95	1694524.11	-0.45	0.22	
60	6001859.73	1694541.86	-0.09	0.60	
	6001873.06	1694538.53	-0.20	0.59	
61	6001854.57	1694525.73	-0.74	1.44	
	6001863.92	1694522.00	-0.98	1.47	
62	6001853.57	1694523.55	-0.84	1.43	
	6001862.89	1694519.60	-0.90	1.46	
63	6001358.42	1694744.70	-0.17	0.33	
	6001363.81	1694755.64	-0.22	0.46	
64	6003071.55	1695572.47	-0.08	0.39	
	6003071.03	1695558.66	-0.10	0.50	
65	6002822.08	1695554.95	-0.36	0.15	
	6002820.97	1695568.24	-0.38	0.15	
66	6002527.22	1695547.45	-0.23	0.20	
	6002527.38	1695562.41	-0.24	0.17	
67	6002318.33	1695546.23	-0.35	0.58	
	6002324.14	1695557.77	-0.35	0.62	
68	6002287.41	1695553.26	-0.19	0.76	
	6002292.30	1695565.43	-0.31	0.67	
69	6002133.52	1695623.76	-0.05	0.35	
	6002138.22	1695633.50	-0.07	0.15	
70	6001965.45	1695687.54	-0.48	0.09	
	6001974.31	1695708.27	-0.63	-0.05	
71	6001801.05	1695767.81	-0.18	0.35	
	6001807.38	1695780.68	-0.25	0.27	

UNIQUE ID	NORTHINGS	EASTINGS	IL	TOP	
72	6001624.57	1695861.08	-0.43	0.04	
	6001620.61	1695852.29	-0.44	0.14	
73	6001309.05	1693206.85	-0.45	0.20	
	6001309.61	1693219.93	-0.54	0.09	
74	6001294.48	1693221.21	-0.12	0.00	BOX CULVERT
	6001274.91	1693218.94	-1.34	-0.21	
75	6001005.34	1693342.51	-0.36	0.13	
	6001009.83	1693352.08	-0.41	0.06	
76	6000746.98	1693467.36	-0.70	0.24	
	6000743.02	1693458.48	-0.75	0.25	
77	6000468.60	1693580.50	-0.33	0.14	
	6000475.38	1693596.69	-0.34	-0.09	
78	6000212.91	1693705.43	-1.21	0.90	
	6000208.91	1693695.96	-1.28	0.78	
79	6000206.45	1693697.15	-1.12	0.80	
	6000210.26	1693706.68	-1.13	0.90	
80	6006020.71	1688472.25	-0.82	1.76	FLOODGATE
	6006020.84	1688456.64	-1.05	1.68	
81	6006009.98	1689161.61	-0.03	0.67	
	6006022.82	1698162.14	-0.43	0.23	
82	6005769.79	1688457.45	-0.26	0.66	
	6005769.80	1688472.68	-0.36	0.79	
83	6005599.01	1688461.72	0.34	0.75	
	6005585.76	1688462.03	0.16	0.92	
84	6004911.30	1689807.26	-0.27	1.38	
	6004911.00	1689813.31	-0.25	1.34	
85	6004623.64	1688468.64	-0.66	1.42	
	6004623.84	1688456.52	-0.74	1.34	
86	6004520.09	1689808.14	0.08	0.73	
	6004519.95	1689795.90	-0.10	0.41	
87	6003951.29	1687891.08	-0.53	-0.12	
	6003961.09	1687884.04	-0.70	-0.06	
88	6003945.85	1688162.90	-0.66	0.09	
	6003956.07	1688161.82	-0.89	-0.23	
89	6003952.57	1688463.80	-0.88	0.91	BOX CULVERT
	6003953.05	1688445.77	-1.09	0.66	
90	6003950.10	1688525.49	-0.44	0.53	
	6003937.54	1688525.26	-0.46	0.61	
91	6003937.97	1689068.60	0.38	0.52	
	6003930.17	1689068.36	0.49	0.80	
92	6003921.54	1689473.10	0.11	0.50	

UNIQUE ID	NORTHINGS	EASTINGS	IL	TOP	
	6003930.04	1689473.14	-0.03	0.42	
93	6003927.95	1689786.28	-0.80	0.50	
	6003927.54	1689798.89	-0.86	0.59	
94	6003925.66	1689798.85	-0.65	0.58	
	6003926.12	1689786.35	-0.76	0.49	
95	6003311.61	1688830.51	-1.23	-0.25	
	6003308.47	1688847.40	-1.22	-0.22	
96	6002811.97	1688115.75	0.18	0.52	
	6002805.82	1688107.24	0.33	0.71	
97	6002782.48	1688494.54	-0.03	0.56	
	6002778.89	1688511.56	-0.33	0.75	
98	6002759.10	1689403.42	-0.47	-0.20	
	6002753.83	1689409.85	-0.54	-0.28	
99	6002552.36	1688289.79	0.79	2.71	
	6002566.99	1688298.03	-1.02	-0.17	
100	6002430.65	1689157.28	-0.73	-0.41	
	6002425.13	1689164.78	-0.96	-0.51	
101	6002297.03	1688636.87	-0.49	0.21	
	6002304.06	1688641.68	-0.69	0.33	
102	6002262.17	1689026.53	-0.68	0.21	
	6002241.24	1689008.76	-0.80	0.05	
103	5999643.38	1693958.72	-0.37	0.24	
	5999638.39	1693947.24	-0.40	0.12	
104	5999368.19	1694079.95	-0.35	0.17	
	5999364.50	1694071.48	-0.39	0.02	
105	5999190.67	1694144.70	-0.44	0.26	
	5999177.30	1694150.57	-0.44	0.23	
106	5999287.66	1694659.70	-0.10	0.43	
	5999278.71	1694666.59	-0.10	0.50	
107	5999071.95	1694008.77	-0.28	0.26	
	5999076.21	1694001.22	-0.32	0.29	
108	5999086.09	1694194.60	-0.52	0.19	
	5999090.45	1694203.89	-0.30	0.31	
108.1	5999079.00	1694211.90	-0.13	0.61	
109	5998786.83	1693640.27	-0.34	0.25	
	5998793.99	1693629.40	-0.41	0.09	
110	5998460.02	1693175.29	-1.38	-0.16	
111	5998564.22	1694438.80	-0.64	-0.15	
	5998559.30	1694427.51	-0.82	-0.45	

UNIQUE ID	NORTHINGS	EASTINGS	IL	TOP	
112	5998258.64	1694449.16	-0.56	-0.01	
	5998259.30	1694437.68	-0.59	-0.18	
113	5998117.04	1694426.53	-0.55	0.59	
	5998119.27	1694416.56	-0.64	0.46	
114	5997587.06	1694330.23	-0.79	-0.44	
	5997586.22	1694340.63	-0.60	-0.19	
115	5997093.42	1694249.82	-1.29	-0.52	
	5997099.72	1694250.51	-1.36	-0.52	
116	6000494.50	1695139.36	-0.02	0.64	
	6000489.09	1695127.51	-0.27	0.12	
117	6000260.44	1695241.83	-0.19	0.49	
	6000255.62	1695231.85	-0.29	0.28	
118	5999701.14	1695545.78	-1.02	0.63	
	5999709.62	1695536.50	-1.16	0.68	
119	5999602.37	1695679.09	-0.11	0.46	
	5999592.16	1695671.19	-0.34	0.14	
120					
121	5999317.58	1695956.64	-0.67	1.35	BOX CULVERT
	5999308.21	1695977.35	-0.96	1.06	
122	5999261.23	1695976.43	0.15	0.46	
	5999256.86	1695992.78	-0.06	0.29	
123	5999152.43	1695961.57	-0.51	0.02	
	5999148.14	1695976.19	-0.61	0.04	
124	6002229.30	1698973.70	0.18	1.13	
	6002234.95	1698982.34	0.42	1.32	
125	6001867.03	1698565.46	-0.57	1.52	
	6001854.72	1698568.15	-0.61	1.41	
126	6001811.45	1698562.41	-0.07	0.41	
	6001801.43	1698573.10	-1.06	-0.67	
127	6001429.95	1698187.32	-0.22	0.49	
	6001420.98	1698197.93	-0.30	0.34	
128	6000977.21	1697753.26	0.04	0.59	
	6000993.93	1697754.70	0.06	0.58	
129	6000954.92	1697754.05	-0.52	0.14	
	6000947.37	1697753.83	-0.58	0.19	
130	6000938.97	1697731.10	-0.78	2.04	BRIDGE
131	6000771.96	1697471.24	-0.22	0.74	
	6000765.63	1697470.87	-0.22	0.73	
132	6000367.01	1697739.93	-0.78	0.42	

UNIQUE ID	NORTHINGS	EASTINGS	IL	TOP	
	6000366.59	1697727.37	-0.82	0.19	
133	5999626.44	1697729.25	0.01	0.29	
	5999620.84	1697729.21	0.11	0.36	
134	5999160.59	1697720.69	-0.09	0.80	
	5999164.66	1697720.80	-0.12	0.80	
135	5998640.80	1696468.86	-0.33	0.13	
	5998640.51	1696478.69	-0.37	0.09	
136	5998717.39	1696485.20	-0.57	0.53	
	5998730.33	1696485.35	-0.68	0.28	
137	5998705.95	1696989.01	-0.07	0.39	
138	5998701.81	1697263.48	-0.29	0.09	
	5998714.27	1697263.47	-0.47	0.06	
139	5998710.46	1697696.52	-0.46	0.81	
	5998710.26	1697709.22	-0.54	0.72	
140	5998691.90	1697711.81	-0.40	0.22	
	5998706.98	1697712.67	-0.53	0.12	
141	5998542.30	1698179.88	0.02	0.57	
	5998555.05	1698183.23	-0.30	0.27	
142	5998542.21	1698592.02	-0.22	0.10	
143	5998527.63	1698772.20	0.03	0.43	
	5998539.12	1698771.83	-0.01	0.55	
144	5998531.60	1699384.52	-0.26	0.88	FLOODGATE
	5998531.71	1699382.42	-0.33	1.29	
145	5998511.38	1699390.38	0.00	0.49	
	5998511.68	1699399.92	-0.06	0.44	
146	5998515.87	1699898.94	-0.35	2.80	
147	5997051.25	1695994.74	-0.18	0.80	
	5997061.98	1695990.76	-0.21	0.73	
148	5997083.94	1696062.57	0.06	0.40	
	5997090.31	1696058.79	0.27	0.68	
149	5997138.82	1696148.67	0.10	0.41	
	5997130.09	1696150.28	-0.15	0.26	

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