REPORT

Thames Coastal Protection Project - Feasibility Study

Fluvial Modelling Report Update

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1 Introduction

Thames Coromandel District Council (TCDC) engaged Royal HaskoningDHV (RHDHV) in 2019 to undertake a feasibility study for coastal protection measures at nine locations in the Coromandel Peninsula for TCDC's Shoreline Management Plan (SMP) (RHDHV, 2022) shown in **Figure 1-1** below.

Figure 1-1 Feasibility Study for Coastal Protection Measures in the Coromandel Peninsula (RHDHV, 2022)

One of the locations was Thames, where the proposed coastal protection measures included a combination of earth embankments and concrete T-Walls. The extent of the possible defence solutions is presented in **Figure 1-2**, with approximately 2,962 m of embankment (shown in blue and purple) and 4,200 m of concrete wall (shown in green and red). The pumping of stormwater runoff retained behind the raised sea defences was included in this solution, albeit based on fundamental hydrology and hydraulic assumptions, and the specific size and location of the proposed gates and pumps was not defined.

Figure 1-2: Thames Coastal Protection - Preliminary Concept Design (RHDHV, 2022)

From the preliminary assessment, although considered possible, it was noted that it would be very challenging from both an engineering and planning perspective to protect the Thames township against coastal inundation for a 1% AEP storm over the next 100 years as the estimated costs were expected to be significant and needed to be refined and detailed prior to any final decision making. It was recommended that a detailed study be undertaken that considers a suite of events and scenarios, includes initial geotechnical investigations, full hydrodynamic modelling, and joint probability analysis of coincident coastal and fluvial flooding events to understand the impact of coastal defences on both coastal and fluvial inundation.

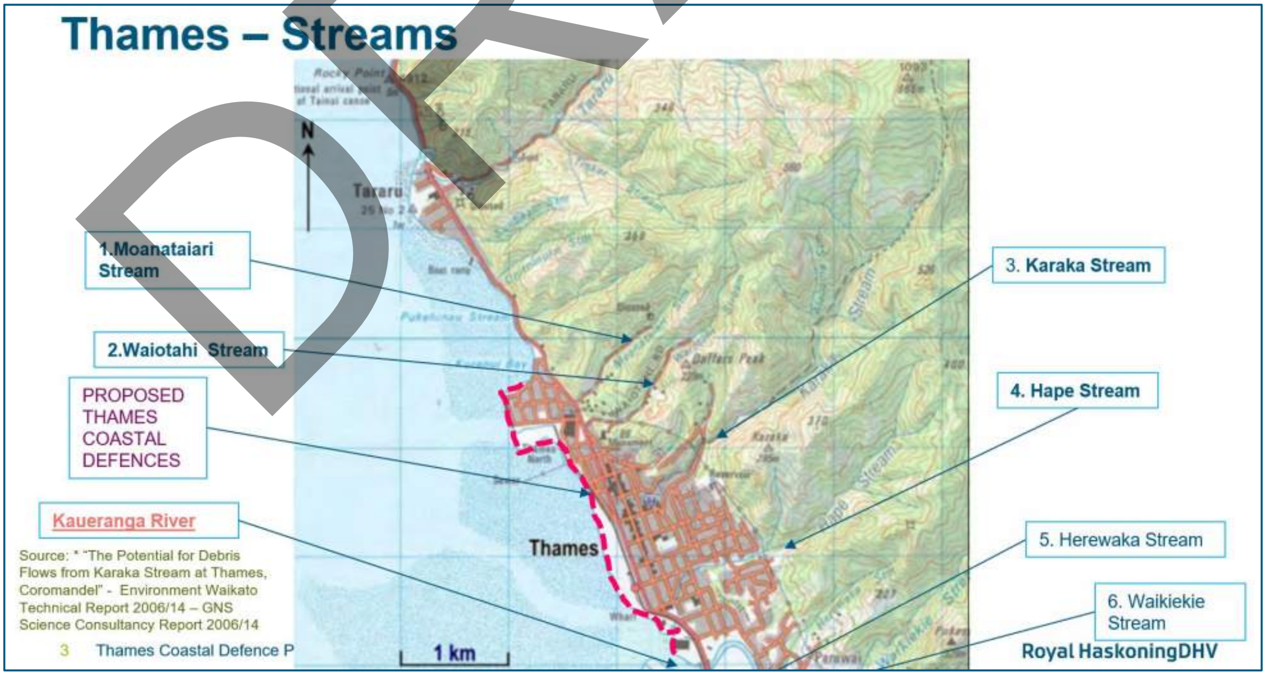
TCDC engaged RHDHV in 2023 to develop concept designs for Coastal Defence structures that give Council an achievable pathway to enhance the protection of the Thames township from flooding issues that will worsen with climate change induced sea level rise and rainfall intensity (Coastal Defence Concept Design). The purpose of the concept design was to improve the flood immunity of Thames from coastal inundation, but also to assess the potential impact of raised coastal defences on pluvial / fluvial flooding behind the defences. As part of this concept design development, it was identified that there was an opportunity to develop a more robust assessment of the hydrologic / hydraulic response of the catchments draining through the coastal floodplain in Thames, during major coastal storm events, which would enable the basis of design and costing of gate and pump infrastructure to supplement the coastal defence scheme.

A workshop held with Waikato Regional Council (WRC) in September 2023 and detailed site walk over indicated that the study (and both TCDC and WRC) would jointly benefit from more sophisticated 1D/2D hydrologic / hydraulic hydrodynamic investigations (TUFLOW modelling) to firm up the likely size and location of stormwater release gates (i.e. either penstock type or non-return gates at the end of each stormwater channel), plus the requirement for location and capacity of stormwater pump stations. Added benefits would be the production of up-to-date flood mapping for development planning, the assessment of potential flood mitigation works (culverts, channel upgrades etc) as well as the ability to provide up-to-date flood risk management mapping for Councils web portals.

As such, as part of this Study, RHDHV were engaged to:

- Develop a hydrologic and hydrodynamic (TUFLOW) model to simulate the effects of coastal and fluvial inundation;
- Calibrate/validate the model to available historic events;
- Investigate the impact of the proposed coastal defences on fluvial flooding effects; and
- Investigate mitigation options for fluvial flooding in the event of sea level rise.

A high level of sophistication was allowed for in the model build, calibration and validation to ensure that the TUFLOW model could be used for the purposes listed above (including flood mapping and flood mitigation assessment for TCDC and WRC), however, we note that the primary purpose of this study was to investigate the impact of coastal defences on coastal and fluvial inundation and investigate the feasibility of stormwater pumping.



Source: " "The Potential for Debris Flows from Karaka Stream at Thames, Coromandel" - Environment Waikato Technical Report 2006/14 – GNS Science Consultancy Report 2006/14

Figure 1-3: Streams in Thames

Through discussions with TCDC, it was decided that the area of focus for this study was within the extent marked in **Figure 1-4** below (bound by Albert Street to the north and Richmond Street to the south),flooding in this area is primarily caused by flooding in Karaka and Hape Streams.

Figure 1-4: Study Area

2 Available Data

Table 2-1 sets out the data that was available for this study.

Table 2-1: Available Data

Data	Description	Format	Source
Waikato LiDAR 2021	1m Digital Elevation Model (DEM) LiDAR of the Waikato region. Covers majority of the TUFLOW model study area (missing area of Kauaeranga River to the south of Thames). Elevation in New Zealand Vertical Datum 2016 (NZVD2016) and projection in New Zealand Geodetic Datum 2000 (NZGD2000)	GeoTIFF	LINZ Data Service (LINZ)
Waikato Thames LiDAR 2017-2019	1m DEM LiDAR of the Waikato region. Covers Thames and fills in the gap in the Waikato LiDAR 2021 near the Kauaeranga River. Elevation in NZVD2016 and projection in NZGD2000.	GeoTIFF	LINZ
Coastal Strip Drone Imagery	Drone survey of the coastal strip of Thames including a DEM with a 0.1 m resolution and aerial photography captured on 14 March 2023.	GeoTIFF	TCDC
Storm Water Network	GIS format of the stormwater network provided by TCDC (from 3 Waters database. Contains dimensions, invert levels (unreliable) and alignment of pipes as well as pits and manholes. Vertical datum is uncertain.	Shapefile	TCDC
Buildings	GIS format of building footprints in Thames.	Shapefile	TCDC
Property Boundaries	GIS format of property boundaries in Thames	Shapefile	TCDC
Stream Cross Sections	Stream Cross Sections of Hape Stream in Thames from a survey conducted in 2012. Provided data included a survey of Karaka Stream in Thames but eastings and northings for these survey points were not able to be provided. Vertical datum is uncertain.	Excel	TCDC
Hape Stream Bridge Details	Inspection reports from an inspection in 2022 of the following bridges on Hape Stream: • Mackay Street No.1 Box Culvert; • Rolleston Street Bridge; and • The Terrace Bridge. Contains photos of the bridges and notes on the condition of the crossing.	PDF	TCDC
Road Lines	GIS format of road line centrelines and names in Thames.	Shapefile	LINZ
Thames EWS Rainfall Gauge Data	Pluviograph data for two historic events at the Thames EWS: • June 2002 Event (Weather Bomb) (30 minute interval) • February 2023 Event (10 minute interval)	CSV	NIWA CliFlo Database

Data	Description	Format	Source
Pinnacles Rainfall Gauge Data	Pluviograph data for the February 2023 Event at the Pinnacles Rainfall Gauge in the Kauaeranga River catchment.	CSV	WRC
Design Rainfall Data	Design Rainfall intensities and depths for design rainfall events and climate change. Extracted from the Thames EWS rainfall gauge using NIWA's High Intensity Rainfall Design System (HIRDS) v4. Standard error added to rainfall.	CSV	NIWA
	Pluviograph data for the February 2023 Event at the Pinnacles Gauge.	CSV	WRC
Historical Flood Photos (TCDC)	Photos of historic flooding in Thames. The photos were reviewed, however, the photos were taken either in locations outside of the study area or during historic storms which were not significant enough to justify calibration / valdation of the model (this study focused on the June 2002 Event and the February 2023 Event): • Rhodes Park and Thames Rugby Club (outside of the study area – south of the Kauaeranga River) • Photos in Thames in the study area but from a storm event in January 2011)	PNG	TCDC
Historical Flood Photos (from Resident of Thames)	Photos taken from a drone after the peak of the February 2023 Event showing flooding in the vicinity of Brown St and Victoria Park. A meeting was also held with the resident who provided additional information regarding the February 2023 Event which is discussed further in **Section 4.8**.	JPG	Stuart Caisley (Owner of the Lady Bowen Airbnb)
Survey	Survey undertaken on 20 June 2024 by Coromandel Surveyors Ltd. The survey included: • Detailed ground survey of the crossings of Moanataiari, Waiotahi, Karaka and Hape Streams (stream cross section at the crossing, invert level, waterway width and height, bridge deck soffit, bridge deck thickness, railing height, and services in the vicinity); • Ocean outlets (dimensions, identification of flap gate or non-return valves, invert level, condition); and • The Richmond St Pump Station (sump height, sump size, pipe size, surrounding pits and connected pipes). Elevation in NZVD2016 and projection in NZGD2000.	DWG and PDF	Coromandel Surveyors Ltd.
Hape Stream Cross Sections	Cross sections of Hape Stream from a survey conducted in 2012.	Excel	TCDC

Data	Description	Format	Source
Tararu Tidal Gauge Data	Historical tidal data recordings from the Tararu Tidal Gauge off the coast of Thames (directly west of Fergusson Drive) for the June 2002 Event and the February 2023 Event. Elevation provided in the Tararu Vertical Datum 52 (TVD-52). Elevations in TVD-52 should be shifted down by 0.197 m when converting to NZVD2016.	CSV	WRC
Smiths Cableway Flow Gauge Data	Historical water level recordings and rated flow from the Smiths Cableway Gauge off the coast of Thames (approximately 7 km upstream of the outlet of the Kauaeranga River to the ocean) for the June 2002 Event and the February 2023 Event. The gauge records water level and (and rated flow) in the Kauaeranga River and is outside of the tidal range and thus only records flow from the Kauaeranga River catchment. Elevation provided in the Tararu Vertical Datum 52 (TVD-52). Elevations in TVD-52 should be shifted down by 0.197 m when converting to NZVD2016.	CSV	WRC
Richmond St Pump Station Information	Details of the Richmond St Pump Station including pump capacity as well as operating controls.	PDF and PNG	TCDC
Kauaeranga River Bathymetry	Bathymetry of the Kauaeranga River with resolution of 1 m. Elevation in NZVD2016 and projection in NZGD2000.	GeoTIFF	WRC
Kauaeranga River Stopbanks	Stopbanks in the vicinity of the Kauaeranga River including the northern and southern stopbanks. Other WRC asset data included (pipes and flap gates) but not used since it was outside of the study area. Elevation in NZVD2016 and projection in NZGD2000.	GeoPackage	WRC

3 Previous Studies

Table 3-1 sets out the previous studies, either in the vicinity of the study area or relevant to the study.

Table 3-1: Previous Studies

Study	Description
Coastal Protection Feasibility Study for the Coromandel Peninsula (RHDHV, 2022)	A feasibility study for coastal protection measures at nine locations in the Coromandel Peninsula for TCDC's Shoreline Management Plan (SMP). At the nine locations identified, high level designs were developed for coastal protection measures.
Albert Street, Thames, Stormwater Upgrade – Flood Mitigation (Ruari Hampton, 2011)	A study which investigated the potential for pumping stormwater ponding in the vicinity of Albert St. The study recommended replacement of flap gates, upgrading of pits and new pipeline connections as well as the installation of a pump station to pump stormwater over the sea wall into the Firth of Thames at the end of Albert St. The study noted a constraint at the site due to the western area of Albert St being significant to the local Iwi, Ngati Maru due to a Urupa (Maori buria site) in the vicinity. It should be noted that the study used the local catchment draining to Albert St and did not account for the overtopping of Karaka Stream in larger events.
Albert St Pump Operation Memo (Metis Consultants Ltd., 2024)	A memo investigating the potential for temporary (above ground) pumping stations on the western end of Albert St to mitigate ponding. The study noted that TCDC currently deploys a pump at the intersection of Albert St and Beach Rd to drain the southern side of Albert St, and recommended a preferred option of an additional pump on the northern side of Albert St. This would not require any earthworks to potentially impact the Urapa in the vicinity.
The Weather Bomb – 21 June 2002 – Final Technical Report (WRC, 2002)	A report providing an overview of the storm event on 21 June 2002 which affected many parts of the TCDC and South Waikato Districts. The study noted that between 120 – 130 mm of rainfall occurred over 24 hours, as recorded by rainfall gauges operated by two residents of Thames. The study noted that a peak flow of 80 m^3/s occurred in Karaka Stream which was estimated to equivalent to a 100 year return period flow. The report notes that this flow was recorded and that it was the highest flow recorded since establishment, but no gauge has been identified by TCDC or WRC on Karaka Stream.
Thames Stormwater Upgrade – Richmond St Catchment (Opus, 2005)	Detailed drawings issued for tender of works on Richmond St which includes the pipes along Richmond St and adjacent streets and connecting to the existing pump station.
Summary of Mike21 modelling – Karaka Stream, Thames (Amon Martin, 2006)	Two reports for this study. One report which summarised flood modelling of Karaka Stream in Thames. A MIKE-21 hydraulic model was developed to produce hazard maps. Peak inflow was calculated using several methods and was calculated to be 81.4 m^3/s based on the relative ratio

Study	Description
	method. The study noted that the 100 year ARI flow was estimated to be 80 m^3/s and that the Karaka Stream was designed to pass the 50 year ARI flow of 60 m^3/s. The study also noted that in a flood event in 1985, 1 m depth of infilling occurred in the channel due to debris. The other report gave a more detailed description of the model setup and characteristics of the Karaka Stream catchment. The report tabulated the rainfall intensity extracted from HIRDS (v2) which was 113 mm/hr for the 100 year ARI 30 minute event. Future intensities with climate change were estimated to be 125.2 mm/hr and 146.1 mm/hr for the 2030 and 2080 projections.
Thames Hospital Redevelopment – Debris Flow Protection Wall (Amon Martin 2006)	A study investigating a protection wall upstream of the hospital (on the southern bank of Karaka Stream) to protect from debris carried by floodwaters down Karaka Stream. The modelling was based on the MIKE-21 modelling from Amon Martin (2006). The debris wall (which has since been constructed) was shown to divert flows which broke out of Karaka Stream back towards the stream.
Capital Works Project – Albert Street, Thames – Stormwater Upgrade (Opus , 2005)	A study which investigated stormwater upgrade options to reduce flooding around Albert St. Modelling using MIKE-11 and InfoWorks was undertaken to understand the performance of the existing pipe system and to design upgrade options. The study recommended a staged approach involving stormwater network upgrades and a pump station. The study also noted the existence of potential Urupa as a constraint for the proposed works.
Waihou and Ohinemuri Model Build Report (Stantec, 2023)	A study involving hydraulic modelling of the Waihou and Ohinemuri Rivers for WRC. The models were built using MIKE Hydro 2021 and were calibrated. Design flood estimates were then derived for the two catchments. In the report, design flows for the Smiths Cableway Gauge were tabulated which showed a 1% AEP (100 year ARI) peak flow of 1,247 m^3/s, as estimated by WRC.
Kauaeranga River Hydraulic and Service Level Review WRC, 2011)	A report summarising a hydraulic review of WRC's flood protection assets on the Kauaeranga River. The study involved hydraulic modelling of the Kauaeranga River catchment which informed the review of the service level of the flood protection assets.
The Potential for Debris Flows from Karaka Stream at Thames, Coromandel (WRC, 2006)	A study that assessed the potential for debris flows from Karaka Stream. The report highlights that while debris flows reaching Thames are rare, with an estimated recurrence interval of over 100 years, the town remains vulnerable to smaller, more frequent events. It was indicated that the smaller events could cause significant issues by blocking waterways with debris, leading to localised flooding and increased erosion.
Analysis of Whitianga, Tararu and Kawhai sea-level records to 2014	This study analysed sea-level records from gauges at Whitianga, Tararu, and Kawhia to understand how tides, weather, and waves affect sea levels. It found that storm surges are influenced by

Study	Description
(Stephens, Robinson, and Bell, 2015)	different factors on the east and west coasts of New Zealand, with Whitianga experiencing surges mainly due to low-pressure systems and Kawhia due to strong winds. Of particular interest to this study (by RHDHV) was the shape of the storm-surge of historic events at the Tararu gauge (near Thames).

4 Model Setup

The following section describes the model setup for the TUFLOW model, the model calibration / validation and for the modelling of design flood events. Detailed figures of the TUFLOW model setup are shown in **Appendix A**.

4.1 Catchments and Gauges

Figure 4-1 shows the catchments draining to Thames as well as several recording sites in the vicinity of Thames which were relevant to the study. The gauges shown on the figure are:

1. The Smiths Cableway Stream Gauge which has a continuous water level record from 1959 to today (65 years).
2. The Thames EWS Rainfall Gauge at the Thames Aerodrome, located on the southern side of the Kauaeranga River, which has a continuous rainfall record from 1966 to today (58 years);
3. The Pinnacles Rainfall Gauge, located at the top of the Kauaeranga River catchment, which has a continuous rainfall record from 1991 to today (25 years); and
4. The Tararu Tidal Gauge which has continuous recorded tidal levels from 1990 to today (34 years).

The largest catchment affecting the township of Thames is the Kauaeranga River Catchment which has an area of approximately 119 km^2 draining to the Smiths Cableway Stream Gauge. Several other catchments drain to the Thames township which can be seen in more detail in **Figure 4-2**. The streams draining to the Thames township include the Moanataiari, Waiotahi, Karaka, Hape, Herewaka and Waikiekie Streams.

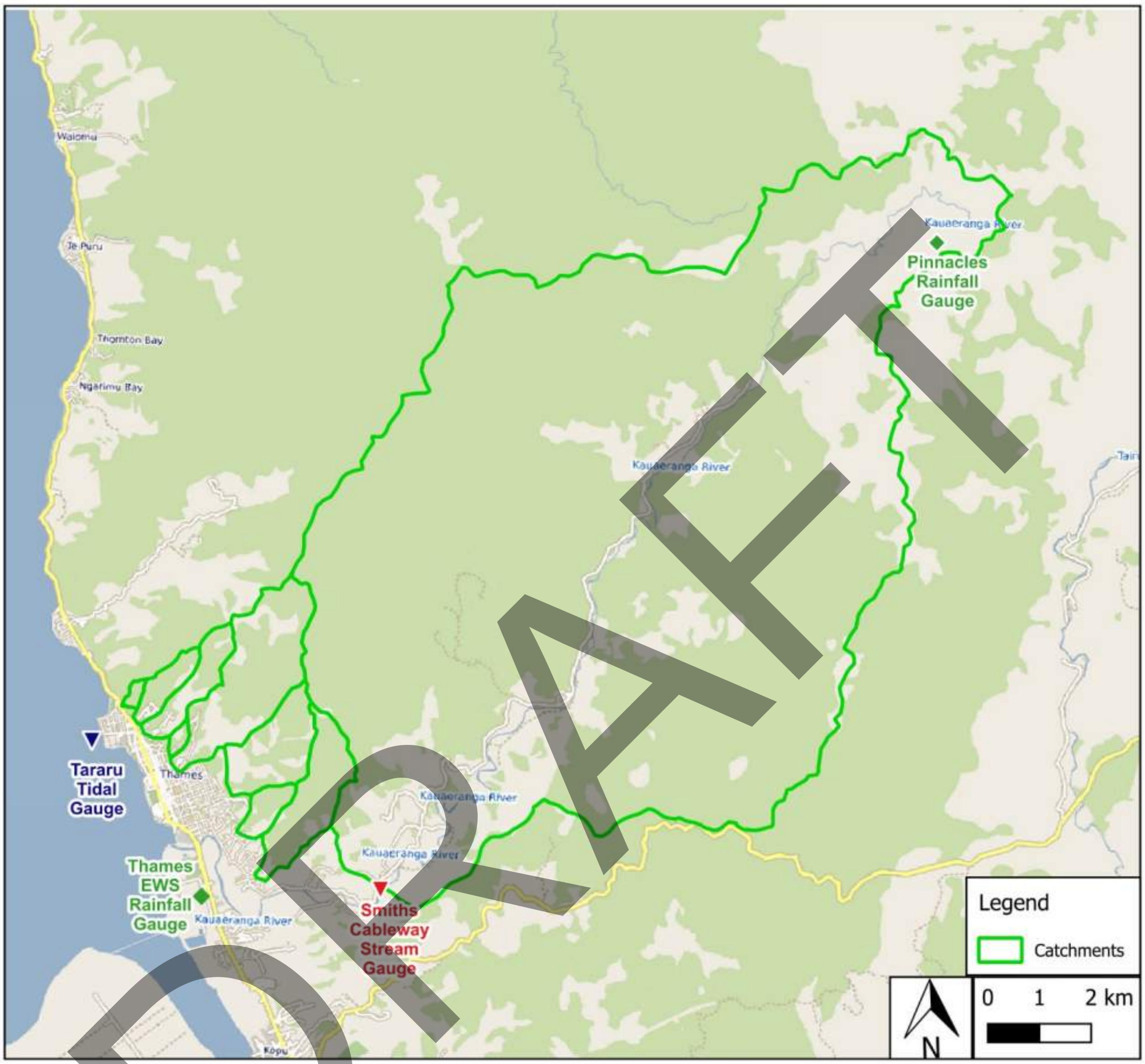


Figure 4-1: Catchment Layout

4.2 Boundary Conditions

Given the layout of the catchments draining to the Thames township and the Kauaeranga River catchment which outlets south of the Thames township, the model was built with direct-rainfall for the local stream catchments, with an inflow (flow versus time) boundary condition at the Smiths Cableway Stream Gauge and an outflow boundary condition (water level versus time) at the ocean in Firth of Thames (refer below). As such, the 2D domain of the model only included the local stream catchments, and the entire Kauaeranga River catchment was not included in the model.

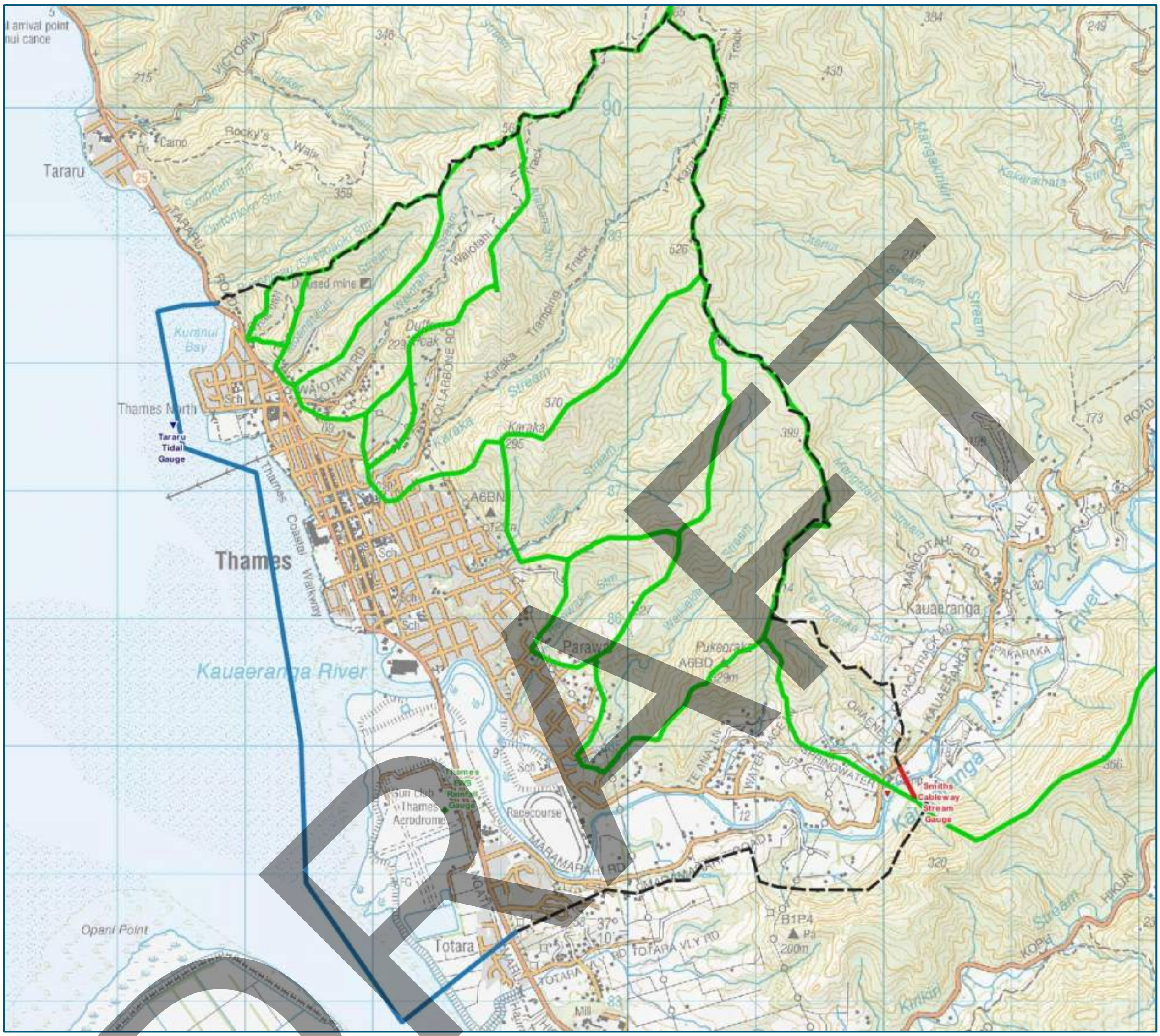


Figure 4-2: TUFLOW Model Boundary Conditions

4.3 Grid Cell Size

Various grid cell sizes (ranging from 32 m to 0.5 m) were used based on the location and detail required (Quadtree) and Sub-Grid-Sampling (SGS) was used which allowed larger grid sized in areas of less interest to the study (in the upper catchment) while maintaining an accurate conveyance to the Thames township (refer **Figure 4-3** below). The Thames township mostly consisted of a 4 m grid cell size, with refinement to 2 m for the Hape Stream and 0.5 m for the Karaka Stream. The latest TUFLOW engine at the time of the study (2023-03-AE) was used.

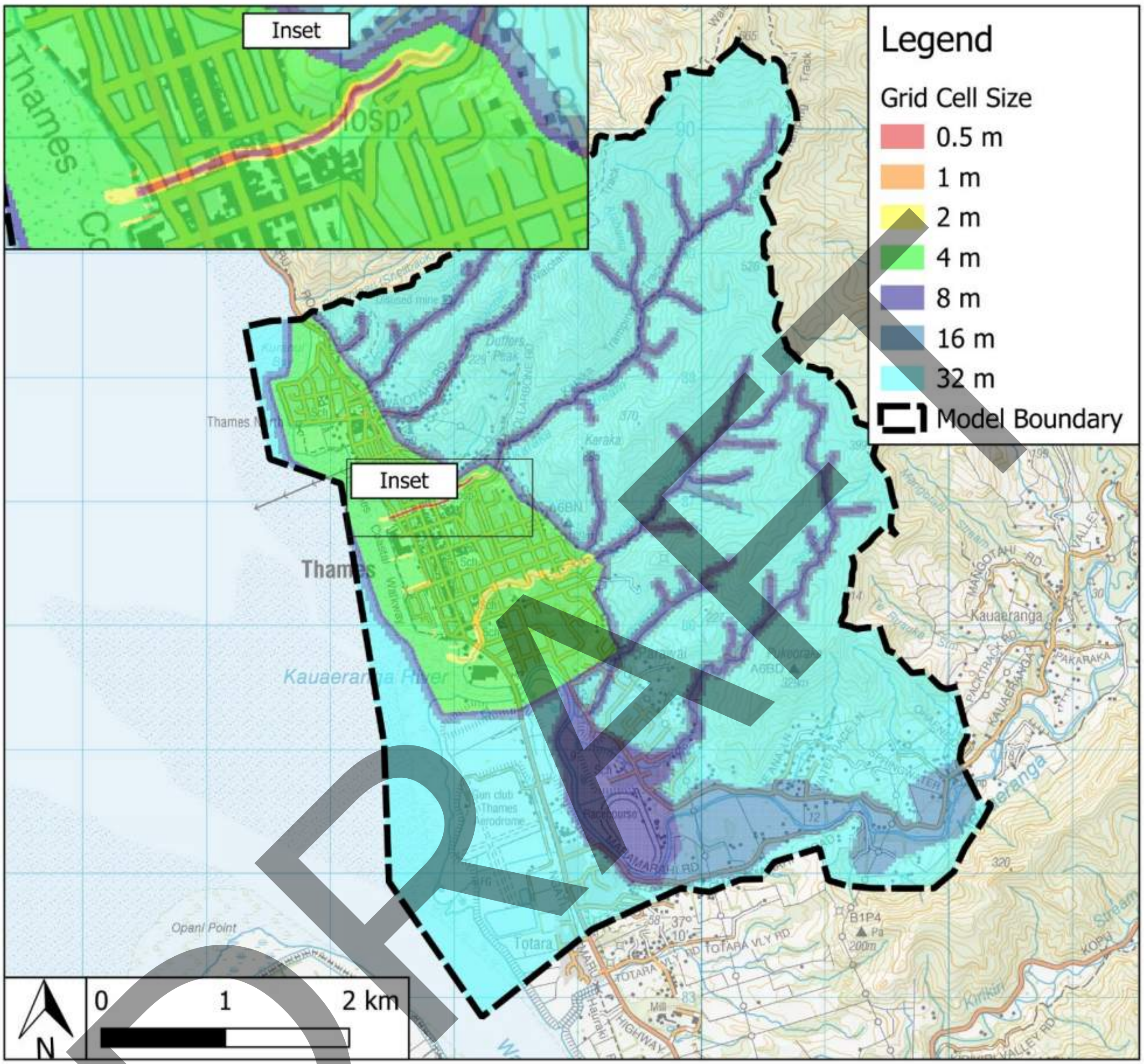


Figure 4-3: Grid Cell Sizes Adopted in the TUFLOW Model

4.4 Topography

The model topography was built with the following DEMs in order of priority (no 1. Highest priority and set on top of the model topography):

1. A Survey TIN (Triangulated Irregular Network) was created for several channels which were surveyed by Coromandel Surveys on 20 June 2024;
2. Kauaeranga River Bathymetry;
3. Waikato LiDAR 2021;
4. Waikato Thames LiDAR 2017 – 2019.

The surveyed cross sections of Hape Stream when compared to the Waikato LiDAR 2021 and were found to match closely so it was decided that the LiDAR would be suitable for use without adjustment in Hape Stream. Given that the LiDAR appeared to be captured during low tide and the surveyed invert level of the

Hape Stream at the Queen Street Bridge closely matched the LiDAR, bathymetry was not required in the downstream end of Hape Stream

4.5 Richmond Street Pump Station

The Richmond Street Pump station (shown on **Figure 4-4** below) is located on the western end of Richmond Street and was designed to reduce local ponding as a result of elevation ocean water levels in the channel to the south of Danby Field. The details of the pump are as follows:

- 2 x Model: Flygt 7055 / 680 pumps (one duty pump and one backup pump);
- Each pump has a capacity of 540 L/s (conservative estimate based on the technical specifications provided by TCDC and considering the head losses on the flapgates on the outfall);
- A DN1050 pipe flows into the pump sump, with a DN1050 overflow pipe which outlets in the channel to the south of Danby Field;
- The pumps operate from a single wet sump with a plan area of 5.6 m x 3.35 m, and a depth of approximately 3 m, however the pumps operate from a depth of approximately 1.2 m (below the lid of the sump) and standing water was observed to be in the sump below this level at the time of the Survey (meaning that there is approximately 1.2 m depth of storage above the pump intake level); and
- Pump operator controls for the duty and backup pump which were provided by TCDC.

Figure 4-4: Richmond St Pump Station

4.6 Drainage Network and Major Crossings

The drainage network was initially based on the 3 Waters data provided by TCDC. This data included numerous pipes, but many of the smaller pipes were not included in the model, to enable the modelling to focus on key structures such as major culvert crossings, ocean outlets, and larger pipes within Thames. The drainage information utilised in the model was verified and adjusted based on the survey conducted on 20

June 2024 by Coromandel Surveyors, following a survey brief provided by RHDHV. The survey included the following details:

- Bridge/Culvert Crossings of Main Streams:
    - Invert levels at upstream and downstream ends;
    - Dimensions of culverts/bridges or waterway areas;
    - Bridge soffit levels;
    - Bridge deck thickness;
    - Presence of any railings or barriers on the bridge;
    - Crown of the road across the entire bridge length, extending at least 50 m on either side;
    - Details of all piers, including their diameter and shape;
    - Any blockages observed at the time of the survey; and
    - Service crossings, including the number of pipes, their diameters, and levels.
- Roadway with Drainage:
    - Invert levels and dimensions of all drainage pipes along the road;
    - Invert levels and dimensions of all incoming pipes;
    - Pit invert levels, cover levels, and dimensions, showing all incoming and outgoing pipes and their invert levels and diameters in the vicinity;
    - Road crest, bottom of kerb, top of kerb, and property boundary levels on both sides; and
    - Points at no more than 10m spacings to facilitate the creation of a 3D TIN surface.
- Sea Outlets:
    - Surveyed for diameter/size of the outlet and the presence of flap gates and/or pump stations (for all ocean outlets with a diameter > 300 mm based on the 3 Waters database).
- Visible Services:
    - Details of services and service covers visible at or above ground level, including service pit sizes and power pole diameters in the vicinity of the surveyed drainage structures.

Most major bridges and culverts along Karaka and Hape Stream were represented with 1D bridge structures, while trash screens, smaller footbridges, bridge railings and the Queen Street bridge were represented by layered flow constrictions (2D) which allowed for modelling of losses due to railings, partial blockage and piles. Road crest levels, bridge railing heights, and channel topography were included in the model and the structures based on the survey.

No allowance for debris blockage was undertaken for this assessment.

4.7 Coastal Defences

The majority of the existing coastal defences were well represented with LiDAR data since they are earthen embankments which are wide enough to be captured by a LiDAR survey. The coastal defences that were not represented well by LiDAR (such as T-walls and sheetpile walls) were digitised using breaklines, with heights either provided by WRC or based on levels captured in the Coastal Strip Drone Imagery provided by TCDC. The DEM from the Coastal Strip Drone Imagery was not used in the model aside from setting levels for the coastal defence structures, since the Drone DEM did not filter out vegetation.

4.8 Karaka Stream

The Karaka Stream culverts were modelled in several different ways (2D with layered flow constriction shapes, 1D culverts and 1D bridges) due a desire to confirm the results regarding the capacity of the Bella Street Culvert, as this structure is critical in terms of how much flow can escape from Karaka Stream during high flow flood events. Previous modelling indicated that Karaka Stream was designed to have a capacity of some 60 m^3/s for the 50 year ARI event (according to design peak flow estimates at the time). However, the capacity of the Karaka Steam was found to be significantly less due to two constrictions:

- The Bella Street Footbridge with a peak flow capacity of 50 m^3/s; and
- The Bella Street Culvert with a peak flow capacity of approximately 17 m^3/s.

Of main concern is the capacity of the Bella Street Culvert. This lack of flow capacity is due to several reasons:

- Steep Channel Grade: The channel has a steep grade of more than 4%, resulting in high approach velocities;
- Limited waterway area of the culvert, which has a waterway area opening height of only 1.5 meters;
- Hydraulic Jump: The high velocities and change in hydraulic gradient cause a hydraulic jump when the flow reaches the Bella Street Culvert; and
- Concrete Walls: The stream has concrete walls on either side that contain the flow up to a height of approximately 2 – 2.5 m, which end at the upstream end of the culvert (shown on **Figure 4-5** below). The walls do not prevent the flow from spilling onto the road, causing a significant amount of water to spill out of the channel at the culvert;

Figure 4-5: Concrete Walls on Karaka Stream (Taken from Google Streetview from Bella Street Looking East)

Compared to previous 1D modelling, which assumed all flow would enter the culvert, the 2D modelling provides a more realistic representation of the flood behaviour at this culvert. The 2D model shows that the flow is diverted onto the road due to the limited culvert capacity and the lack of containment, leading to significant flow spilling onto Bella Street (shown on **Figure 4-6** and **Figure 4-7** below).

The figures below show peak flow estimates in the area of the Bella Street for the 50 year ARI event:

- A peak flow of approximately 90 m^3/s arrives at the Bella Street Footbridge;
- From this approach flow, a peak flow of only 50 m^3/s passes beneath the footbridge and flows into Karaka Stream (between the vertical concrete walls), while the rest of the flow either overtops or runs parallel to the channel. The water is not allowed to re-enter Karaka Stream due to the vertical

concrete walls which are higher than ground level of the overbank areas between the footbridge and the culvert;

- A peak flow of 17 m^3/s passes through the Bella Street culvert; and
- The remaining water overtops the Bella Street culvert and flows north down Bella Street with a peak flow of approximately 40 m^3/s.

The water that overtops the Bella Street Culvert flows north-west through the residential area towards the ultimate low point at Albert Street.

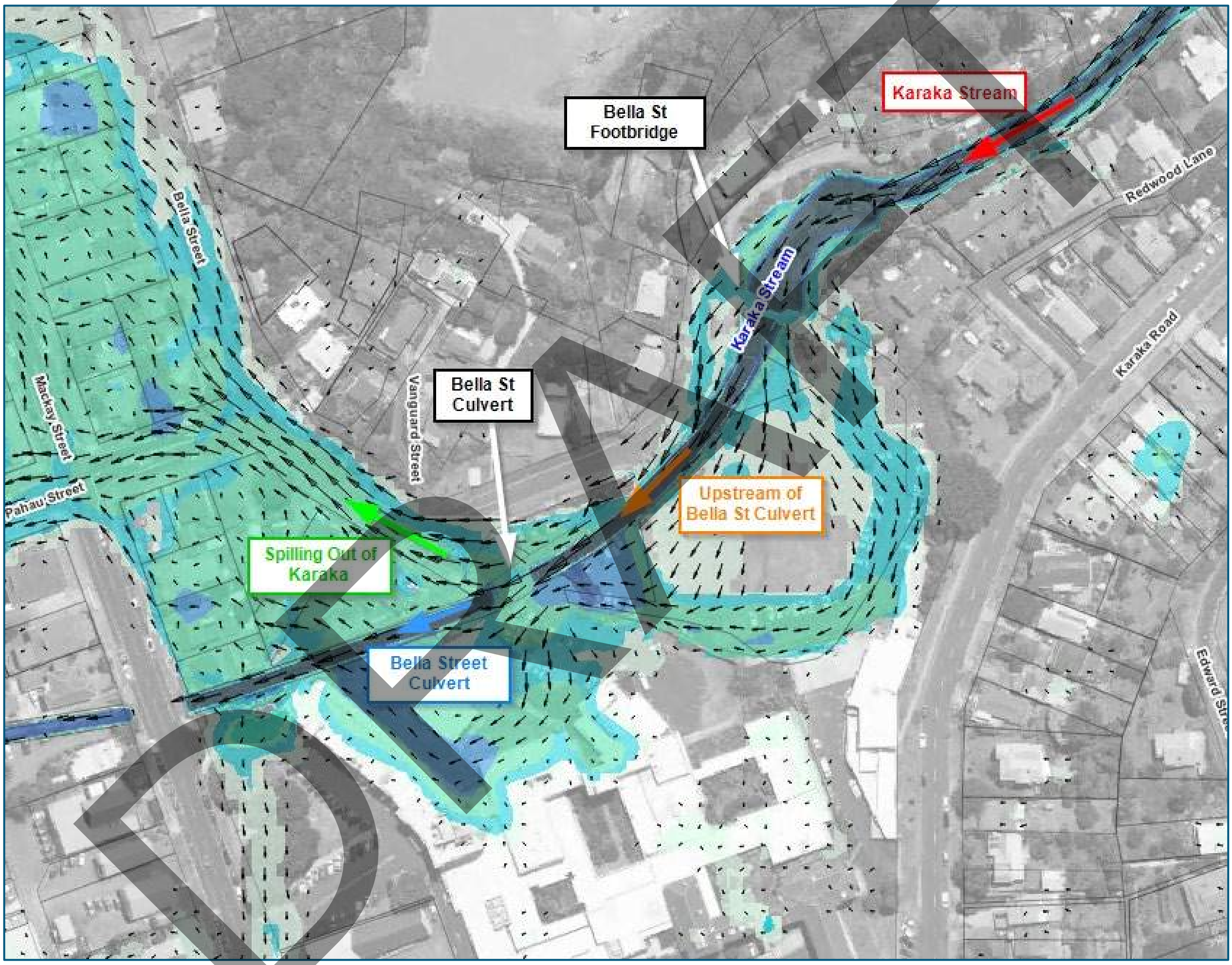


Figure 4-6: Flow Patterns in Karaka Stream – 50 year ARI - refer colour coded arrows referring to flow hydrographs in the Figures below

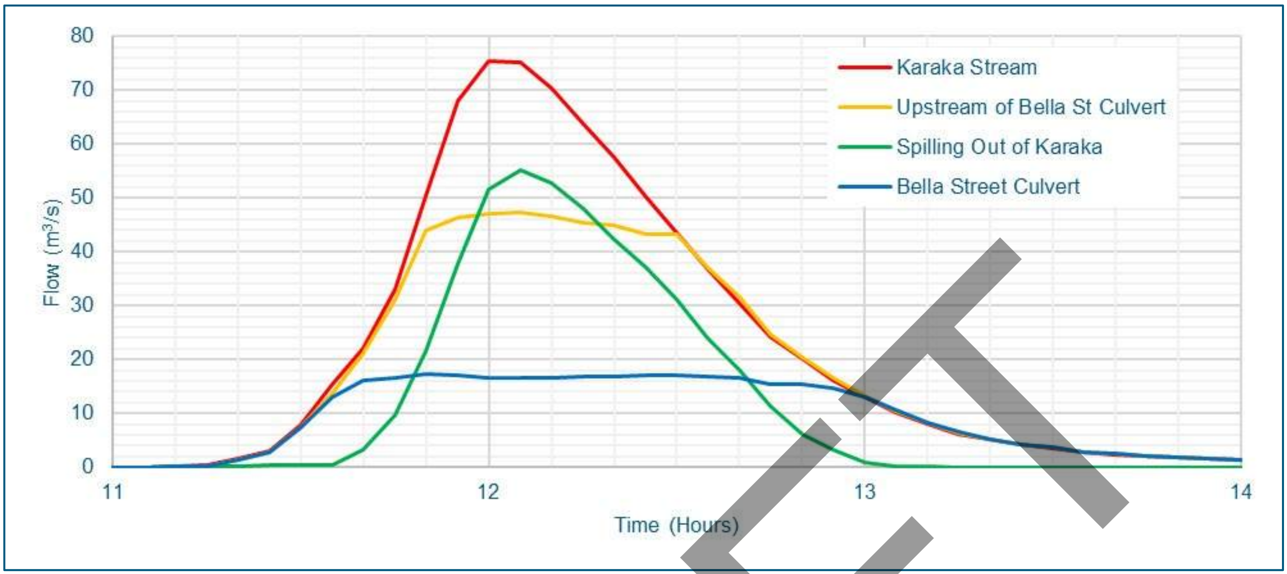


Figure 4-7: Flow Hydrographs in Karaka Stream – 50 year ARI – refer Figure 4-6

5 Model Calibration/Validation

Hydraulic model calibration and validation involves the development of a model to represent real flood conditions from historic events as closely as possible by running simulations using recorded data, such as rainfall, stream flows, and tidal data. The model structure and various parameters, such as roughness and infiltration rates, are adjusted to obtain a good match between the recorded data and the model results. A typical example of this is the calibration of a model of a gauged catchment where a hydrologic model is run with historic rainfall recordings, and the hydrograph output from the model is matched to a recorded hydrograph from a gauge at the same location. A validation event is then run using the same parameters to test the model's performance in another storm event.

In this study, although good records exist for input to the model (the Tararu Tidal Gauge just offshore from the Thames township, the Thames EWS rainfall pluviography located in the Thames Aerodrome and the Smiths Cableway Gauge on the Kauaeranga River), limited information was available to test the model's performance such as flood marks or photographs of flooding. There was no water level gauge to attempt to calibrate the model, other than the Kauaeranga River Gauge (refer **Section 6**). The Thames EWS rainfall gauge was used, which is in a reasonable location to assume uniform rainfall across the local stream catchments, however, the Kauaeranga River catchment is too large to make this assumption, and additional spatial information for rainfall was used, such as the Pinnacles Rainfall Gauge, which is near the top of the river catchment. As part of some additional investigations commissioned by TCDC, the Kauaeranga River Gauge was attempted to be used for calibration purposes, as has been done in the Waihou and Ohinemuri Model Build Report (Stantec, 2023).

Initially, the calibration of the Kauaeranga River catchment was outside the scope of this study. However,. As part of an extra investigation commissioned by TCDC, RHDHV expanded the model domain to include the Kauaeranga River to test the infiltration and roughness parameters used in the TUFLOW model and using the Pinnacles Rainfall Gauge. Challenges were encountered with the spatial variation of rainfall, refer to **Section 6**.

The two events used for calibration and validation in this study were an event which occurred on 14 February 2023 (the February 2023 Event) and an event which occurred on 21 June 2002 (The "Weather Bomb"). Both of these events consisted of significant rainfall and flooding within the Thames township and had the most data available for calibration and validation purposes. The calibration information available for this study were drone shots taken by Stuart Caisley, the owner of the Lady Bowen Air-bnb, who took drone photographs during the February 2023 event and provided additional anecdotal evidence in a phone call held on 31 July 2024. As such, the model was initially calibrated to the February 2023 Event, but limited validation was able to be performed for The Weather Bomb (2002), due to a lack of recorded flood mark data within Thames. For further information on the attempts to calibrate the Kauaeranga River catchment, please refer to **Section 6**.

5.1 February 2023 Calibration

The following section describes the calibration of the hydrologic / hydraulic (TUFLOW Rainfall-On-Grid) TUFLOW model to the February 2023 Event (i.e. ignoring the Kauaeranga River catchment). Flood maps showing the estimate peak flood depth in this event can be found in **Figure 1** in **Appendix B**.

In the February 2023 Event, approximately 200 mm of rainfall was recorded over a 48 hour period at the Thames EWS Gauge (refer **Figure 5-1** below) which is approximately equivalent to a 100 year ARI event based on design rainfall from the NIWA HIRDS v4 database with design rainfalls extracted from the Thames EWS Gauge. No significantly elevated ocean levels occurred during this event, with a peak level recorded by the Tararu Tidal Gauge of approximately 1.7 m NZVD (refer **Figure 5-2**) and no overtopping of the coastal defences occurred in Thames. Note that the Mean High Water Springs (MHWS) is 1.48 m NZVD and the Highest Astronomical Tide (HAT) in Thames is 1.88 m NZVD. A peak flow of approximately 1000 m^3/s was recorded by the Smiths Cableway Gauge (refer **Figure 5-3**) for the Kauaeranga River.

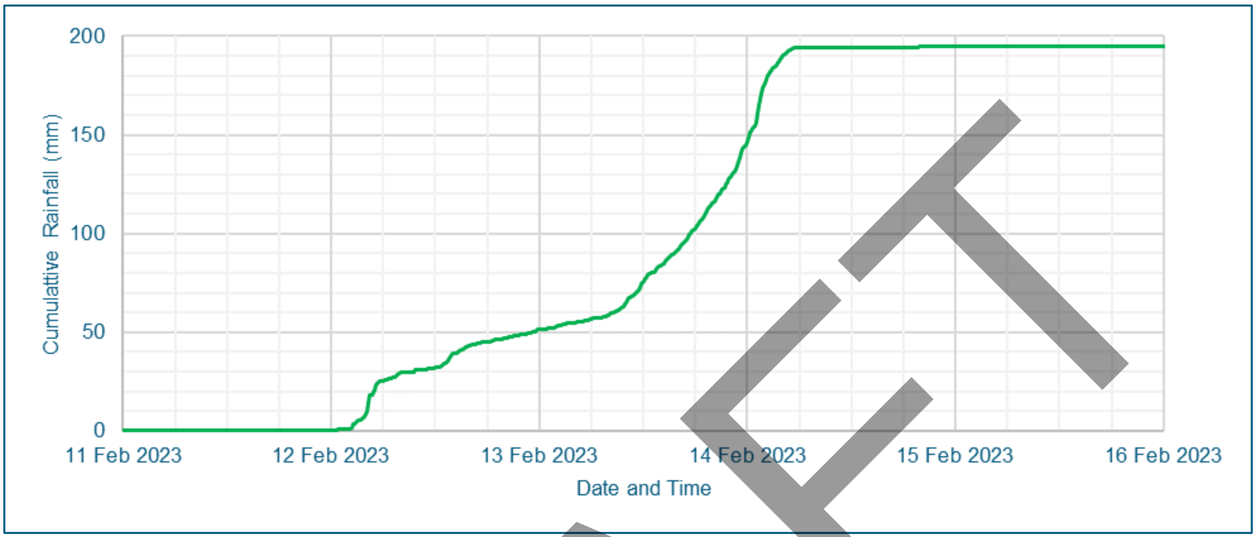


Figure 5-1: Cumulative Rainfall Recorded by the Thames EWS – February 2023 Event

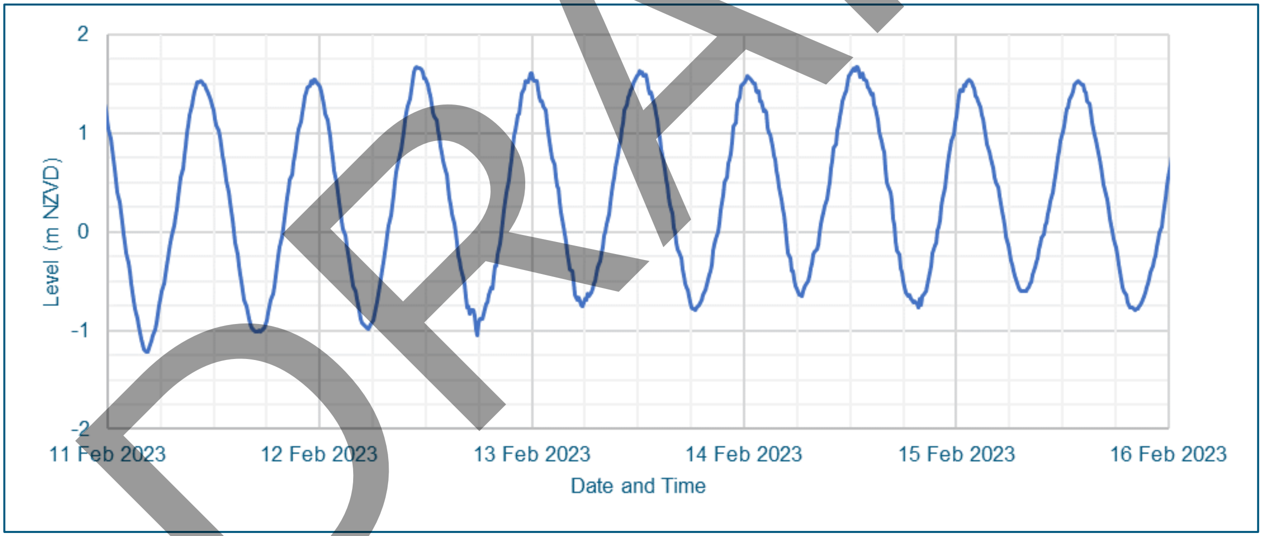


Figure 5-2: Water Level Recorded by the Tararu Tidal Gauge - February 2023 Event

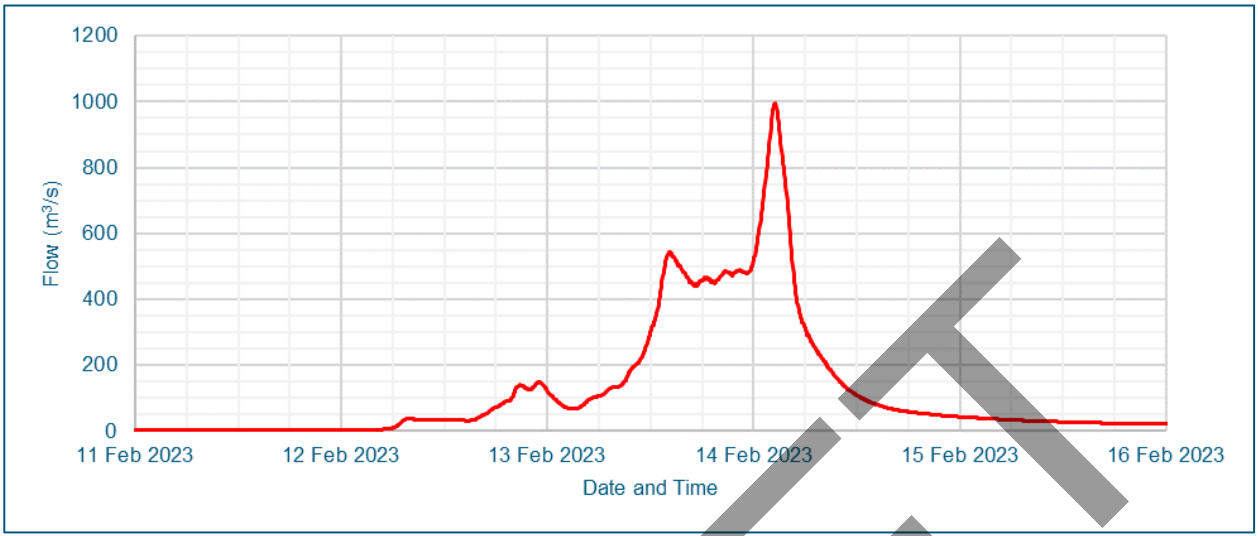


Figure 5-3: Rated Flow Recorded by the Smiths Cableway Gauge – February 2023 Event

Without recorded peak flood levels within Thames to calibrate to, the drone photographs and anecdotal evidence were used. These photos were taken after the peak at 7AM on 14 February 204. Anecdotal evidence was gathered through a phone call with Stuart Caisley (who provided the drone photographs).

A summary of the phone call held with Stuart Caisley is as follows:

- In the event in February 2023, there was clear water running from the rear of their property (not salt water), clear water at the front of the property, and muddy water towards the intersection of Brown and Albert Street; RHDHV suggest that the clear water could potentially have been local runoff from the urban area of Thames, while the muddy water could have been water that escaped from the Karaka Stream during this event, and flowed down towards the low point in town at Albert Street;
- The peak of the event occurred between the evening of 13 February 2023 and the early morning of 14 February 2023;
- In the peak of the event, there was up to 5 inches (12.7 cm) of water at the back of the property and floodwaters reached the front door; and
- The flood level in The Weather Bomb (June 2002 Event) was a few inches lower than in the February 2023 Event– approximately up to the level of the footpath of the front door.

Rainfall records and modelling indicate that the peak of the event occurred at approximately 01:00AM in the morning of 14 February, which is in agreement with anecdotal evidence. **Figure 5-4** and **Figure 5-5** show the flooding in Thames in the morning after the peak of the flood event in February 2023 taken using a drone at approximately 7AM on 14 February 2023 (courtesy of Stuart Caisley). **Figure 5-6** shows the TUFLOW model results at the same timestep as when the photographs were taken (after the peak subsided). A comparison of the flood extents is shown in **Figure 5-7** below which shows a good agreement between the observed and modelled flood extents. The initial and continuing losses were set to 10 mm and 4.5 mm/hr, respectively, to achieve a good match between recorded and observed flood extents. Of note in the comparison is that:

- Flood waters inundate Queen Street, Davy Street and Brown Street near the intersections with Albert St with roughly the same extent between the observed and modelled flooding;
- The intersection of Queen Street and Albert Street is dry, as well as the intersection of Brown Street and Albert Street;
- The water is a brown colour, indicating that the source of the water is the stream catchments, rather than the local catchment runoff, or from the overtopping of the coastal defences; and

- The roads and Victoria Park are roughly inundated to the same extent.

Figure 5-4: Drone Photograph of Flooding on Albert Street – Taken at 06:45AM on 14 February 2023 (Courtesy of Stuart Caisley)

Figure 5-5: Drone Photograph of Flooding in Northern Thames – Taken at 06:48AM on 14 February 2023 (Courtesy of Stuart Caisley)

Figure 5-6: Modelled Flood Depth at 06:50AM on 14 February 2023

Figure 5-7: Comparison Drone Photography and Model Results – February 2023 Event at 07:00AM

In the peak of the February 2023 event, 28 cm of depth was indicated by the model. Anecdotal evidence suggested that flood waters reached the front door of the Lady Bowen Air-bnb. **Figure 5-8** below shows the location of the peak depth on the crest of the road as well as the front door. It is difficult to determine the exact level of the front door in the image and the balcony at the front of the property does not allow for accurate levels of the footpath from LiDAR. However, cross sections of the road cut at adjacent locations show the footpath on the side of the Lady Bowen Air-bnb are level or slightly higher than the crest of the road. This would indicate that flood waters may have reached the front door with a depth of approximately 28 cm.

Figure 5-8: Comparison of Modelled Level and Observations at the Lady Bowen Airbnb – February 2023 Event (Courtesy of Google Streetview)

The ponding observed at the low point in Albert Street is in part due to the lack of head available to drain from the land side to the ocean side during periods of elevated ocean levels. **Figure 5-9** below shows the flow and upstream (land side) and downstream (ocean side) water levels for an existing piped ocean outlet on the western end of Albert Street. The figure shows that although the upstream level is elevated due to the ponding, the pipe cannot flow to its full capacity due to an elevated ocean level, due to there not being enough head.

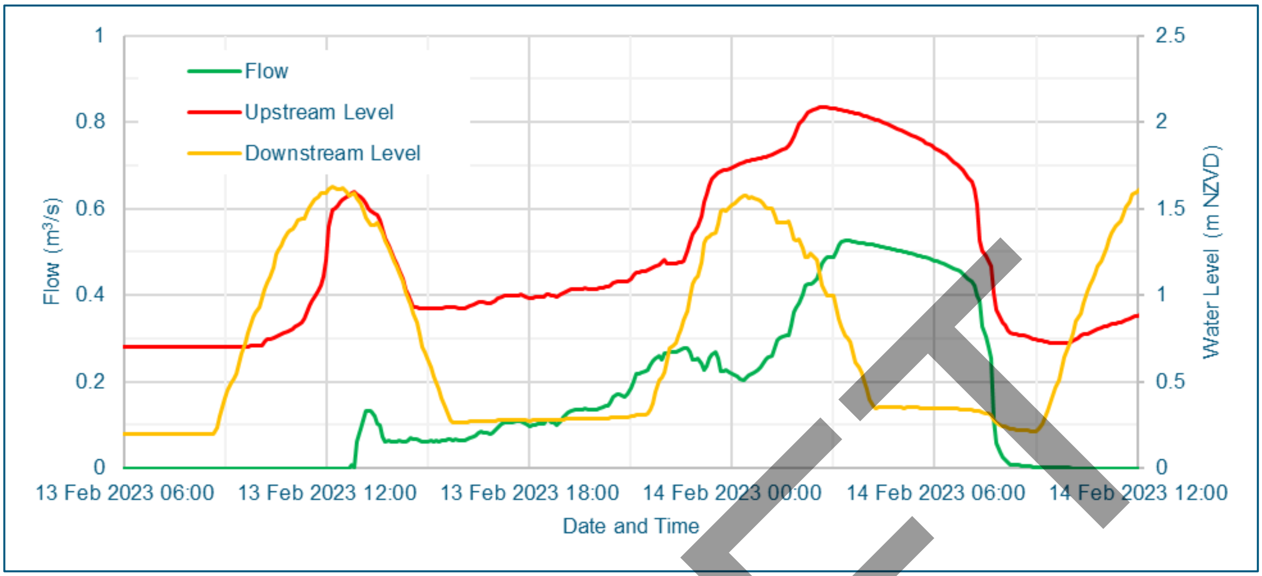


Figure 5-9: Piped Ocean Outlet at Albert Street – February 2023 Event – showing elevated upstream levels and flow limitation due to elevated tailwater conditions

Figure 5-10 and **Figure 5-11** below show that the February 2023 Event was largely contained within the Karaka Stream with only 20 m^3/s arriving at the Bella Street Footbridge, and only approximately 2.5 m^3/s overtopping at the Bella Street culvert. Note that the flow in Karaka Stream is identical to the flow upstream of the Bella Street Culvert. The February 2023 Event was also contained within Hape Stream with a peak flow of approximately 11 m^3/s arriving in the Thames township.

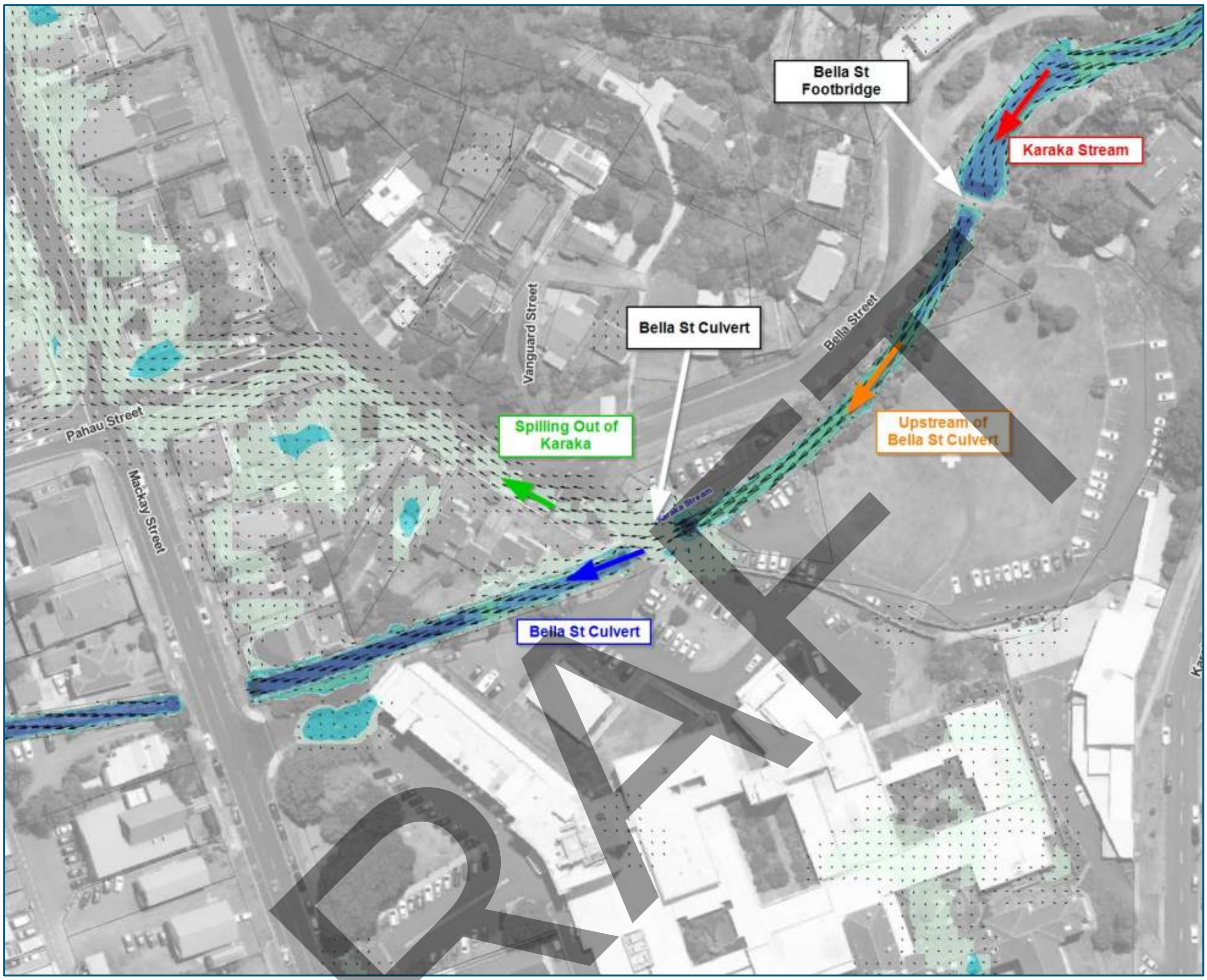


Figure 5-10: Flow Patterns in Karaka Stream – February 2023 Event – refer colour coded hydrographs below

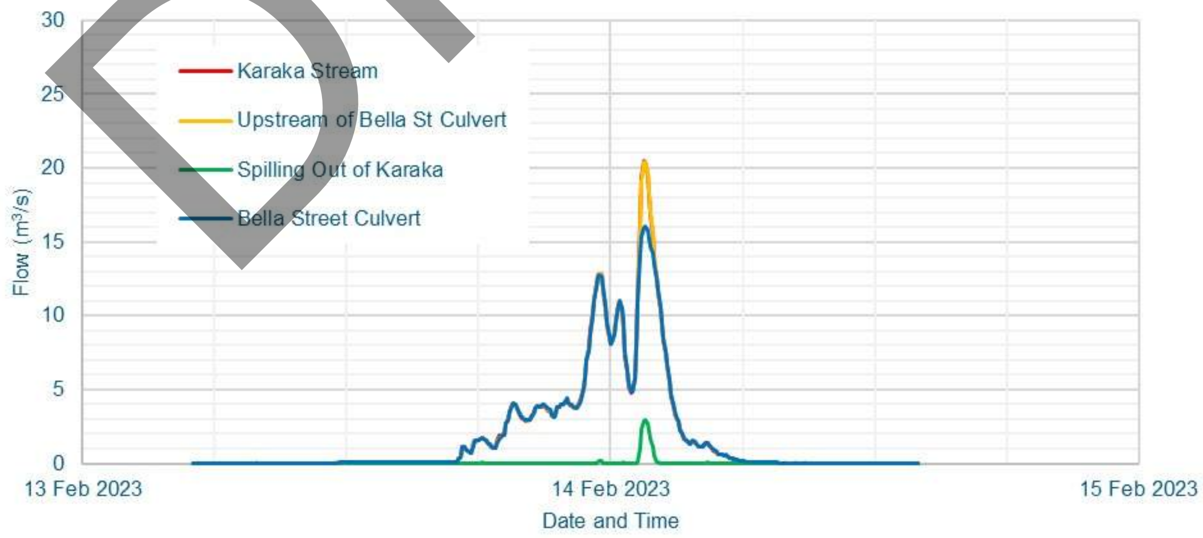


Figure 5-11: Estimated Flow Hydrographs in Karaka Stream – February 2023 Event

5.2 June 2002 (The Weather Bomb) Validation

The following section describes the validation process for the 2002 Weather Bomb event, however, limited data was available. A brief description of the flooding in The Weather Bomb is provided, and additional information should be reviewed and further validation could be carried out in future stages, if more information should come to hand. Flood maps showing the peak depth in this event can be found in **Figure 2** in **Appendix B**. The model structure for The Weather Bomb was the same as for the February 2023 Event calibration, except that the Richmond Street Pump Station was removed since it was known to be constructed after June 2002.

In the 2002 Weather Bomb event, approximately 150 mm of rainfall over a 72 hour period was recorded by the Thames EWS Gauge, with a high intensity burst occurring around midnight on 20 June 2002 (refer **Figure 5-12** below). No significantly elevated ocean levels occurred during this event, with a peak level recorded by the Tararu Tidal Gauge of approximately 1.75 m NZVD (refer **Figure 5-13**) and no overtopping of the coastal defences from the ocean side occurred in Thames. A peak flow of approximately 600 m^3/s was recorded by the Smiths Cableway Gauge (refer **Figure 5-14**).

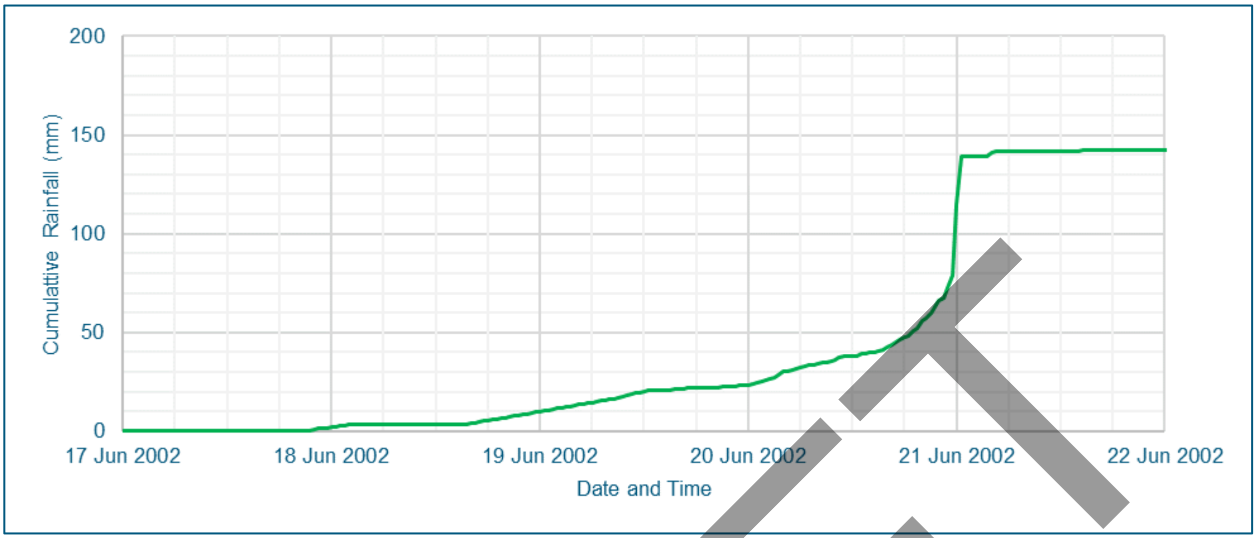


Figure 5-12: Cumulative Rainfall Recorded by the Thames EWS – The 2002 Weather Bomb

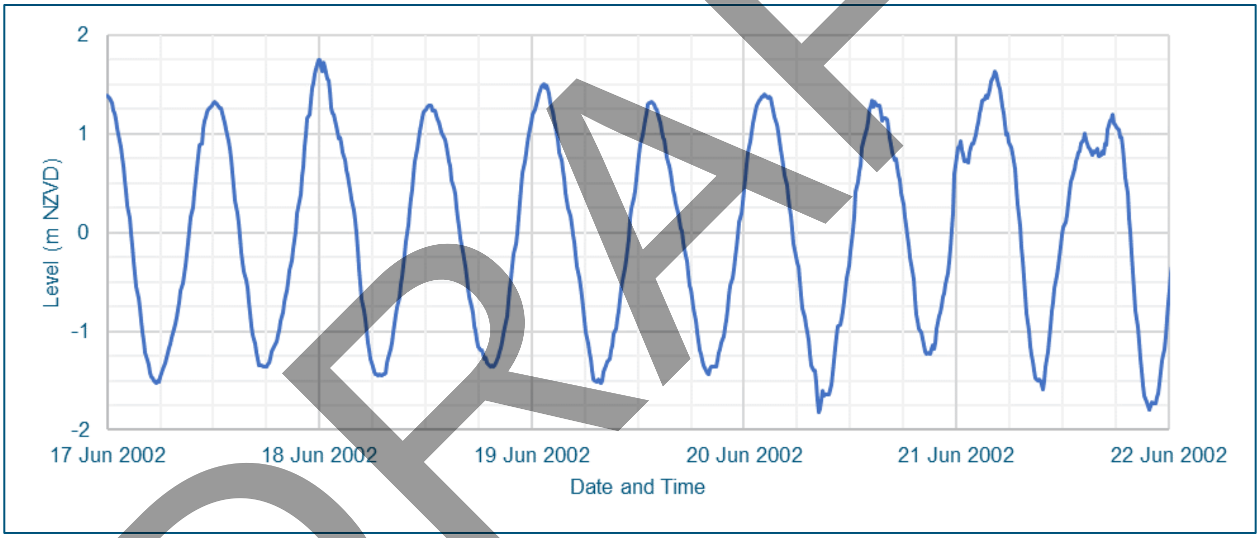


Figure 5-13: Water Level Recorded by the Tararu Tidal Gauge – The 2002 Weather Bomb

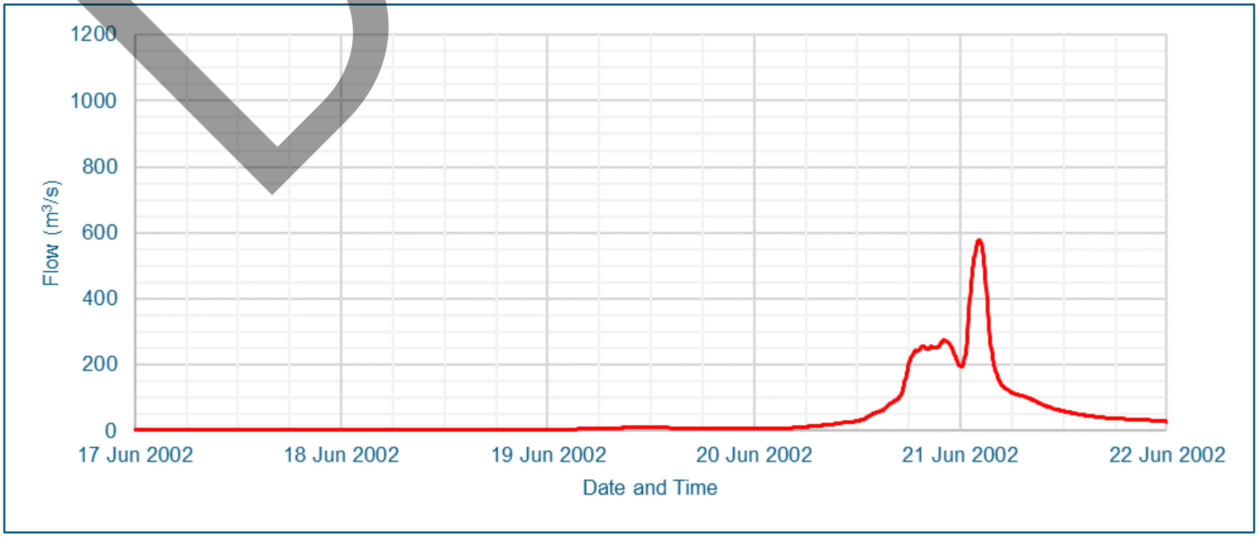
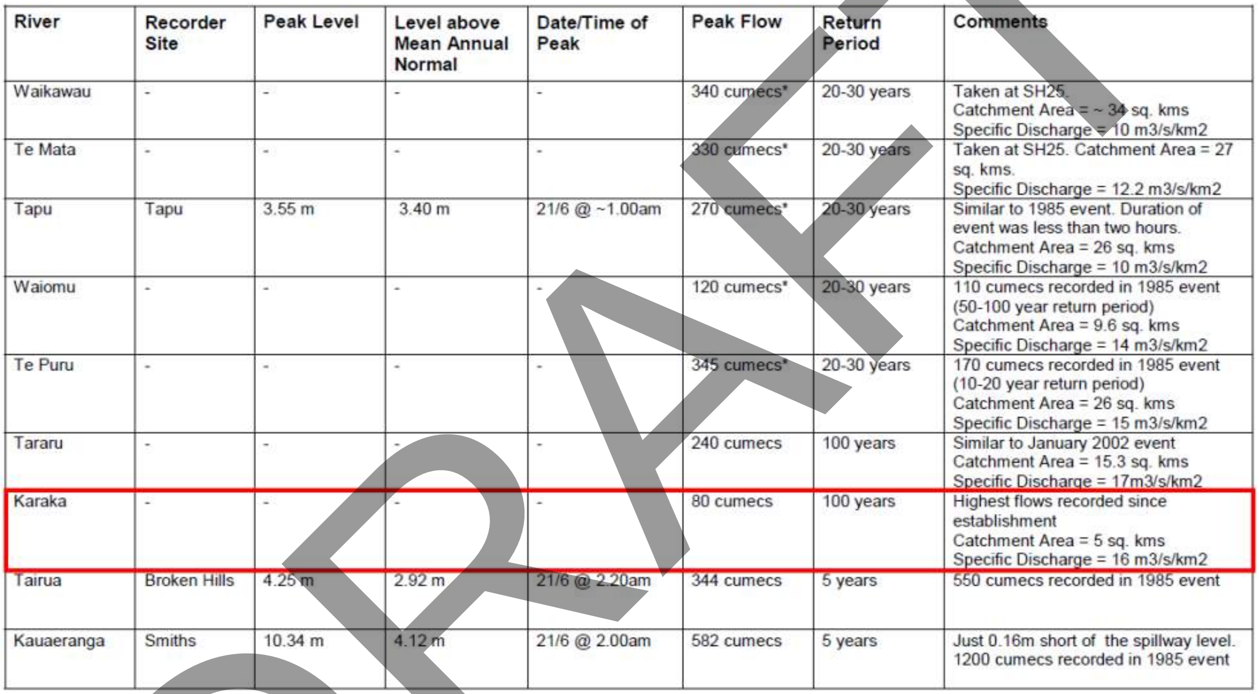


Figure 5-14: Rated Flow Recorded by the Smiths Cableway Gauge – The 2002 Weather Bomb

Anecdotal evidence from Stuart Caisley indicated that the peak water level at their property was lower in The 2002 Weather Bomb than in the February 2023 Event. This does not align with model results and should be followed up to confirm given that the estimated peak flow in Karaka Stream was significantly higher in the 2002 Weather Bomb than in the February 2023 Event.

The modelled peak flow in Karaka Stream was 84 m³/s which closely matches a peak flow noted in The Weather Bomb Report (Environment Waikato, 2002). The report indicated that a peak flow of 80 m³/s was 'recorded' in Karaka Stream in The Weather Bomb (refer **Table 5-1** below). However, we are not aware of a gauge located in Karaka Steam, and so the source of the information is unknown.

Table 5-1: Peak Flow in Karaka Stream (Environment Waikato, 2002)



River	Recorder Site	Peak Level	Level above Mean Annual Normal	Date/Time of Peak	Peak Flow	Return Period	Comments
Waikawau	-	-	-	-	340 cumecs*	20-30 years	Taken at SH25. Catchment Area = ~ 34 sq. kms Specific Discharge = 10 m3/s/km2
Te Mata	-	-	-	-	330 cumecs*	20-30 years	Taken at SH25. Catchment Area = 27 sq. kms. Specific Discharge = 12.2 m3/s/km2
Tapu	Tapu	3.55 m	3.40 m	21/6 @ ~1.00am	270 cumecs*	20-30 years	Similar to 1985 event. Duration of event was less than two hours. Catchment Area = 26 sq. kms Specific Discharge = 10 m3/s/km2
Waiomu	-	-	-	-	120 cumecs*	20-30 years	110 cumecs recorded in 1985 event (50-100 year return period) Catchment Area = 9.6 sq. kms Specific Discharge = 14 m3/s/km2
Te Puru	-	-	-	-	345 cumecs*	20-30 years	170 cumecs recorded in 1985 event (10-20 year return period) Catchment Area = 26 sq. kms Specific Discharge = 15 m3/s/km2
Tararu	-	-	-	-	240 cumecs	100 years	Similar to January 2002 event Catchment Area = 15.3 sq. kms Specific Discharge = 17m3/s/km2
Karaka	-	-	-	-	80 cumecs	100 years	Highest flows recorded since establishment Catchment Area = 5 sq. kms Specific Discharge = 16 m3/s/km2
Tairua	Broken Hills	4.25 m	2.92 m	21/6 @ 2.20am	344 cumecs	5 years	550 cumecs recorded in 1985 event
Kauaeranga	Smiths	10.34 m	4.12 m	21/6 @ 2.00am	582 cumecs	5 years	Just 0.16m short of the spillway level. 1200 cumecs recorded in 1985 event

Figure 5-15 and **Figure 5-16** below show that Karaka Stream was unable to contain the flow in The Weather Bomb event. Approximately 84 m³/s is estimated as arriving at the Bella Street Footbridge, with only 50 m³/s passing underneath. With a capacity of 17 m³/s at the Bella Street Culvert, the remaining water with a peak flow of approximately 40 m³/s is estimated to have overtopped and flowed North towards the ultimate low point on Albert Street leading to significant ponding.

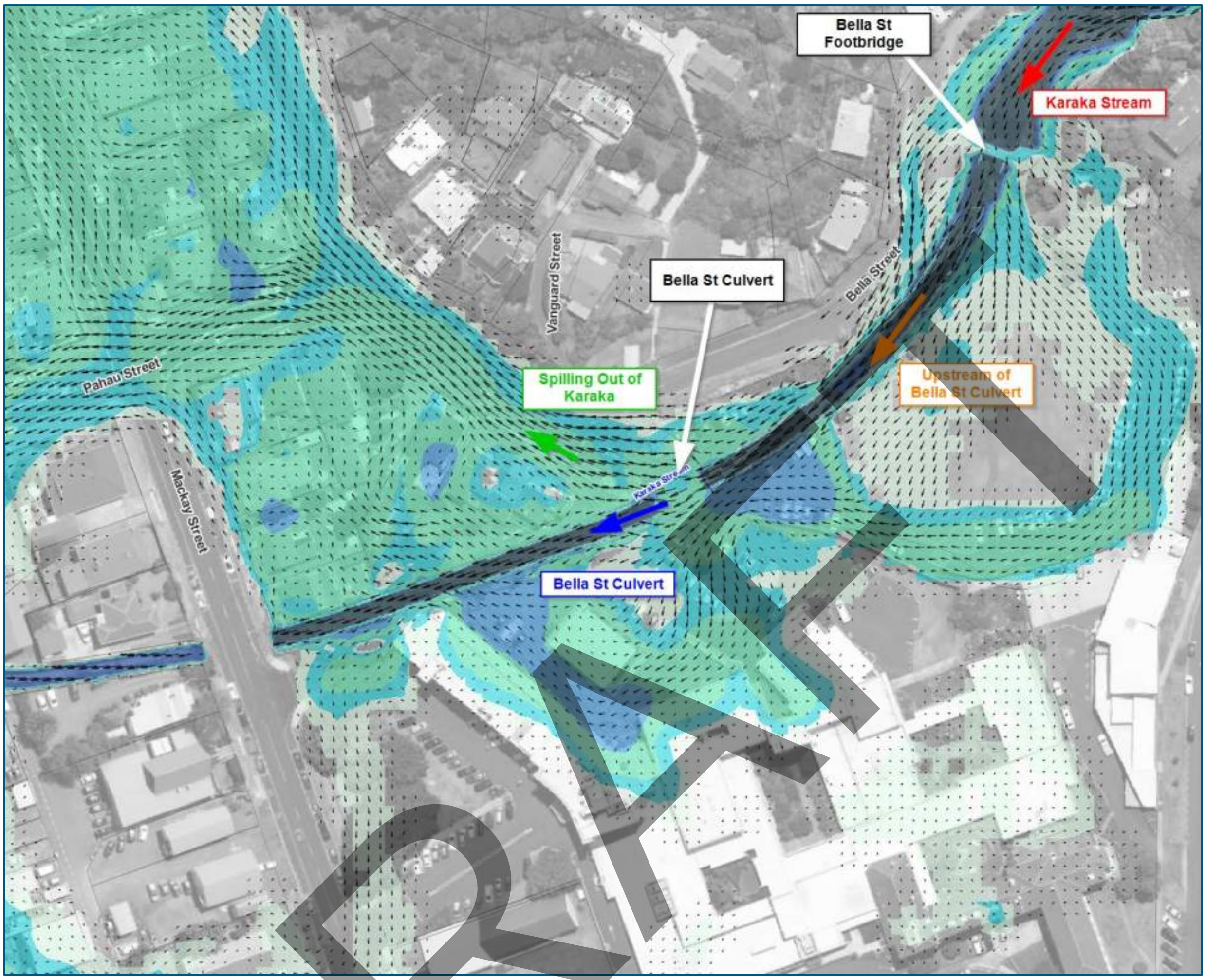


Figure 5-15: Flow Patterns in Karaka Stream – The Weather Bomb

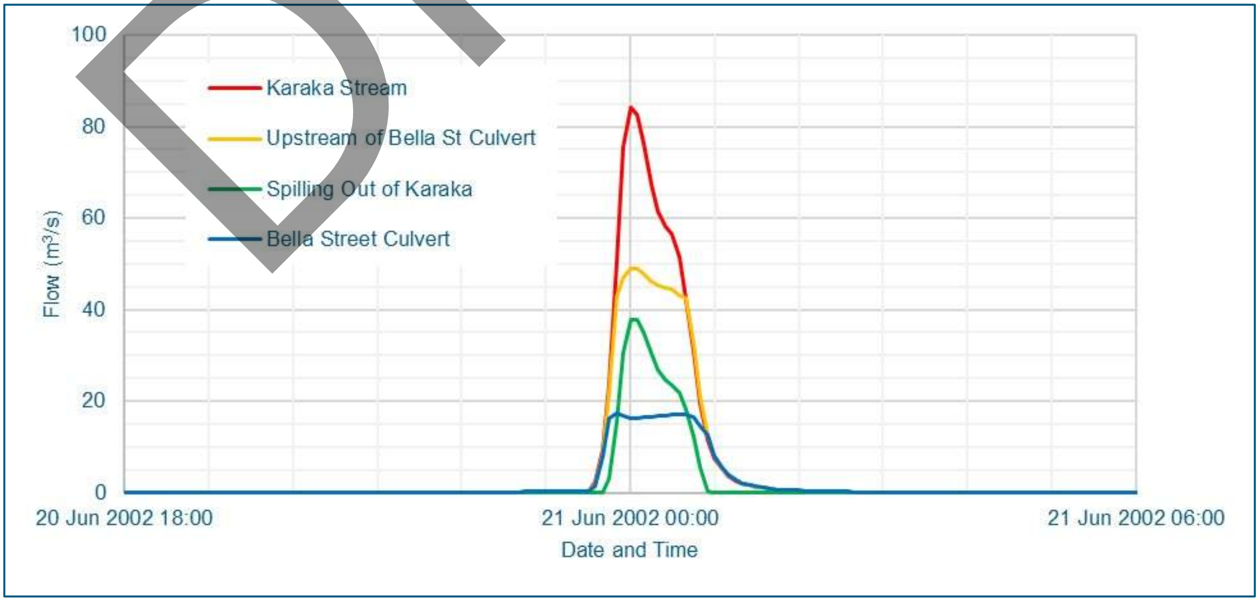


Figure 5-16: Flow Hydrographs in Karaka Stream – The Weather Bomb

Similar to the February 2023 Event, the ponding observed at the low point in Albert Street is in part due to the lack of head available to drain from the land side to the ocean side during periods of elevation ocean levels. However, during The Weather Bomb event, the model estimated a significant amount of water ponding at the Albert Street low point, and it is unlikely that lower ocean tailwater levels would lead to a significant difference in the peak ponding depth. **Figure 5-17** below shows the flow and upstream (land side) and downstream (ocean side) water levels for an existing piped ocean outlet on the western end of Albert Street. The figure shows that although there is a head difference between the upstream (land) and downstream (ocean) side of the pipe, it takes approximately 9 hours for the majority of the water to drain to the ocean, due to limited pipe capacity and large volume of ponded water.

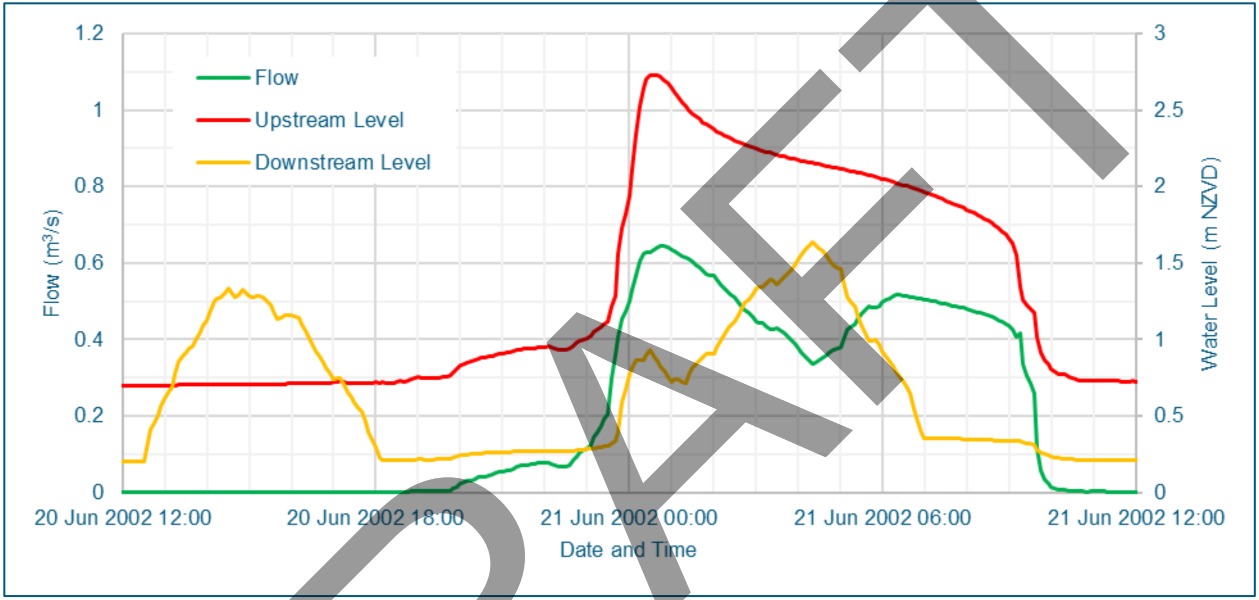


Figure 5-17: Piped Ocean Outlet at Albert Street – The Weather Bomb

Figure 5-18 and **Figure 5-19** show that the peak flow arriving in the Thames township from Hape Stream was estimated as approximately 45 m^3/s in The Weather Bomb. The most upstream bridge crossing, the Terrace Bridge, did not experience overtopping. Downstream of the Terrace Bridge, water is estimated to have broken out of Hape Stream flowing north immediately upstream of Augustus Street South towards Richmond Street with an estimated peak flow of approximately 5 m^3/s. Approximately 37 m^3/s arrived at the Rolleston Street bridge further downstream which did not experience overtopping. The flow continued down Hape Stream until reaching the Mackay Street bridge which had a capacity of only 20 m^3/s, resulting in significant overtopping of Grey Street and Mackay St. The State Highway 25 (Queen Street) did not experience overtopping in this event.

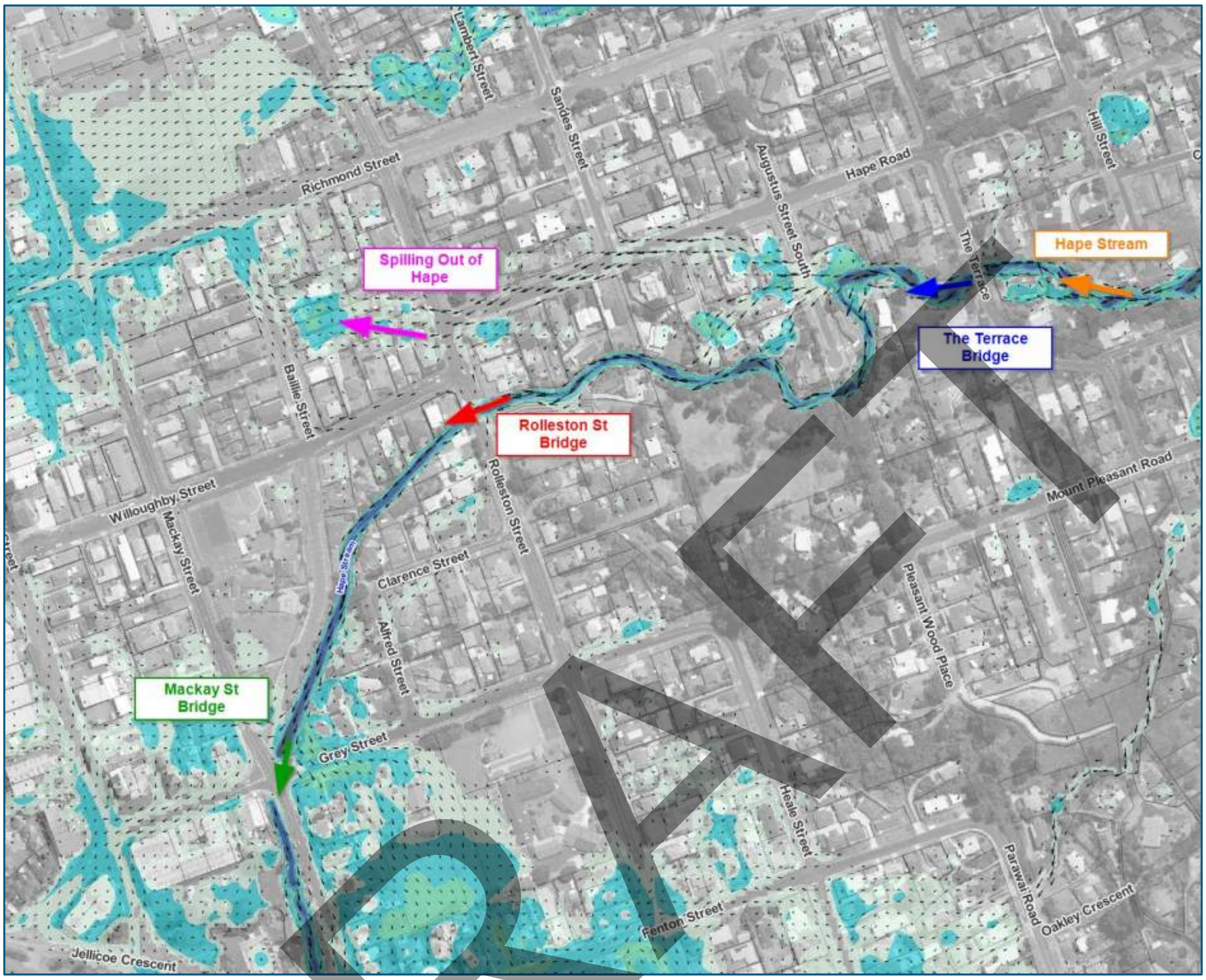


Figure 5-18: Flow Patterns in Hape Stream – The Weather Bomb

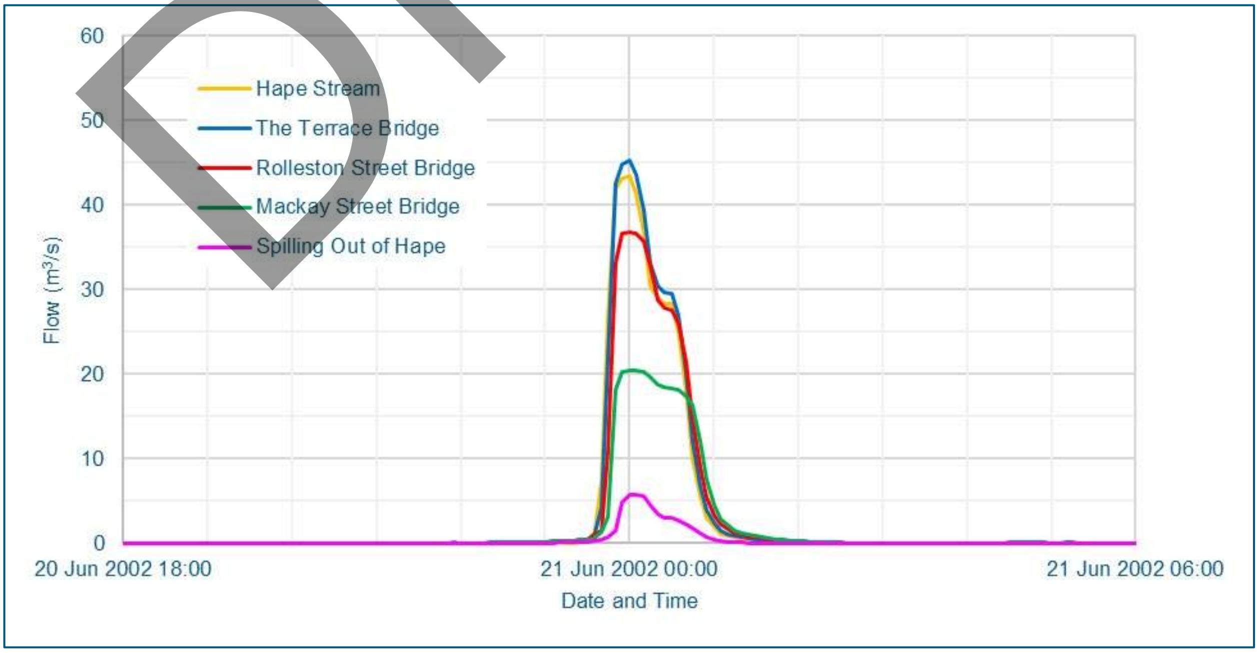


Figure 5-19: Flow Hydrographs in Hape Stream – The Weather Bomb

6 Additional Kauaeranga River Modelling

Following the calibration of the Thames streams catchments to the February 2023 Event and the limited information available for the validation to The Weather Bomb, an opportunity was identified to further calibrate the model through the modelling of the Kauaeranga River Catchment and comparing modelled and recorded flows at the Smiths Cableway Gauge. This was with the aim of further calibrating the model and gaining more confidence in the estimated historic and design peak flows arriving in Thames from the streams, most notably Karaka Stream.

This involved:

- Extending the TUFLOW Model to include the entire Kauaeranga River Catchment within the 2D domain;
- Performing a calibration / validation of the model using 2 historic events recorded by the Smiths Cableway Gauge;
- Comparing design peak flow estimates from the model to a Flood Frequency Analysis (FFA) of peak flows performed on the Smiths Cableway Gauge, conducted by WRC;

The idea was that this would lead to a more thorough calibration and more confidence in the design peak flow estimates for the project.

The aim was to attempt to adjust the roughness and loss parameters adopted for the stream catchments and hence provide more confidence in the design peak flow estimates at the streams due to the comparison of the Kauaeranga River design flood results to the FFA undertaken by WRC at the Smiths Cableway Gauge.

Table 6-1 presents the significant flood events recorded at the gauge. The table below shows that the largest events on record were in June 2014 and February 1985, though the February 2023 event was similar in magnitude and the selection of this event would also allow simultaneous calibration within the Thames township given the available Historical Flood Photos (refer Section 5). The Weather Bomb event was also chosen as a validation event, due to its smaller magnitude compared to the calibration event, allowing for an assessment of the model's performance in smaller flood events.

Table 6-1: Notable Events Recorded by the Smiths Cableway Gauge

Event	Peak Flow in Kauaeranga River (m^3/s)	Approximate ARI	Other information available?
February 2023	994	20 – 30 year	Rainfall and Tidal Information available
June 2002 (The Weather Bomb)	579	2 – 5 year	Rainfall and Tidal Information available
June 2014	1075	30 – 40 year	Rainfall and Tidal Information available
February 1985	1078	30 – 40 year	Rainfall and Tidal Data **not** available

The key findings of this exercise are summarised below and elaborated further in the following sections:

- A good fit was achieved to recorded flow at the Smiths Cableway Gauge for the February 2023 event;
- A good fit was not able to achieved for the 2002 Weather Bomb;

- A good match to peak flows between the model and the FFA by WRC at the Smiths Cableway Gauge without broad assumptions about the rainfall distribution in the Kauaeranga River catchment between the Thames EWS and the Pinnacles Gauge;
- A good level of confidence in the design rainfall losses to be adopted was achieved through the calibration to the February 2023 Event; and
- A good level of confidence in the catchment roughnesses to be adopted was found through the calibration to the February 2023 Event.

6.1 Model Extension to Include Kauaeranga River

Figure 6-1 below shows the TUFLOW Model extension to include the Kauaeranga River. The boundary was extended to include the entire Kauaeranga River catchment in the 2D domain, so that direct rainfall could be applied across the entire catchment, and modelled flows at the Smith Cableway Gauge could be compared to recorded data for the selected events. The Waikato LiDAR 2021 was used for the model topography in the Kauaeranga River catchment. Rainfall from the Thames EWS gauge was used in the lower part of the catchment, while rainfall data from the Pinnacles gauge was used in the upper part of the catchment. The rainfall distribution between these points is key to the entire calibration / validation and is discussed further in **Section 6.2**.

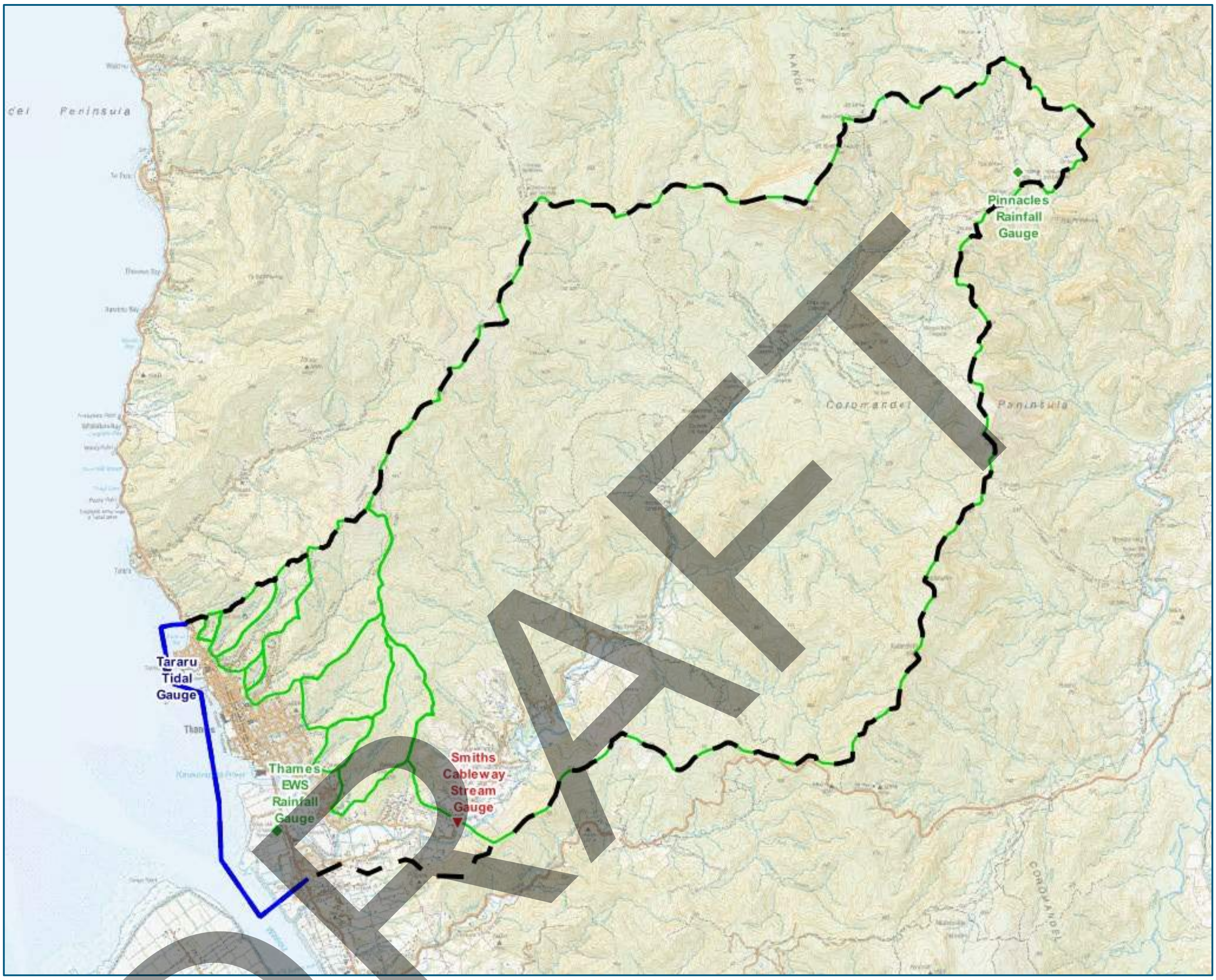


Figure 6-1: Extended TUFLOW Model Boundary Conditions

The Kauaeranga River catchment was separated into 3 land cover classifications which are summarised with their associated Manning's roughness values in **Table 6-2** below. In the initial calibration run for the Kauaeranga River, the same classifications and roughness values were used as for the Thames stream catchments in the previous TUFLOW model setup.

Table 6-2: Initial Kauaeranga River Calibration Parameters – February 2023 Event

Land use	Manning's Roughness	Initial Loss (mm)	Continuing Loss (mm/hr)	Rainfall Distribution
Forested Slopes	0.15 – 0.08 (from 0.4 m to 2 m depth)	50	4.5	As per Figure 6-3 below
Grass / Fields	0.045	50	4.5	
Rough Riverbed	0.08	50	4.5	

Figure 6-2 below shows the extent of each land cover classification within the Kauaeranga River catchment. While the extent of land cover classifications (such as forested slopes, grass/fields, and rough riverbed) in the Thames stream catchments remained unchanged, the roughness of these classifications was adjusted in the Thames stream catchments to match the adjustments made in the Kauaeranga River through the River model calibration process, which is outlined in the following section.

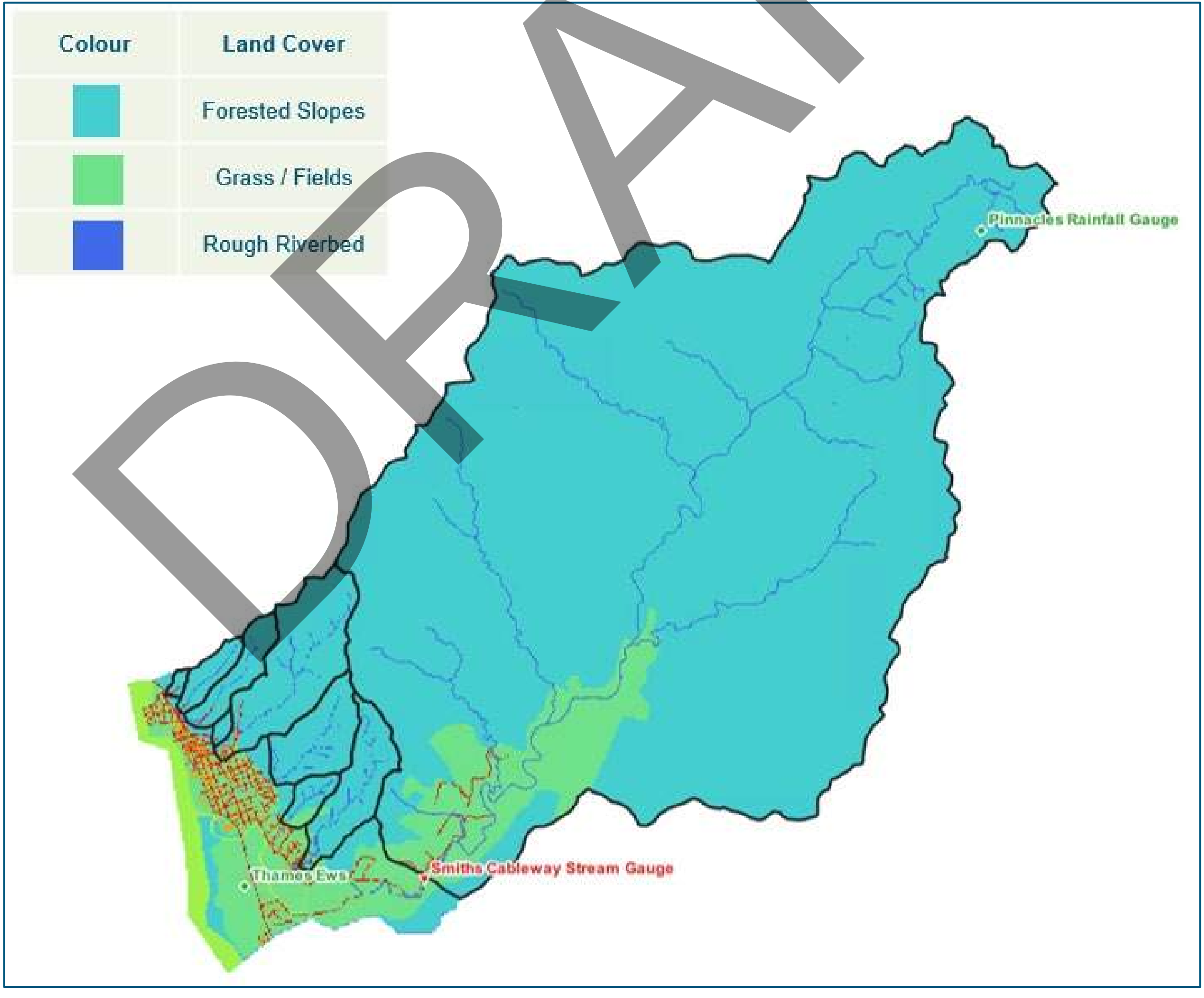


Figure 6-2: Extended TUFLOW Model - Land Cover Types

6.2 Kauaeranga River Calibration/Validation

The Kauaeranga River catchment was calibrated to the February 2023 Event and then the same parameters were used to simulate The Weather Bomb as a validation exercise.

6.2.1 February 2023 Kauaeranga River Calibration

Rainfall recorded by the Thames EWS Rainfall Gauge was applied at the bottom of the catchment and the Pinnacles Rainfall Gauge at the top of the catchment. The rainfall in between the two locations was initially distributed using an inverse distance weighting (meaning that the closer a point was to a gauge, the more influence that gauge's data had on the rainfall at that point).

Figure 6-3 below shows the rainfall assigned to the catchment based on inverse distance weighting.

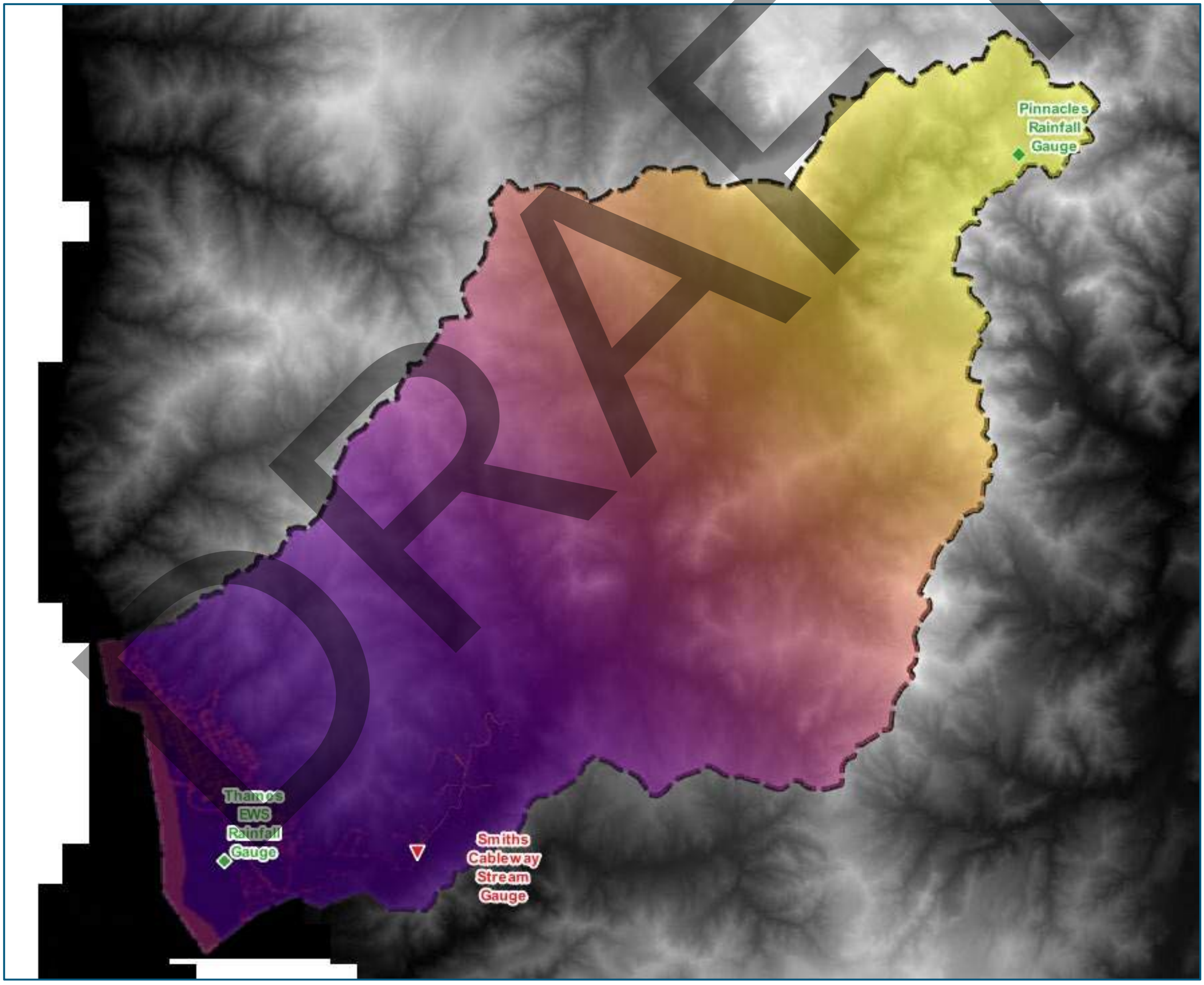


Figure 6-3: February 2023 – Initial Calibration attempt - Modelled Rainfall Distribution – Inverse Distance Weighting (PRELIMINARY)

Figure 6-4 below shows that during the February 2023 event, approximately 200 mm of rainfall was recorded by the Thames EWS gauge and approximately 630 mm was recorded by the Pinnacles gauge. The figure also shows that a peak flow of 1000 m^3/s was observed by the Smiths Cableway Gauge, peaking between 02:00 and 03:00 on 14 February 2023. **Figure 6-4** also shows the flow hydrograph at the Smiths Cableway from the simulation with parameters as described above – **Modelled Calibration Flow**

(Preliminary). The figure shows that the recorded hydrograph had significantly more volume that the modelled hydrograph, The figure also shows that the modelled hydrograph peaked almost 2 hours before the recorded hydrograph.

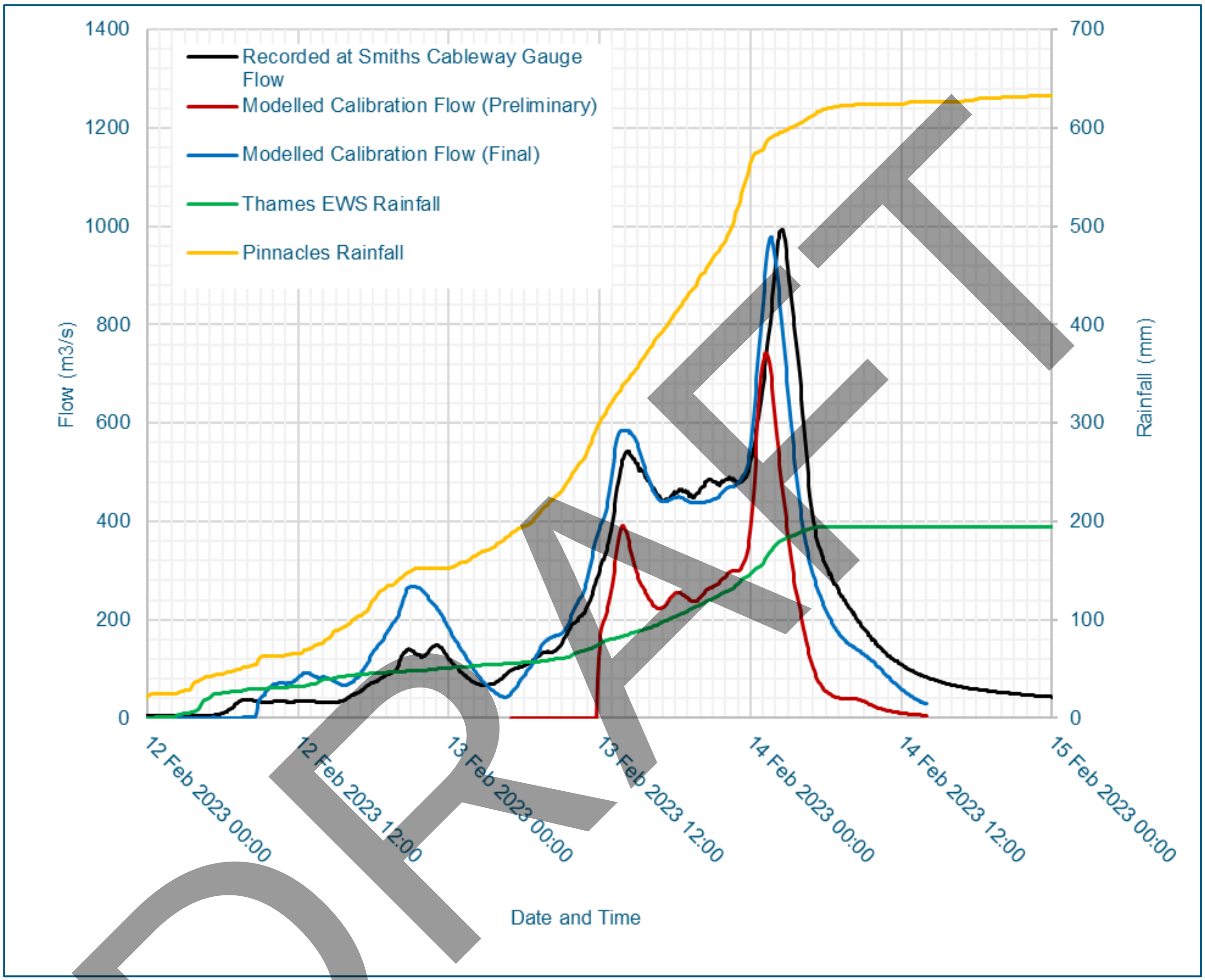


Figure 6-4: Recorded Rainfall and Recorded and Modelled Flow at Smiths Cableway – February 2023 Event

As a result of this initial calibration attempt, the rainfall losses were incrementally reduced from 4.5 mm/hr, however it was found that the peak flow at the Smiths Cableway gauge was not as sensitive to the loss rate as the distribution of the rainfall across the catchment.

The initial loss was changed from 50 mm to 10 mm, and again it was found that flow was also not sensitive to initial losses.

Therefore, the rainfall distribution was changed based on an approximation of the orographic effect. The orographic effect is a phenomenon where an increase in elevation results in an increase in rainfall due to the clouds being pushed up and releasing more precipitation which may have been the reason why more rainfall was recorded at the Pinnacles gauge than the Thames EWS. As such, it was decided to examine the topography of the Kauaeranga River catchment and see where a likely boundary would be, where higher elevations may be influencing orographic rainfall. It was assumed that the downstream end of the catchment would have the Thames EWS applied and the upstream side would have the Pinnacles gauge applied, with an elevation based distribution in between.

The approximated rainfall distribution adopt for this calibration attempt is shown in **Figure 6-5** below. This, in combination with increased roughness and reduced losses resulted in a hydrograph more closely matching what was recorded – **Modelled Calibration Flow (Final)**. The shape of the falling limb more closely matches the recorded hydrograph, indicating that the continuing losses are more accurate and the timing of the peak is closer to the recorded data. There is also a good match on flow for the first peak after 12:00 13 February, as well as the second peak after 00:00 14 February. For a better match, more information would have to be gathered regarding the distribution of rainfall over the catchment using weather radar data (if available).

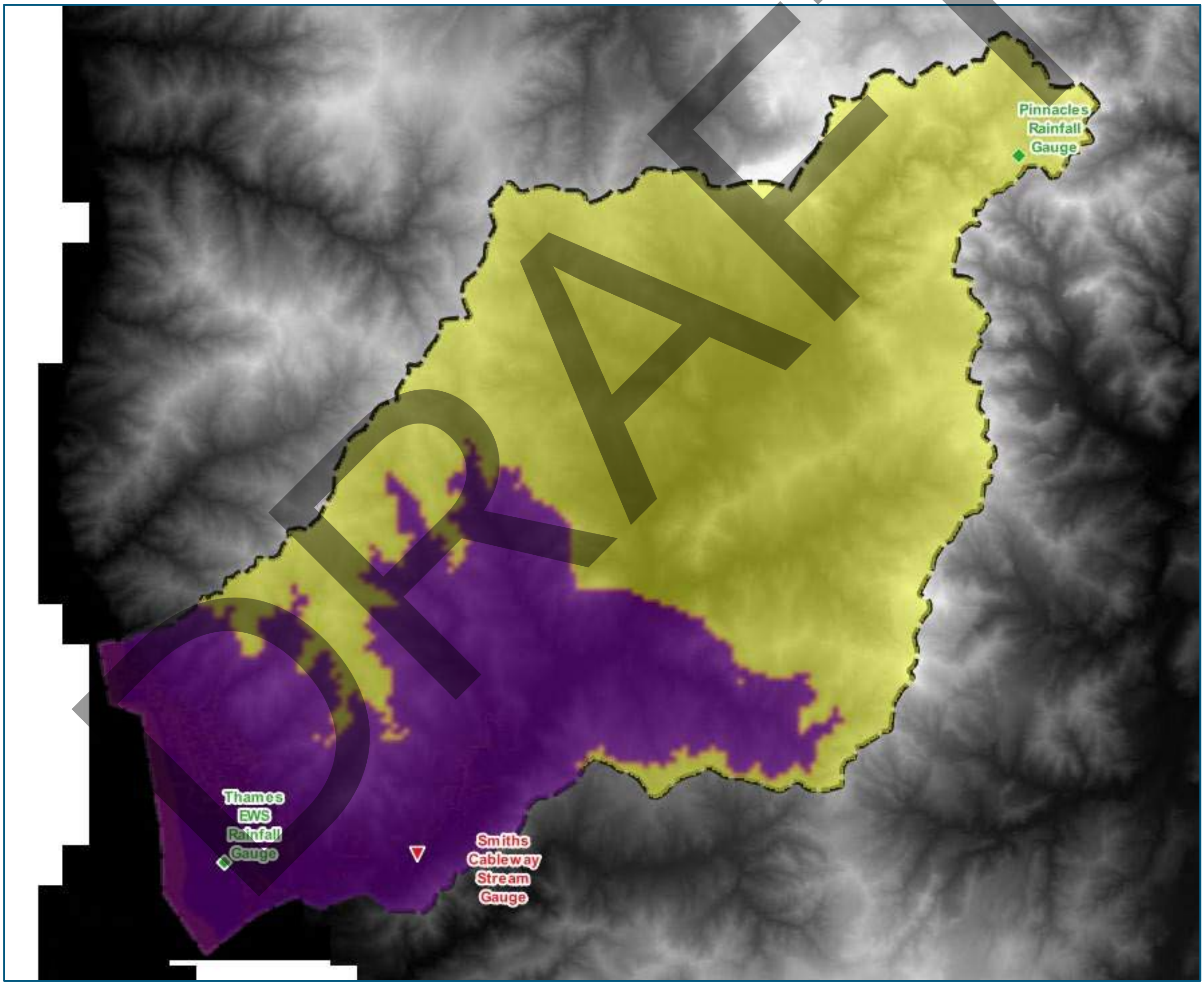


Figure 6-5: February 2023 Modelled Rainfall Distribution – Approximation Based on Elevation affecting Orographic Effects (FINAL)

The final calibration parameters are shown in **Table 6-3** below.

Table 6-3: Final Kauaeranga River Calibration Parameters – February 2023 Event

Land use	Manning's Roughness	Initial Loss (mm)	Continuing Loss (mm/hr)	Rainfall Distribution
Forested Slopes	0.25 – 0.22 (from 0.4 m to 2 m depth)	10	1.3	As per Figure 6-5 above
Grass / Fields	0.045	10	1.3	
Rough Riverbed	0.22	10	1.3	

The roughness estimated in the Kauaeranga River catchment for final calibration was adopted in the Thames stream catchments. The rainfall distribution in Kauaeranga River did not have any substantial effect on the Thames stream catchments and so the Thames EWS rainfall gauge was adopted for the Thames stream catchments, which means that they had the same rainfall as in the previous calibration to the Drone Photographs.

Figure 6-6 below shows the rainfall recorded by the Pinnacles and Thames EWS gauges leading up to the simulation of the February 2023 Event. The Pinnacles gauge recorded nearly 800 mm of rainfall in the two weeks before the start of the flood event, whereas the Thames EWS gauge recorded only 200 mm, in comparison. For this reason, the rainfall losses in the Kauaeranga River were adjusted to 1.3 mm/hr through the calibration process and the rainfall losses were kept at 4.5 mm/hr for the Thames stream catchments, since it was assumed that the rainfall falling on the Thames stream catchments in this event was more similar to the Thames EWS than the Pinnacles Gauge, due to the Thames streams being at a much lower elevation.

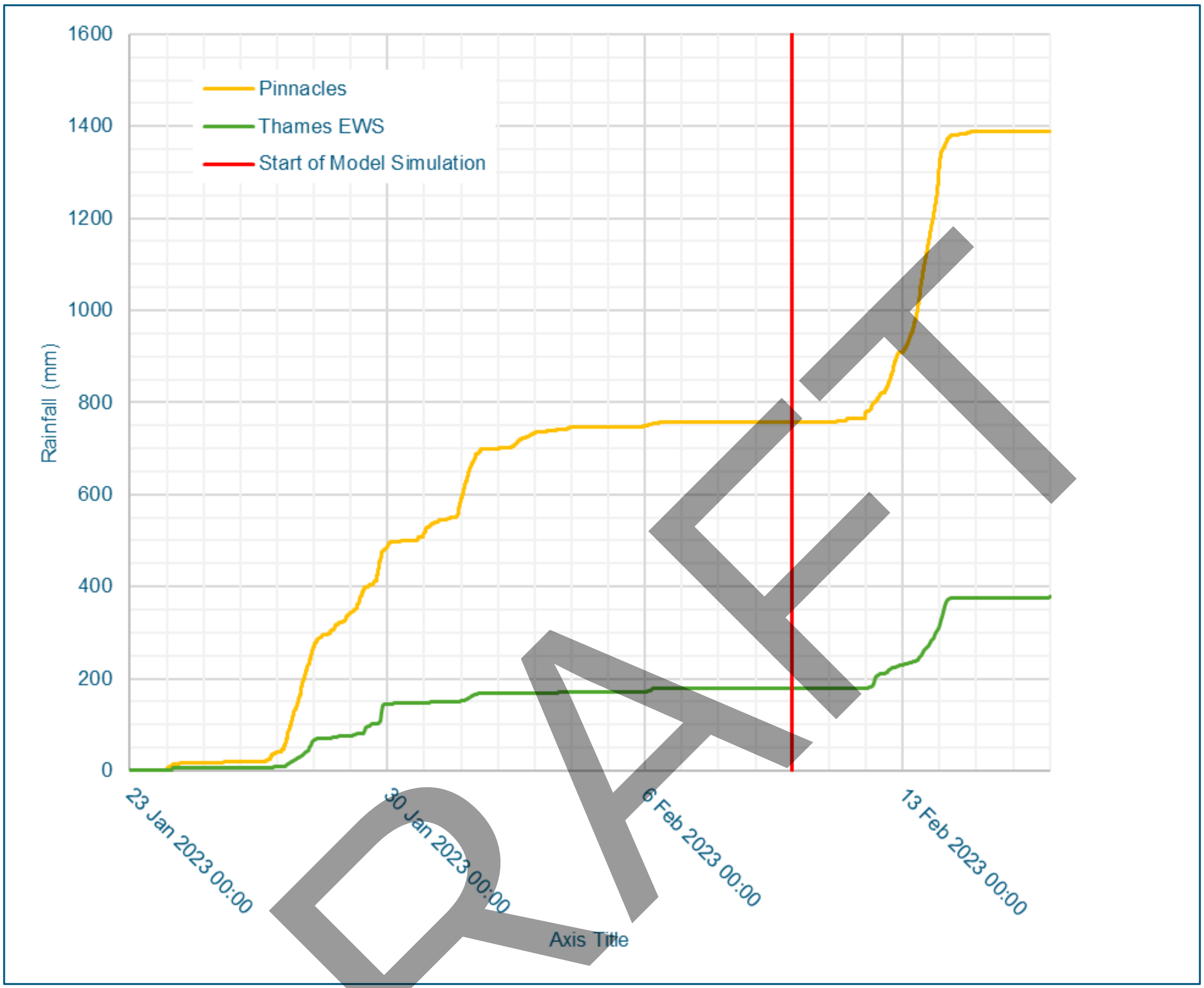


Figure 6-6: Rainfall Leading up to February 2023 Event

Figure 6-7 below shows the modelled flow in Karaka Stream for the February 2023 event before and after calibration of the model to the Kauaeranga River. The figure shows a slight reduction in peak flow (approximately 1 m^3/s) due to the increased roughness. Note that the additional flow in the simulation after calibration around 13 February is due to the model simulation starting earlier, whereas the previous run commenced after 13 February (difference shown with a dashed red circle in the Figure below).

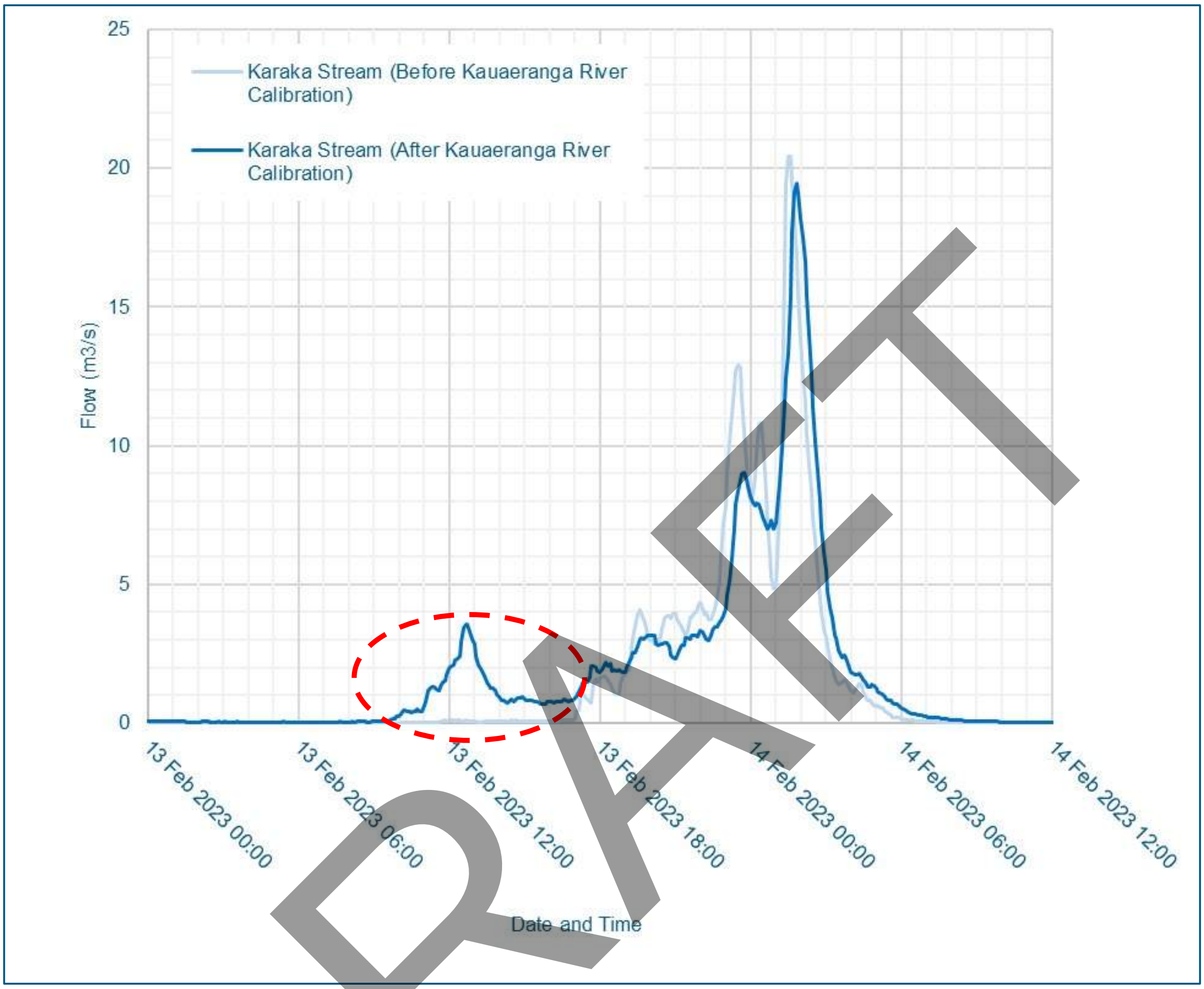


Figure 6-7: Flow in Karaka Stream Before and After Kauaeranga River Calibration – February 2023 Event

6.2.2 June 2002 (The Weather Bomb) Kauaeranga River Validation

Figure 6-8 below shows that approximately 140 mm was recorded by the Thames EWS gauge and approximately 310 mm was recorded by the Pinnacles gauge during the 2002 Weather Bomb event. The figure also shows that a peak flow of 580 m^3/s was observed by the Smiths Cableway Gauge, peaking between 02:00 and 03:00 on 21 June 2002. **Figure 6-8** also shows the flow hydrograph at the Smiths Cableway from the simulation with parameters determined from the calibration to the February 2023 Event, including the rainfall distribution shown on **Figure 6-5** above – Modelled Calibration Flow (Preliminary). The figure shows that the recorded hydrograph had a smaller first peak followed by a larger second peak compared to the modelled hydrograph.

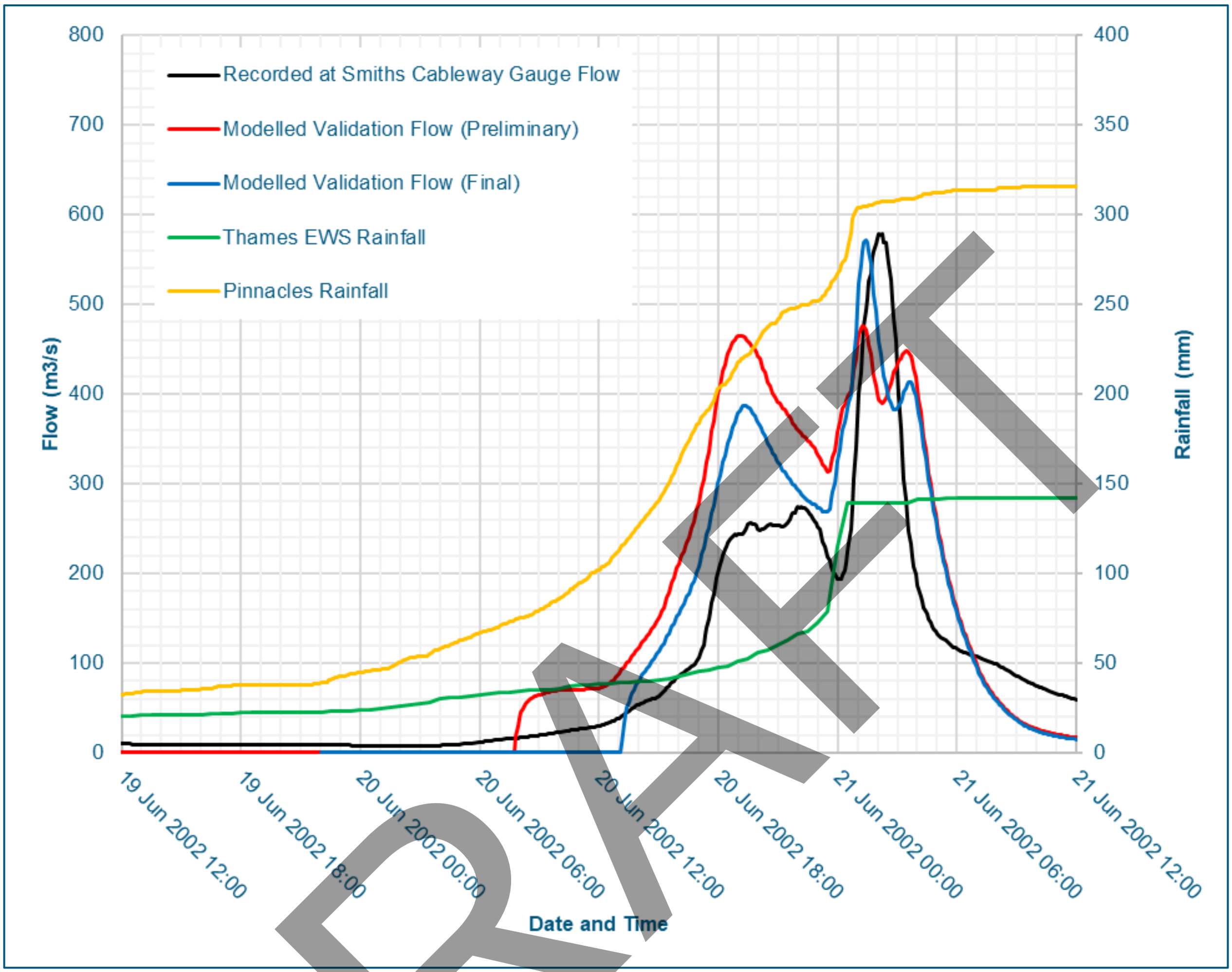


Figure 6-8: Recorded Rainfall and Recorded and Modelled Flow at Smiths Cableway – The 2002 Weather Bomb

The figure shows that the Thames EWS recorded a rainfall pattern more similar to the observed hydrograph at the Smiths Cableway Gauge given that there is a spike in rainfall before the second peak, whereas the first peak was likely due to the small spike seen in the Pinnacles Rainfall Gauge at approximately 18:00 on 20 June. As such, the rainfall was adjusted so that more rainfall from the Thames EWS was applied to the River catchment for this event. This resulted in an overestimation of the second peak and underestimation of the first. Several rainfall distributions were tested as well as several continuing loss rates to attempt to match the recorded hydrograph. The flow was found to be sensitive to rainfall distribution, but not to rainfall losses.

Figure 6-8 above shows the flow hydrograph at the Smiths Cableway Gauge from the simulation with the final parameters for validation – Modelled Validation Flow (Final). **Figure 6-9** below shows the rainfall distribution used for the final validation of the 2002 Weather Bomb with an initial loss rate of 1.5 mm/hr. This was decided based on the match between the recorded and modelled peak flow, but attempts to further match the shape of the hydrograph and the magnitude of the first peak were unsuccessful due to the uncertainty of the actual rainfall distribution that occurred. The importance of the rainfall distribution to the flood behaviour in the Thames Township were less critical than in the Kauaeranga River, as mentioned above due to the proximity of the Thames stream catchments to the Thames EWS Gauge, and confidence in the catchment parameters derived in the February 2023 Calibration was decided to be satisfactory.

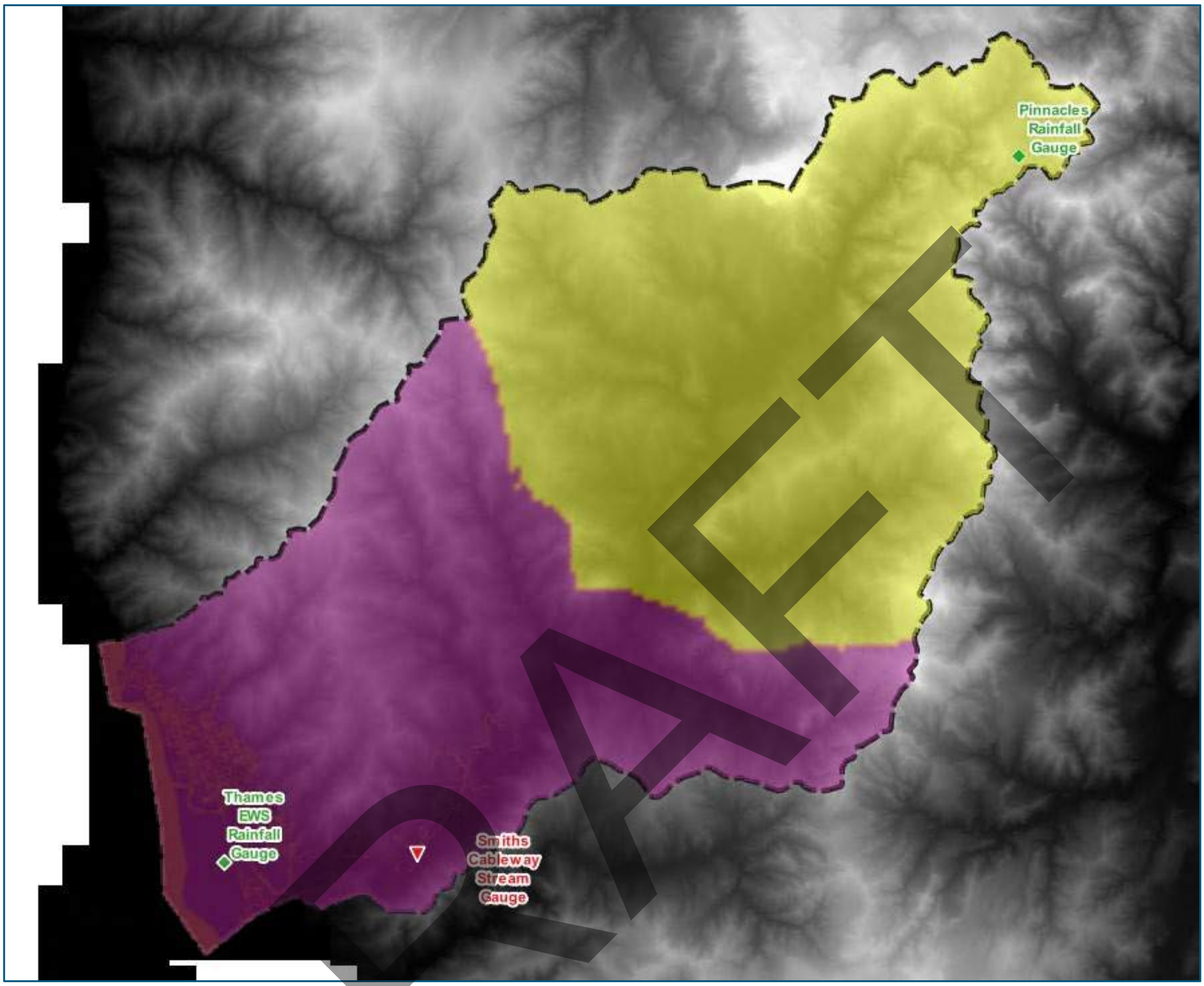


Figure 6-9: The Weather Bomb Modelled Rainfall Distribution – Approximation Based on Orographic Effect

Figure 6-6 below shows the rainfall recorded by the Pinnacles and Thames EWS gauges leading up to the simulation of the 2002 Weather Bomb. Both gauges recorded between 50 to 100 mm of rainfall in the two weeks before the start of the simulation. For this reason, the rainfall losses in the Kauaeranga River and the stream catchments were both set at 1.5 mm/hr.

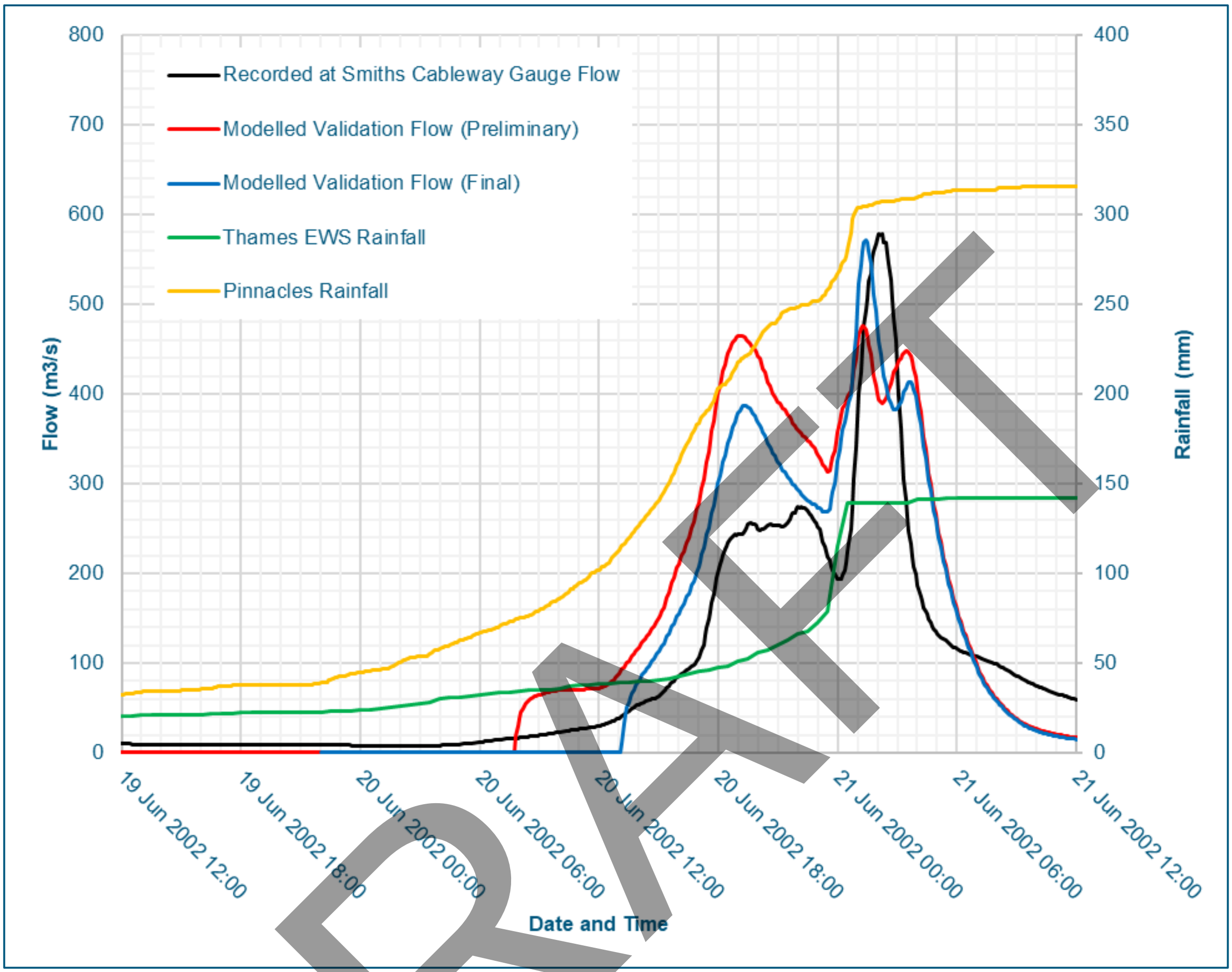


Figure 6-7 below shows the modelled flow in Karaka Stream in the 2002 Weather Bomb before and after calibration of the model to the Kauaeranga River. The figure shows a slight reduction in peak flow (approximately 5 m^3/s) due to the increased roughness and reduction in continuing loss from 4.5 mm/hr to 1.5 mm /hr.

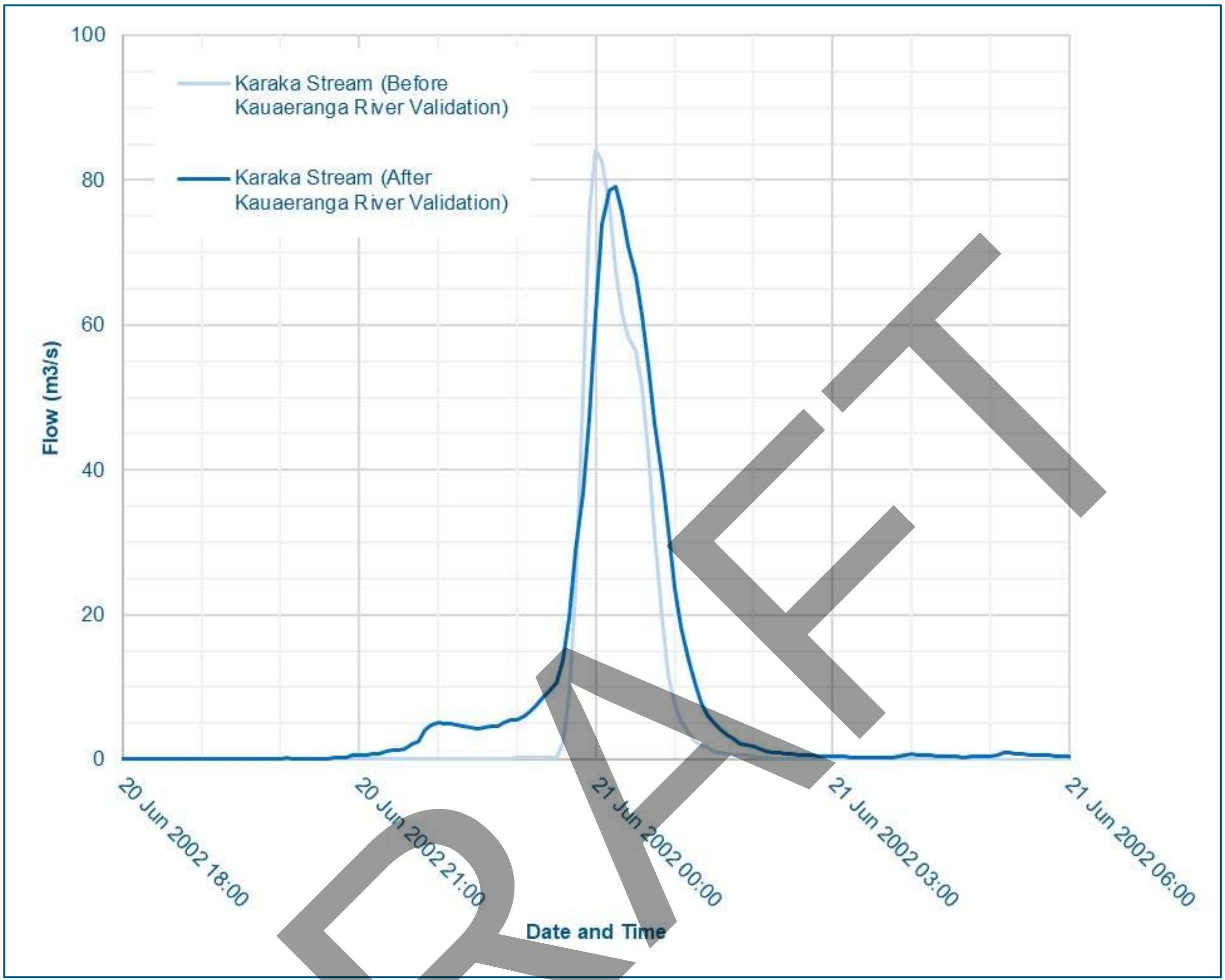


Figure 6-10: Flow in Karaka Stream Before and After Kauaeranga River Calibration – 2002 Weather Bomb

6.3 Comparison of Kauaeranga River Design Peak Flow Estimates

Design rainfall depths from the NIWA HIRDS v4 database were used to generate design storm discharge estimates for the Thames streams. The Thames EWS gauge and the Pinnacles Gauge were selected and design rainfall depths derived at two locations were used, at the these two gauges. The design rainfall depths were applied with the addition of the standard error.

The derived design rainfall depths are shown in **Figure 6-11** below. The figure shows that the design rainfall in the vicinity of the Pinnacles Gauge is significantly higher than at the Thames EWS, for example the 100 year ARI, 1 hour design rainfall depth at the Thames EWS is approximately 70 mm and at the Pinnacles gauge it is approximately 100 mm.

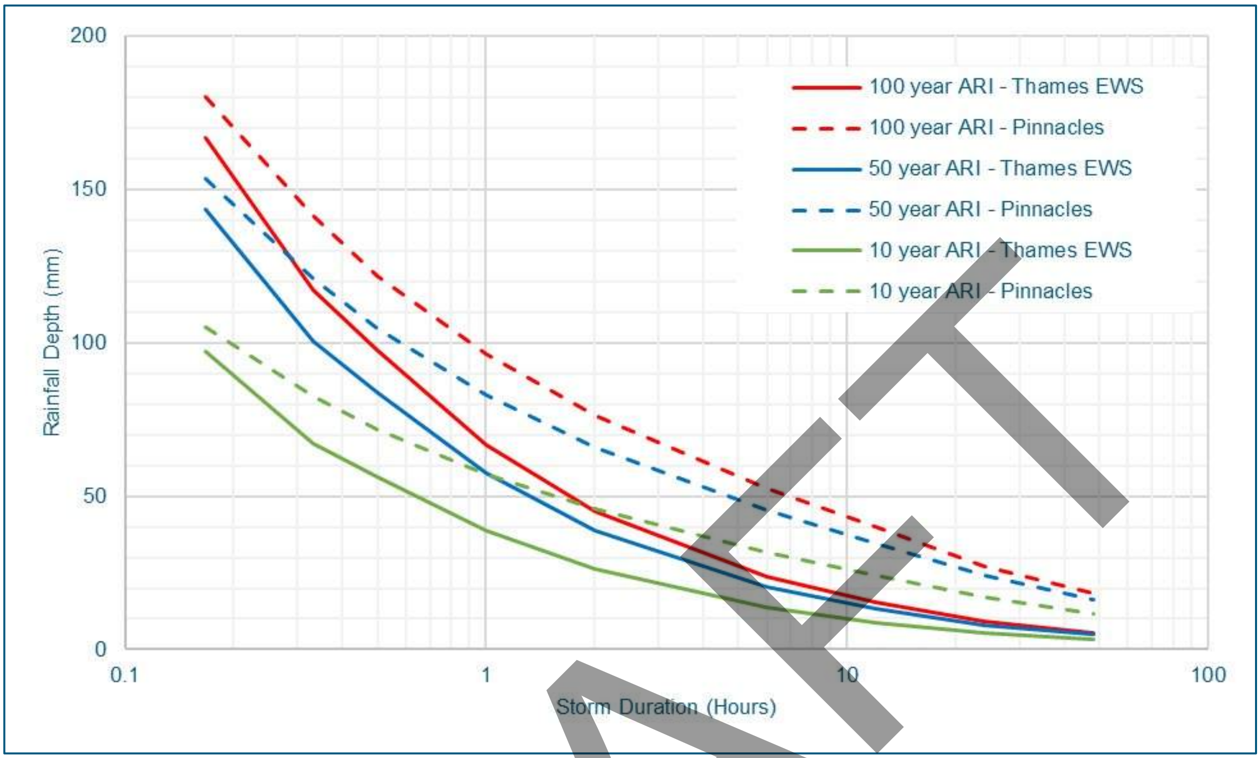


Figure 6-11: Design Rainfall Depths at the Thames EWS and Pinnacles Gauges

The design rainfalls were applied similarly to the historic events used for the calibration, where the rainfall from each gauge was split, with the rainfall between the upstream and downstream end of the catchment.

Several rainfall distributions were tested with the aim of matching the peak flows which were derived from the FFA undertaken by WRC. The first to be tested was the distribution used for the February 2023 Event which is pictured above in **Figure 6-5**.

This rainfall distribution resulted in a significant overestimate in peak flows (refer **Table 6-4** below). Several other rainfall distributions were tested and through this process, it was found that the peak flow at the Kauaeranga River was most sensitive to the distribution rather than other factors such as rainfall losses.

The distribution which was used to achieve the best match to the 100 year ARI peak flow is shown in **Figure 6-12** below with an initial loss of 10 mm and continuing loss of 1.3 mm/hr, which was the loss rate used in the February 2023 Calibration for the River. The table shows that although the 100 year ARI flow in the model was close to the FFA estimate, the smaller events were significantly underestimated.

Table 6-4: Comparison of Design Peak Flow Estimates and the Smiths Cableway Gauge

Event	**FFA**	**Modelled (Preliminary)**	**Modelled** (Final)
10 year ARI	806	Not Modelled	558
50 year ARI	1104	1935	983
100 year ARI	1230	2267	1204

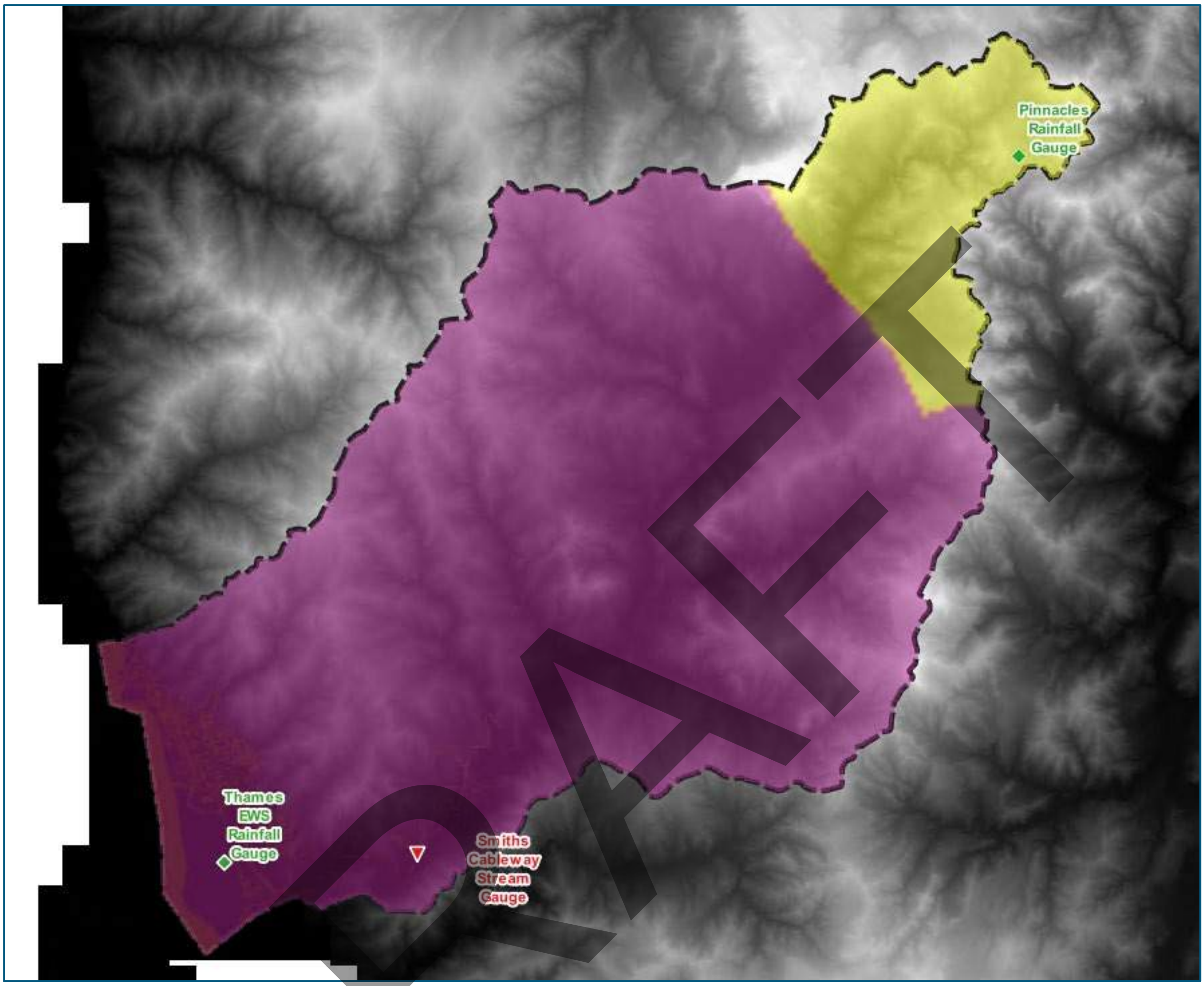


Figure 6-12: Design Event Modelled Rainfall Distribution – Approximation Based on Orographic Effect

The distribution shown in **Figure 6-12** above was made with the aim of matching of the 100 year ARI peak flow, but as mentioned above, the estimate of more frequent events was underestimated. The distribution was not based on a physical phenomenon, especially given that the matching was only to peak flow and not entire hydrographs where the timing and shape of the hydrograph could be adjusted with catchment parameters and rainfall distributions. This indicated to RHDHV that the attempt to utilise the TUFLOW Model to determine appropriate design inflows to the Thames model was providing less valuable than simply adopting design unit hydrographs for the Kauaeranga River derived from the peak flows estimated through the Flood Frequency Analysis undertaken by WRC.

For this reason, it was decided to adopt the FFA peak flows for the model at the Smiths Cableway Gauge using a synthetic hydrograph shape developed with reference to the *Waihou River Service Level Review* (Stantec, 2023), which is discussed further in **Section 7.3**. The rainfall distribution was also not critical to the flows arriving in Thames from the smaller streams given the proximity of the Thames stream catchments to the Thames EWS gauge. Therefore it was possible to adopt the Thames EWS rainfall for those catchments, regardless of the rainfall distribution used in the much larger Kauaeranga River catchment.

Table 6-5 below shows the peak flow estimates in Karaka Stream and peak water level in the vicinity of Albert Street for the 10, 50 and 100 year ARI events before the calibration. The results for a range of durations are presented with the critical duration for peak flow or peak water level highlighted in red.

Table 6-5: Design Event Results Before the attempted Kauaeranga River Model Calibration

<table>
<tr><th colspan="6">Peak Flow in Karaka Stream Before Calibration</th></tr>
<tr><th>Event</th><th>1 Hour Storm</th><th>2 Hour Storm</th><th>6 Hour Storm</th><th>12 Hour Storm</th><th>24 Hour Storm</th></tr>
<tr><td>10 year ARI</td><td>40.9</td><td>47.4</td><td>26.2</td><td>14.9</td><td>-</td></tr>
<tr><td>50 year ARI</td><td>91.3</td><td>79.5</td><td>41.4</td><td>24.7</td><td>-</td></tr>
<tr><td>100 year ARI</td><td>111.8</td><td>94.2</td><td>49.5</td><td>29.7</td><td>-</td></tr>
<tr><th colspan="6">Peak Water Level in the Vicinity of Albert St Before Calibration (m NZVD)</th></tr>
<tr><th>Event</th><th>1 Hour Storm</th><th>2 Hour Storm</th><th>6 Hour Storm</th><th>12 Hour Storm</th><th>24 Hour Storm</th></tr>
<tr><td>10 year ARI</td><td>2.26</td><td>2.48</td><td>2.44</td><td>2.16</td><td>-</td></tr>
<tr><td>50 year ARI</td><td>2.64</td><td>2.71</td><td>2.64</td><td>2.51</td><td>-</td></tr>
<tr><td>100 year ARI</td><td>2.78</td><td>2.81</td><td>2.73</td><td>2.64</td><td>-</td></tr>
</table>

Table 6-6 below shows the peak flow in Karaka Stream and peak water level in the vicinity of Albert Street for the 10, 50 and 100 year ARI events after the Kauaeranga River calibration. The results for a range of durations are presented with the critical duration for peak flow or peak water level highlighted in red. The table shows that the critical duration for peak flow in Karaka Stream was the 2 hour storm, rather than the 1 hour storm that was evident in Table 6-5 before the River calibration. The peak flow has also reduced from before and after the model calibration despite the reduction in continuing loss. Despite these changes, the differences are relatively minor, and it is suggested that the latest results be adopted going forward.

Table 6-6: Design Event Results After Model Calibration

Peak Flow in Karaka Stream After Calibration (m3/s)					
Event	**1 Hour Storm**	**2 Hour Storm**	**6 Hour Storm**	**12 Hour Storm**	**24 Hour Storm**
10 year ARI	29.1	42.4	29.5	18.9	12
50 year ARI	68.6	75.3	44.4	28.6	18.2
100 year ARI	88.5	91.3	52.6	33.6	20.9

Peak Water Level in the Vicinity of Albert St After Calibration (m NZVD)					
Event	**1 Hour Storm**	**2 Hour**	**6 Hour Storm**	**12 Hour Storm**	**24 Hour Storm**
10 year ARI	2.17	2.48	2.52	2.38	1.83
50 year ARI	2.61	2.71	2.67	2.56	2.38
100 year ARI	2.69	2.85	2.75	2.66	2.47

7 Design Event Modelling

7.1 Selected Design Events

Table 7-1 below outlines the design events assessed for this study. The table shows the design catchment flood events and the coincident catchment and ocean floods used to derive the final design flood conditions for each event. For events more frequent than the 100 year ARI, a Highest Astronomical Tide (HAT) ocean condition was applied. For the 100 year ARI, an 'enveloped' approach was used, with two separate simulations: one with a 100 year ARI catchment flood combined with a 10 year ARI storm tide, and another scenario with a 10 year ARI catchment flood combined with a 100 year ARI storm tide. The worst flood condition at each location from these simulations was then adopted resulting in the 100 year ARI 'Envelope'.

This approach was chosen because a 100-year ARI catchment flood coinciding with a 100-year ARI storm tide is considered a lower probability (less frequent) than a 100-year ARI event. Typically, a 100-year ARI and 10-year ARI coincident probability is used for WRC assessments. While guidance in NSW, Australia, suggests using a 100 year ARI and 20 year ARI coincident probability (Office of Environment and Heritage, 2015), it is noted that heavy rainfall and ocean events in New Zealand are generally not as strongly correlated (S. Stephens W. W., 2022). Therefore, the WRC guidance was adopted for this study.

Table 7-1: Design Events

Design Storm for Peak Flood Level	Catchment Flood	Ocean Water Level
10 year ARI	10 year ARI	HAT
50 year ARI	50 year ARI	HAT
100 year ARI	10 year ARI	100 year ARI
	100 year ARI	10 year ARI
100 year ARI Sensitivity	100 year ARI	100 year ARI
100 year ARI 2080 Climate Change (0.3m SLR over 50 year horizon, as adopted in the Coastal Study) + Vertical Land Movement	100 year ARI + increased rainfall	10 year ARI + SLR + VLM
	10 year ARI + increased rainfall	100 year ARI + SLR + VLM
100 year ARI 2130 Climate Change (0.9m SLR over 100 year horizon, as adopted in the Coastal Study) + Vertical Land Movement	100 year ARI + increased rainfall	10 year ARI + SLR + VLM
	10% AEP + increased rainfall	1% AEP + SLR + VLM

7.2 Design Rainfall derived from NIWA HIRDS v4

Design rainfall depths from the NIWA HIRDS v4 database were used. The location selected was the Thames EWS gauge due to the long period of continuous record used in the design rainfall frequency analysis (1966 – 2008). The design rainfall depths were applied with the addition of the standard error. The adopted design rainfall depths are presented in **Table 7-2** below.

Table 7-2: Design Rainfall Depth (mm) (Standard Error Included)

ARI	Duration							
	20 Minute	30 Minute	1 Hour	2 Hour	6 Hour	12 Hour	24 Hour	48 Hour
Thames EWS								
5	18.5	23.2	31.9	43.6	68.7	89	112	136.9
10	22.4	28.2	38.7	52.7	82.9	107.3	133.4	163.9
20	26.9	33.7	46.2	62.7	98.7	128	158	192
50	33.5	41.9	57.4	77.6	122	158	192	234
100	39	48.9	66.8	90.4	143	184	220	268
250	47.2	59.3	81.6	109.4	172	223	261	317

Calibration losses from the February 2023 Event were applied for design rainfall events, which was an initial loss of 10 mm and a continuing loss of 1.3 mm/hour.

The rainfall was applied with the HIRDS temporal patterns (NIWA, 2018). The 24 hour embedded storm burst which is typically applied based on the *Waikato stormwater runoff modelling guideline* (Earl Shaver (Aqua Terra International Limited), 2020) was tested but was found to provide significantly higher peak flow estimates that the HIRDS temporal patterns. The HIRDS temporal patterns were therefore adopted, given that this study found that peak flow estimates were already higher than previous studies (further details in **Section 7.5**). It was found that for ponding in the Thames township within the study area, the 2 hour duration storm was critical for the 10, 50 and 100 year ARI events and so was used for all subsequent model runs (refer **Figure 7-1**, **Figure 7-2** and **Figure 7-3**). Note that for the 10 year ARI (**Figure 7-1)**, the 6 hour duration was critical but only exceeded the 2 hour duration by 4 cm, so the 2 hour duration was adopted due to the higher peak flow in Karaka and Hape Stream in the 2 hour storm when compared to the 6 hour.

Figure 7-1: Critical Duration for Peak Water Level – 10 year ARI

Figure 7-2: Critical Duration for Peak Water Level – 50 year ARI

Figure 7-3: Critical Duration for Peak Water Level – 100 year ARI

7.3 Kauaeranga River Flow

A unit hydrograph was developed with the peak flows derived from a Flood Frequency Analysis (FFA) of the Smiths Cableway Gauge from WRC. The unit hydrograph was developed with a time to peak of 10 hours which is equivalent to the time to peak derived for the Kauaeranga River design hydrographs from the *Waihou River Service Level Review* (Stantec, 2023) which were determined based on a NAM hydrological model. The hydrographs were input to the TUFLOW model at the upstream boundary of the Thames TUFLOW model at the Smiths Cableway Gauge. Given that the peak of the Kauaeranga River hydrograph arrived near Thames just over 10 hours into the simulation, the peak of the catchment flood from the local streams was delayed to coincide with the peak of the Kauaeranga River hydrograph at the outlet of Hape Stream into the Kauaeranga River (i.e. this is a slightly conservative case).

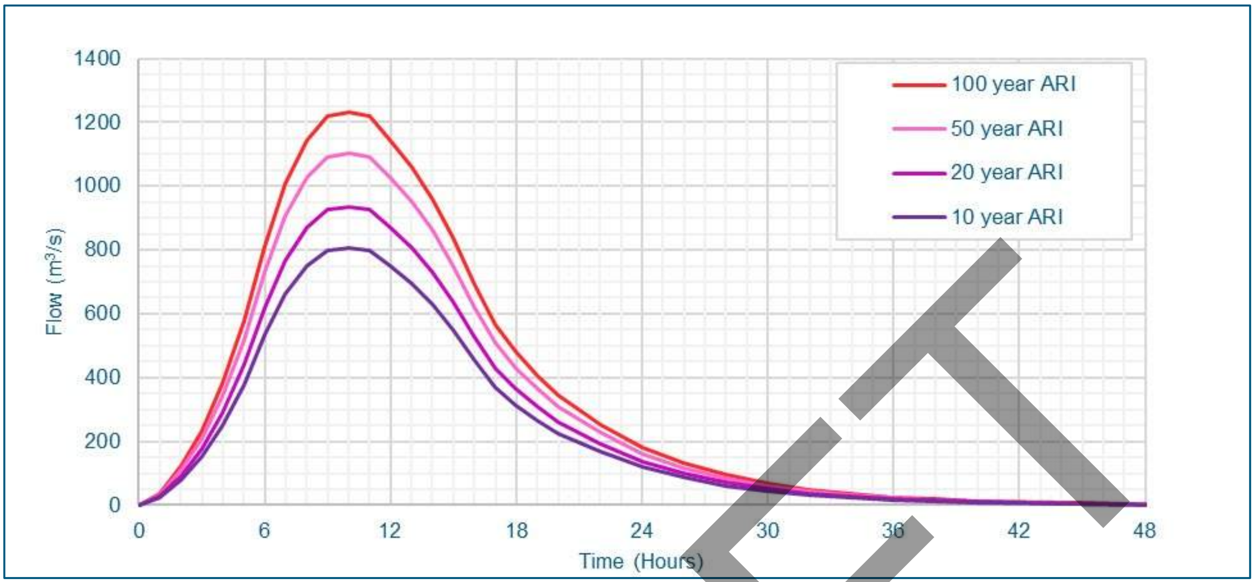


Figure 7-4: Kauaeranga River Design Hydrographs

7.4 Ocean Boundary

A synthetic design storm tide timeseries was applied at the design ocean boundary. This was derived from examining the Tararu tidal timeseries to identify a cycle where the peak water level matched the Highest Astronomical Tide (HAT). This timeseries was then applied for the 10, 20 and 50 year ARI Events as per **Figure 7-5**.

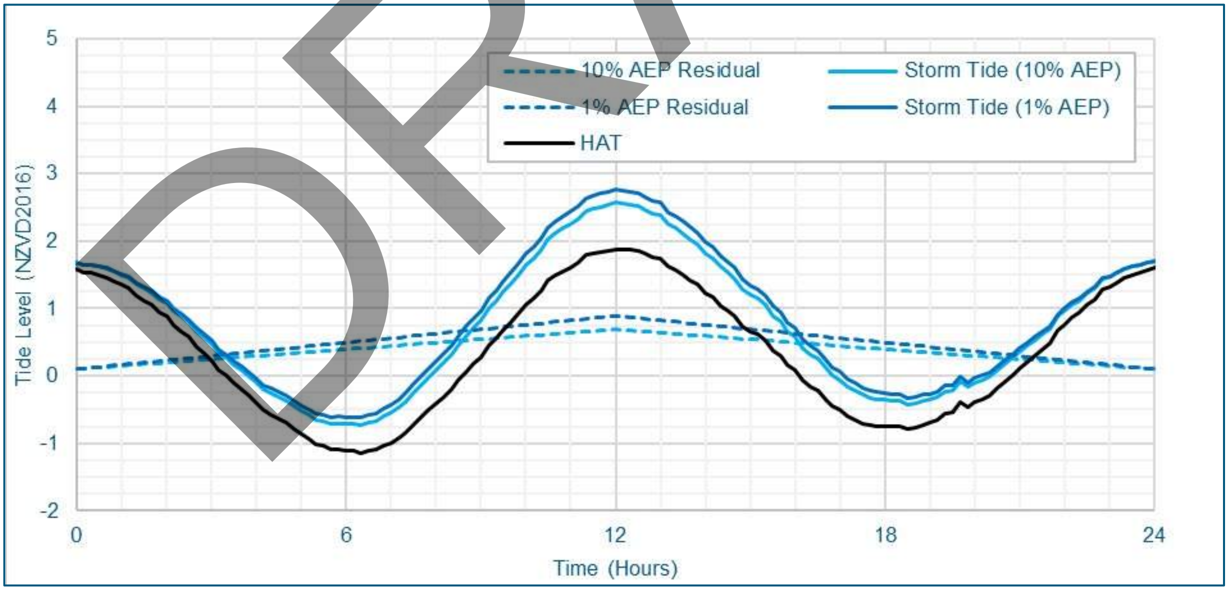


Figure 7-5: Design Storm Tide Timeseries

For the 100 year ARI envelope, the 10 year ARI and 100 year ARI storm tide time series were derived by adding a synthetic 'residual' to the HAT time series. The storm tide levels, based on NIWA's 2019 Storm Guidance, were converted from the Tararu Vertical Datum (TVD 52) to the New Zealand Vertical Datum (NZVD). The appropriate storm tide residual was determined by ensuring that the HAT plus the residual equalled the storm tide level in NZVD. The residuals and storm tide levels are presented in **Table 7-3**.

Table 7-3: Design Storm Tide Levels

Datum / Level	10 year ARI	100 year ARI
HAT (m NZVD)	1.88	1.88
Storm Tide Level (m Tararu Datum)	2.77	2.98
Storm Tide Level (m NZVD)	2.57	2.78
Residual (m)	0.69	0.89

As outlined earlier, the shape of the residual was derived from an analysis of historic storm data recorded at the Tararu gauge (S. Stephens B. R., 2015). The results of that study indicated that for the historic storms assessed, the residual component of the storm tide increased linearly for approximately 24 hours and then decreased linearly for a further 24 hours (refer **Figure 7-6** below). This pattern was then applied to the synthetic residual, aligning its peak with the peak of the HAT timeseries. The peak of the storm tide was aligned with the peak of the catchment flood from the Thames Streams and the Kauaeranga River.

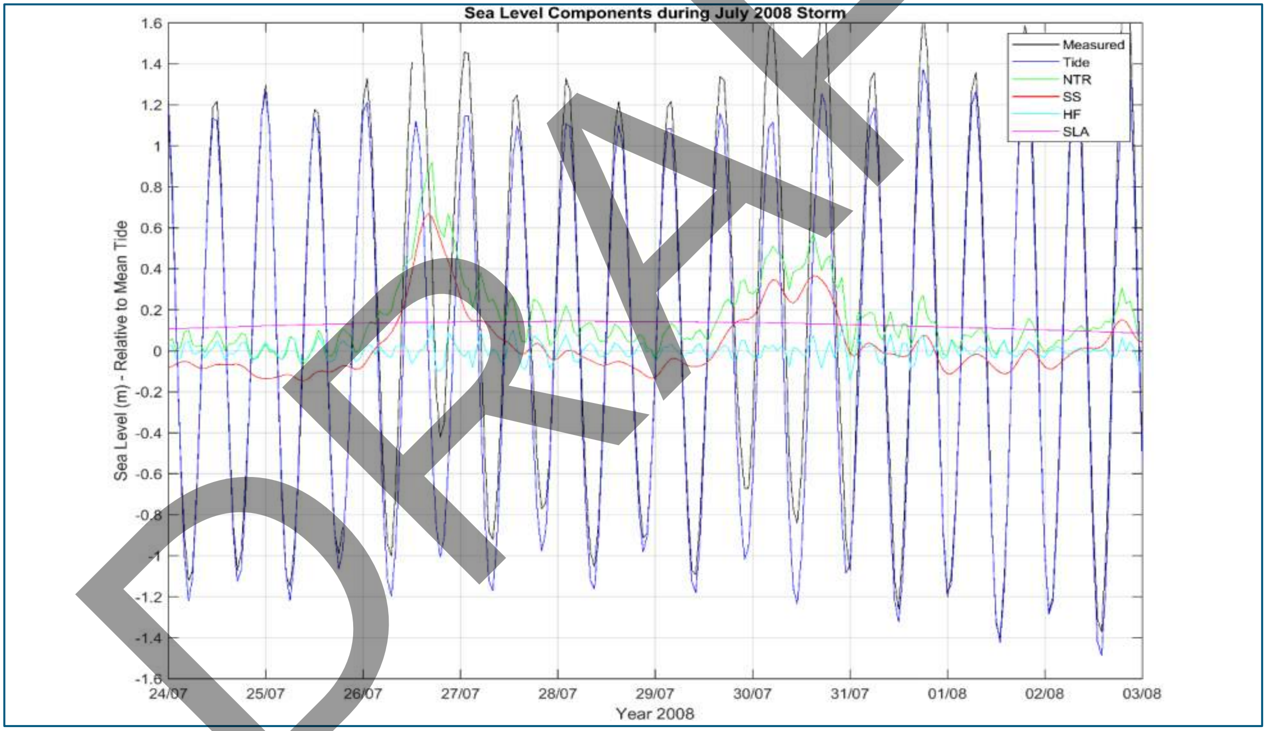


Figure 7-6: Sea Level Components During July 2008 Storm – Tararu Tidal Gauge – Excerpt from (S. Stephens B. R., 2015)

7.5 Comparison of Peak Flows to Previous Study Estimates

Table 7-4 below presents design peak flow estimates for Karaka Stream, Hape Stream and the Kauaeranga River from various sources. Of note is that:

- The estimates for flow in Karaka Stream are higher than previously estimated from Mike21 modelling (Martin, 2006). This can be attributed to the difference in estimation methods (rainfall on grid hydrologic modelling compared to the more simplistic rational method). It should be noted that increasing the calibrated continuing loss beyond 4.5 mm/hr to decrease the modelled peak flow is not recommended;
- No other flow estimates for Hape Stream exist for comparison; and

- Generally, the flow estimates for the Kauaeranga River are consistent across various sources. As outlined in earlier sections of this report, the stream flow estimates from the Kauaeranga River FFA by WRC were adopted for this study.

Table 7-4: Comparison of Peak Flow Estimates to Previous Studies

Location	Source	Peak Flow Estimate (m^3/s)			Method of Estimation
		10 year ARI	50 year ARI	100 year ARI	
Karaka Stream	This Study	42	75	91	TUFLOW Model
	Amon Martin (2006)	55	74	81	Several methods (rational, relative rational, revised regional flood estimation method)
Hape Stream	This Study	26	46	57	TUFLOW Model
Kauaeranga River	This Study	-	-	-	WRC Flood Frequency Analysis adopted
	WRC Flood Frequency Analysis (FFA)	806	1104	1230	Flood Frequency Analysis of Gauge (FFA)
	Stantec (2023)	761	989	1153	NAM Model
	WRC (2011)	902	1190	1300	MIKE FLOOD Model

7.6 Climate Change

As a result of climate change, the township of Thames will be subject to sea level rise and increased rainfall intensity / frequency. Climate change impacts were modelled in this study with a focus on the medium-term (50 years) and long-term (100 years) time horizons which were also adopted for consideration in the Coastal Defence Concept Design criteria. As part of this, the vertical land movement of the Thames township was also considered. The sea level rise and vertical land movement assessed in the study is in alignment with the methodology in the Coastal Defence Concept Design study. Details are provided below.

7.6.1 Sea Level Rise and Vertical Land Movement

The Intergovernmental Panel on Climate Change (IPCC) periodically provides guidance on the trajectories (scenarios) the world has been following and may follow in the future. **Figure 7-7** shows a graphical representation of these different scenarios.

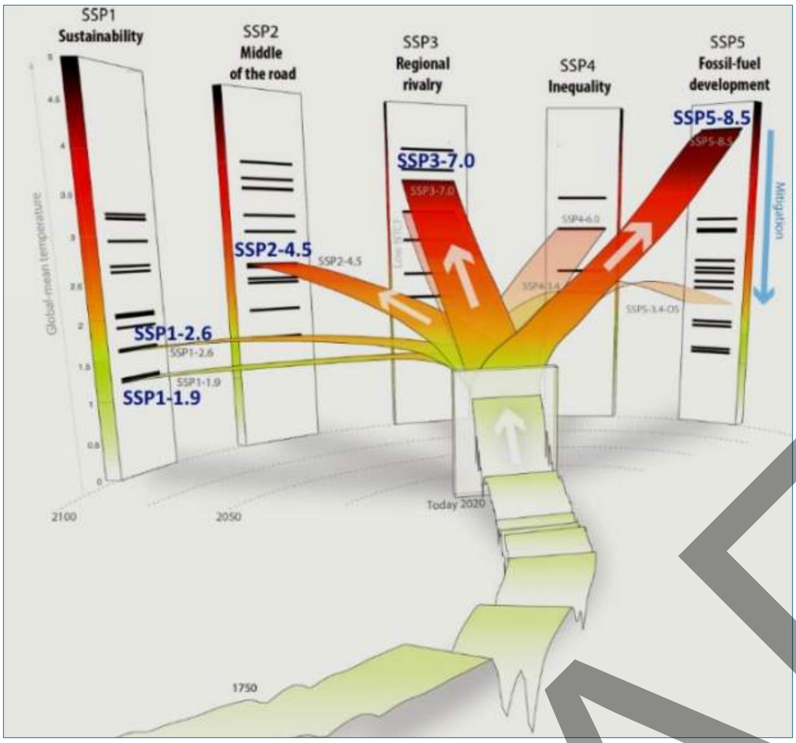


Figure 7-7: Schematic of Climate Change Scenarios (Ministry for the Environment, 2022)

Forecasts for sea level rise in New Zealand, based on IPCC guidance, have been prepared by the NZ Ministry for the Environment. These forecasts, shown in **Figure 7-8** below, were used to determine the appropriate sea level rise to consider in this study.

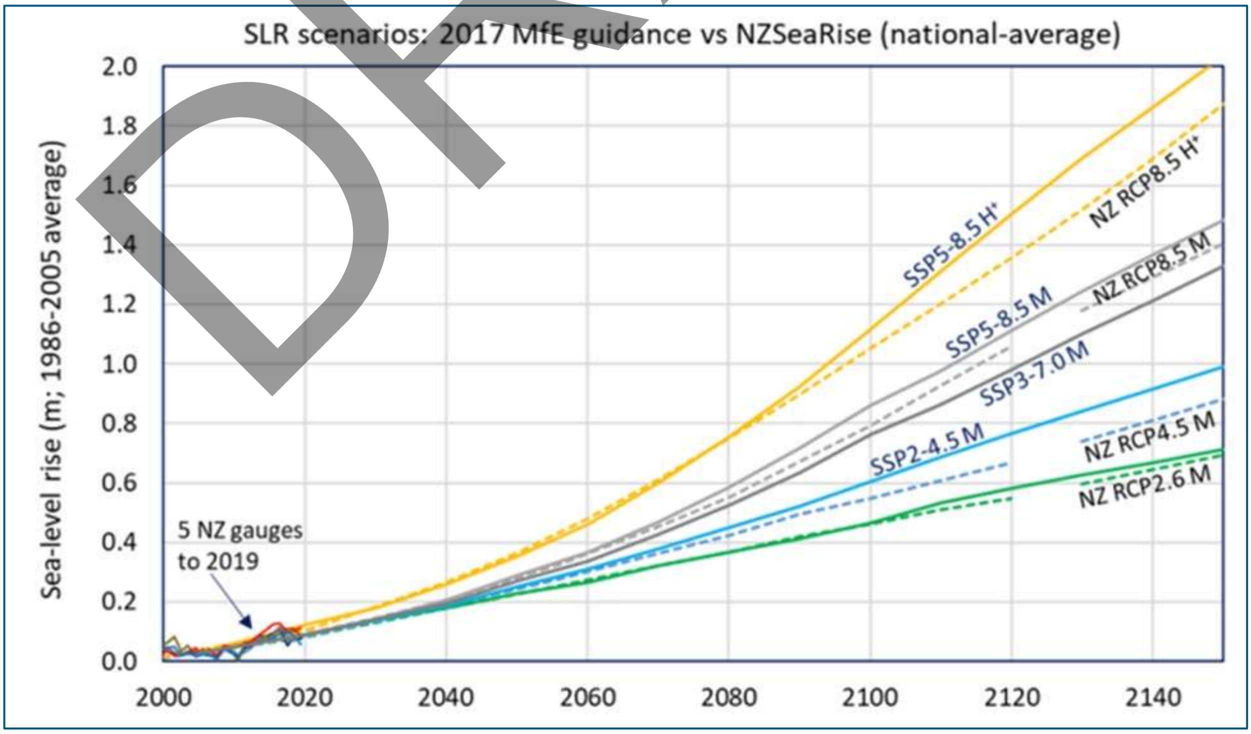


Figure 7-8: Sea Level Rise Projections for New Zealand (Ministry for the Environment, 2022)

Table 7-5 shows the adopted sea level rise projections. For the medium term (year 2080), SSP2-4.5 is considered a likely scenario and should be considered for an adaptive solution with a sea level rise of 0.3 m. For the long term (year 2130), the SSP3-7.0 scenario is more pessimistic and represents a high-end likely scenario. As such, a halfway point between SSP2-4.5 and SSP3-7.0 was adopted with a sea level rise of 0.9 m.

Table 7-5: Adopted Sea Level Rise and Vertical Land Movement (In-line with Coastal Concept Design Study)

Horizon	Scenario	Sea Level Rise	Vertical Land Movement
Medium Term (50 years – year 2080)	SSP2-4.5 (Middle of the road)	0.3 m	0.15 m
Long Term (100 years – year 2130)	Halfway between SSP2-4.5 (Middle of the road) and SSP3-7.0 (Regional Rivalry)	0.9 m	0.3 m

According to the latest data from NZ Sea Rise, the land at Thames is rising at approximately 2.35 mm per year, based on a two square kilometre grid. However, vertical land movement (VLM) varies significantly over short distances, and the data is presented on a 2 km^2 grid, so a different approach was taken to estimate VLM.

On the Thames foreshore, ongoing settlement of recent deposits, many of which are anthropogenic, is causing subsidence. The rate of subsidence varies, with land over deeper or younger mud profiles more likely to experience more significant subsidence. Based on satellite data, a subsidence rate of 3 mm per year was adopted for this study. This results in 0.15 m over 50 years (medium term) and 0.3 m over 100 years (long term) (shown in **Table 7-5** above). Rather than varying the hydraulic model geometry, the predicted vertical land movement was instead added to the predicted sea level rise to account for the expected settlement of the foreshore area over time.

7.6.2 Increased Rainfall

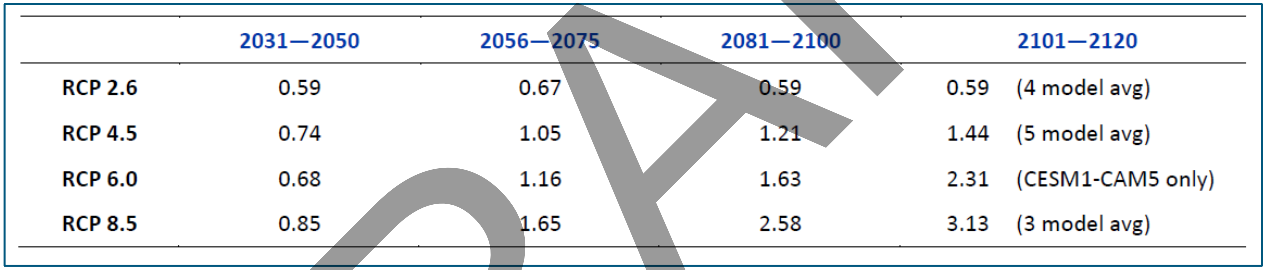
With climate change, an increase in extreme rainfall is expected. The NIWA HIRDS v4 database provides design rainfall depths for the various climate change scenarios from the year 2031 to 2100. Given that the long term projection in this study is until the year 2130, an alternate approach was used, based on guidance from the HIRDS v4 Technical Report (NIWA, 2018).

Table 7-6 below is an excerpt from the NIWA report which shows the percentage increases to rainfall depth per degree of warming. **Table 7-7** is also an excerpt from the NIWA report which shows the expected temperature increase for each climate change scenario over the various time horizons.

Table 7-6: Percentage Change Factors to Project Rainfall Depths Derived from the Current Climate to a Future Climate that is 1 Degree Warmer – Table 6 (NIWA, 2018)

DURATION/ARI	2 YR	5 YR	10 YR	20 YR	30 YR	40 YR	50 YR	60 YR	80 YR	100 YR
1 HOUR	12.2	12.8	13.1	13.3	13.4	13.4	13.5	13.5	13.6	13.6
2 HOURS	11.7	12.3	12.6	12.8	12.9	12.9	13.0	13.0	13.1	13.1
6 HOURS	9.8	10.5	10.8	11.1	11.2	11.3	11.3	11.4	11.4	11.5
12 HOURS	8.5	9.2	9.5	9.7	9.8	9.9	9.9	10.0	10.0	10.1
24 HOURS	7.2	7.8	8.1	8.2	8.3	8.4	8.4	8.5	8.5	8.6
48 HOURS	6.1	6.7	7.0	7.2	7.3	7.3	7.4	7.4	7.5	7.5
72 HOURS	5.5	6.2	6.5	6.6	6.7	6.8	6.8	6.9	6.9	6.9
96 HOURS	5.1	5.7	6.0	6.2	6.3	6.3	6.4	6.4	6.4	6.5
120 HOURS	4.8	5.4	5.7	5.8	5.9	6.0	6.0	6.0	6.1	6.1

Table 7-7: New Zealand land-average temperature increase relative to 1986—2005 for four future emissions scenarios. The three 21st century projections result from the average of six RCM model simulations (driven by different global climate models). The early 22



	2031—2050	2056—2075	2081—2100	2101—2120
RCP 2.6	0.59	0.67	0.59	0.59 (4 model avg)
RCP 4.5	0.74	1.05	1.21	1.44 (5 model avg)
RCP 6.0	0.68	1.16	1.63	2.31 (CESM1-CAM5 only)
RCP 8.5	0.85	1.65	2.58	3.13 (3 model avg)

A temperature increase of 0.74 and 1.44 degrees Celsius was adopted for the medium and long term horizons respectively, corresponding to RCP 4.5 (moderate), which leads to the percentage increase in rainfall depth presented in below **Table 7-8** below.

Table 7-8: Adopted Percentage Increase in Design Rainfall Intensity

Duration	ARI / Scenario			
	10 year ARI 2080 Horizon	10 year ARI 2130 Horizon	100 year ARI 2080 Horizon	100 year ARI 2130 Horizon
1 Hour	15.9	18.9	16.5	19.6
2 Hour	15.2	18.1	15.9	18.9
6 Hour	13.1	15.6	13.9	16.6
12 Hour	11.5	13.7	12.2	14.5
24 Hour	9.8	11.7	10.4	12.4
48 Hour	8.5	10.1	9.1	10.8

7.6.3 Increase in Kauaeranga River Flow

The increased rainfall due to climate change would lead to increased flow in the catchments and given that the Kauaeranga River was not explicitly modelled and a synthetic unit hydrograph was used at the upstream boundary of the TUFLOW model, assumptions were made to derive the 10 and 100 year ARI flow hydrograph at the Kauaeranga River Gauge under climate change conditions.

The Kauaeranga River Hydraulic and Service Level Review (Waikato Regional Council, 2011) conducted hydraulic modelling of the Kauaeranga River and derived peak flow estimates which are tabulated in **Table 7-9** below. Given the close agreement with the peak flows from Waikato Regional Council (2011) to current estimates by Stantec (2023) and WRC's FFA on the Smiths Cableway Gauge, the peak flows resulting from climate change were adopted in this study. The estimates are shown in **Figure 7-9** below.

Table 7-9: Kauaeranga River Design Discharges – Table 10 (Waikato Regional Council, 2011)

Average Recurrence Interval (yrs)	Peak Flood Discharges (m^3/s)			
	Scheme Design 1985	Scheme Review 1994	Waikato Regional Council Hydraulic Review 2007	
			Current Climate	2090 Climate
2	-	-	524	657
5	700	700	759	961
10	850	850	902	1,145
20	980	980	1,032	1,314
50	1,160	1,160	1,190	1,520
100	1,300	1,300	1,300	1,666
1000	approx 1,850	approx 1,850	approx 1,621	approx 2077

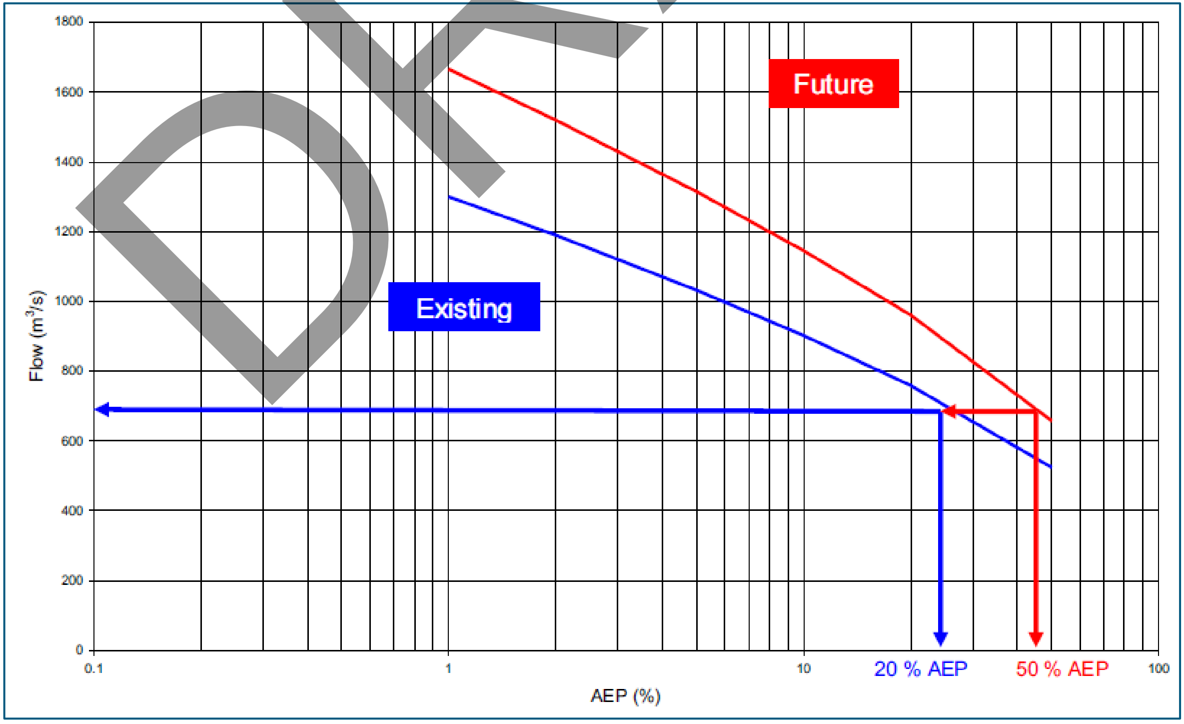


Figure 7-9: AEP of 700m^3/s flow taking into account climate change predictions – Figure 20 (Waikato Regional Council, 2011)

Given that Kauaeranga River flows did not make a significant impact on the study area, the same climate change scenario was adopted for the medium and long term horizons which are shown in **Table 7-10** below.

Table 7-10: Adopted Peak Flow with Climate Change in Kauaeranga River

Event	Adopted Peak Flow (m^3/s)	Comment
10 year ARI (with 2080 and 2130 climate change)	1,200	Approximately equivalent to a present day 100 year ARI event
100 year ARI (with 2080 and 2130 climate change)	1,700	Approximately equivalent to a present day 1000 year ARI event

7.7 Description of Flood Behaviour

Maps showing the baseline flooding conditions and the impact of the Coastal Defence Concept Design on flooding in Thames can be found in **Appendix B**. The following section summarises the key findings of the modelling and refers to **Figures 3 – 12** in **Appendix B**. Although flood results have been shown for all the Thames, the areas north of Burke Street (Moanataiari) and south of Hape Stream were not the focus of this study and so have not been examined in detail. We note that a pumping station exists on Fergusson Drive and that TCDC has indicated that a separate investigation is taking place into a pump to alleviate flooding in the vicinity of Jellicoe Crescent and Fenton Street by pumping into Hape Stream.

7.7.1 Baseline

A list of the figures showing baseline conditions is as follows:

- **Figure 3** – Baseline Peak Flood Depth – 10 year ARI
- **Figure 4** – Baseline Peak Flood Depth – 50 year ARI
- **Figure 5** – Baseline Peak Flood Depth – 100 year ARI Envelope
- **Figure 6** – Baseline Critical Event in 100 year ARI Envelope
- **Figure 7** – Baseline Impact of a Coincident of a 100 year ARI Coincident Catchment and Ocean Event Compared to the 100 year ARI Envelope

Table 7-11 sets out the estimated design peak flows in Karaka Stream, Hape Stream and the Kauaeranga River under baseline, present day conditions. Note that the Kauaeranga River peak flows reflect WRC's FFA on the Smiths Cableway Gauge for the 10, 50 and 100 year ARI peak flow.

Table 7-11: Design Peak Flows – Baseline Present Day Conditions

Location	Peak Flow (m^3/s)				
	10 year ARI	50 year ARI	100 year ARI	100 year ARI Climate Change Medium Term Year 2080	100 year ARI Climate Change Long Term Year 2130
Karaka Stream	42	75	91	112	116
Hape Stream	26	46	57	72	74
Kauaeranga River	806	1104	1230	2077	2077

The most significant area of flooding in Thames is in the vicinity of Albert Street, where significant ponding is observed in all events. The low point on Albert Street can be seen in **Figure 7-10** below. Ponding here results due to both local flooding from the town runoff as well as significant flows which overtop the banks of Karaka Stream and make their way north-west through town towards the low point.

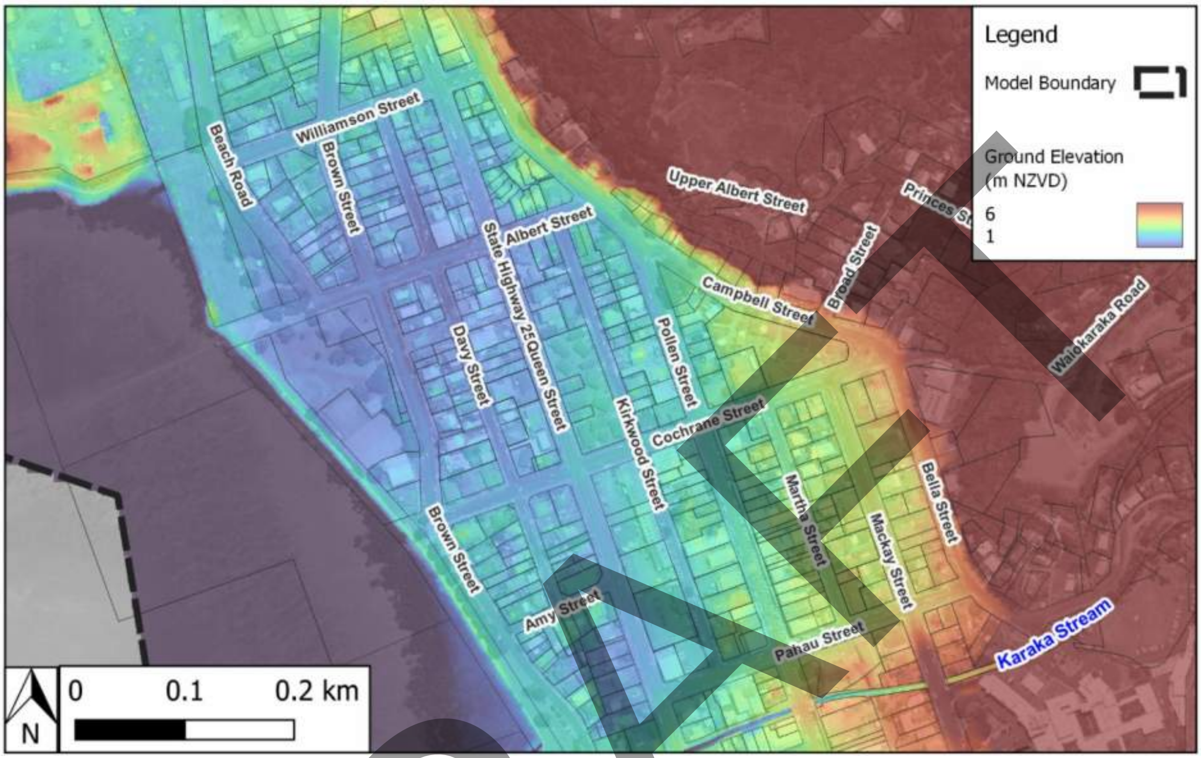


Figure 7-10: Ground Elevations in Thames

In the 10 year ARI Event (shown in **Figure 3** in **Appendix B**), overtopping of Karaka Stream occurs first at the Bella Street Culvert. This results in between 0.5 and 1 m of ponding occurring near Albert Street as both the local catchment in the town as well as the overtopping flow from Karaka Stream ends up at this location. Overtopping of the seawall is observed from the land side in the model to the west of the croquet club (between Albert St and William St), thought a survey should be conducted in this location of the existing seawall level. The seawall is currently represented using LiDAR since the drone photography was unreliable due to the heavy vegetation in this area. The coincident event for the 10 year ARI, the HAT, does not result in overtopping of the existing coastal defences from the ocean side. Hape Stream breaks out immediately upstream of Augustus Street South and an overland flowpath can be seen heading towards Richmond Street with a peak flow of 2.3 m^3/s. Hape Stream also overtops Grey Street at the Mackay Street Bridge.

In the 50 year ARI Event (shown in **Figure 4** in **Appendix B**), overtopping of Karaka Stream occurs at the Bella Street Footbridge and the Bella Street Culvert. This results in between 1 and 1.5 m of ponding occurring near Albert Street as both the local catchment in the town as well as a significant amount of overtopping flow from Karaka Stream ends up at this location. Overtopping of the seawall occurs in various locations between Karaka Stream and William Street from the land side, but the coincident ocean event for the 50 year ARI, i.e. the HAT, does not result in overtopping of the existing coastal defences from the ocean side. Hape Stream breaks out immediately upstream of Augustus Street South and an overland flowpath can be seen heading towards Richmond Street with a peak flow of 5 m^3/s. Hape Stream also overtops Mackay and Grey Street at the Mackay Street Bridge.

In the 100 year ARI Event (shown in **Figure 5** in **Appendix B**), overtopping of Karaka Stream occurs at the Bella Street Culvert as well as the Bella Street Footbridge. This results in significant flooding in the majority of properties between Karaka Stream and William Street with between 1 and 1.5 m of ponding occurring near Albert Street as both the local catchment in the town as well as a significant amount of overtopping flow from Karaka Stream ends up in this location. Overtopping of the seawall occurs in various locations between William Street and Karaka Stream from the land side in the 100 year ARI catchment flood as well as from the ocean side in the 10 year and 100 year ARI ocean event. **Figure 6** in **Appendix B** shows whether the 10 year ARI catchment / 100 year ARI ocean event (ocean dominated) or the 100 year ARI catchment / 10 year ARI ocean event (catchment dominated) was critical in the 100 year ARI envelope. The figure shows that in the majority of areas around Thames, the catchment dominant event is critical, except for in the vicinity of the croquet club between William Street and Beach Road and the areas south of Karaka Stream between the ocean and Pollen Street.

Hape Stream breaks out immediately upstream of Augustus Street South and an overland flowpath can be observed heading towards Richmond Street with an estimated peak flow of 8 m^3/s. The Rolleston Street Bridge, which has a peak flow capacity of 38 m^3/s also experiences overtopping. Mackay and Grey Street overtop at the Mackay Street Bridge. Many properties are inundated south of Sealey Street and West of Pollen Street with between 0.5 and 1 m of ponding occurring on the properties in the vicinity of Richmond Street despite the operation of the existing pumping station.

Figure 7 in **Appendix B** shows the impact of a 100 year ARI ocean event coinciding with a 100 year ARI catchment event (extreme sensitivity case, requested by TCDC), when compared to the 100 year ARI envelope. The figure shows that the most affected areas are Moanataiari (out of study area) and the areas of the Thames township at the outlet of Hape Stream. The increase in peak flood depth is between 0.05 to 0.2 m. The increase in peak flood depth for the 100 year ARI / 100 year ARI combination is between 0.05 to 0.1 m (compared to the 100 year ARI “Envelope” approach).

7.7.2 Climate Change Scenario Results

A list of the figures showing baseline and climate change conditions is as follows:

- **Figure 8** – Baseline Peak Flood Depth – 100 year ARI Envelope with Climate Change in 2080
- **Figure 9** – Baseline Peak Flood Depth – 100 year ARI Envelope with Climate Change in 2130

Figure 8 in **Appendix B** shows that with climate change impacts in the medium term (year 2080) if no measures are made to further protect Thames, a significant increase (0.4 – 0.7 m) in depth may occur as a result of climate change in the 100 year ARI event. This is most severe near the ocean with sea level rise and vertical land movement as the main causes, but the increased rainfall extremes leads to more flooding in the Township as Karaka Stream and Hape Stream have increased flows (refer **Table 7-11** above) and the depth in the streams and the areas where the streams break out increases by between 0.1 and 0.4 m.

A similar pattern can be seen for the climate change impacts in the long term (year 2130) which is shown in **Figure 9** of **Appendix B**. With climate change impacts in the long term, if no measures are made to further protect Thames, a significant increase (i.e. 1 – 1.4 m) in depth is estimated to occur as a result of climate change in the 100 year ARI event. This is most severe near the ocean with sea level rise and vertical land movement as the main causes, but the increase in rainfall extremes leads to more flooding in the Township as Karaka Stream and Hape Stream have increased flows (refer **Table 7-11** above) and the depth in the streams and the areas where the streams break out increases by between 0.1 and 0.4 m.

Figure 7-11, **Figure 7-12** and **Figure 7-13** below show the flow in Karaka Stream in the 100 year ARI event catchment dominated event (100 year catchment event with 10 year ARI ocean event) at the Pollen Street, Queen Street and Brown Street Bridges, respectively. The figures show the 100 year ARI under present day conditions as well as with climate change in 2080 and 2130. The figures also show that from the most upstream bridge of the three (Pollen Street) to the most downstream (Brown Street), the flow capacity of the bridges is significantly decreased with climate change impacts, due to the effect of the ocean tailwater level increasing, leading to increased tailwater conditions, limiting channel capacity, due to reduced hydraulic gradients. **Figure 7-13** shows that at the Brown Street bridge, with climate change in 2080, the 10 year ARI ocean level results in a peak flow capacity of less than half, compared to current day conditions. As can be seen in this Figures, for the 2130 results, the Brown St culvert is completely drowned out by the 10 year ARI ocean storm tide level. Note the present day and climate change events have different flows arriving in Karaka Stream due to climate change in the 100 year ARI event increasing the peak flow in Karaka Stream, however given that the capacity of the Bella Street Culvert is estimated at 17 m^3/s, the maximum amount of flow arriving at these downstream bridges is comparable.

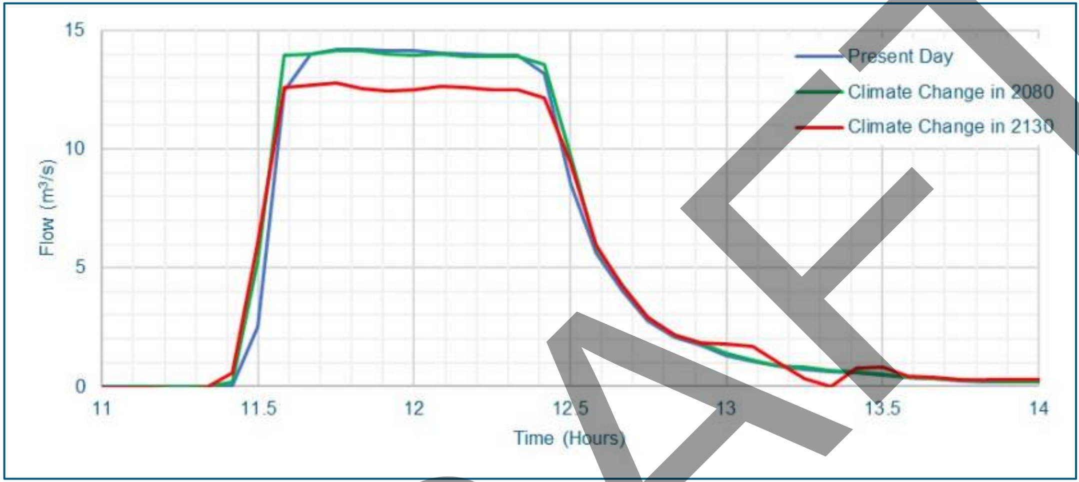


Figure 7-11: Flow in Karaka Stream at the Pollen Street Bridge – 100 year ARI Event

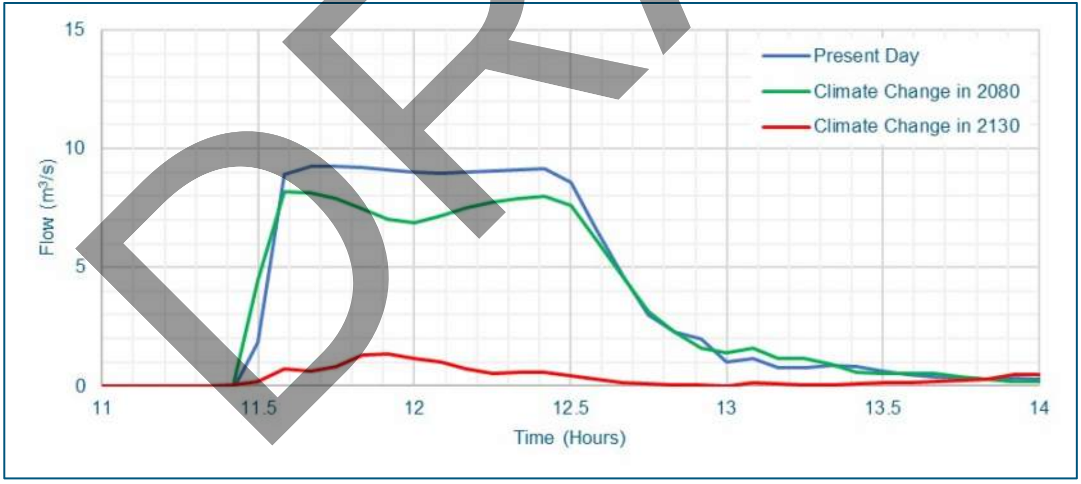


Figure 7-12: Flow in Karaka Stream at the Queen Street Bridge – 100 year ARI Event

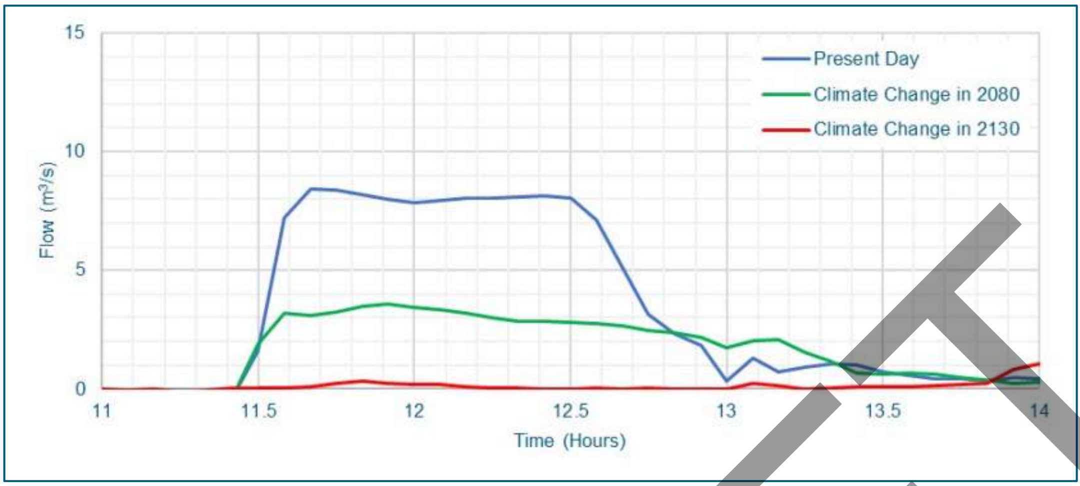


Figure 7-13: Flow in Karaka Stream at the Brown Street Bridge – 100 year ARI Event

7.7.3 Hydraulic Modelling of the Proposed Coastal Defence Concept Design

A list of the figures showing the hydraulic impact of the proposed Coastal Defence Concept Design is as follows:

- **Figure 10** – Impact of Coastal Defence Concept Design on Peak Flood Depth – 10 year ARI
- **Figure 11** – Impact of Coastal Defence Concept Design on Peak Flood Depth – 50 year ARI
- **Figure 12** – Impact of Coastal Defence Concept Design on Peak Flood Depth – 100 year ARI Envelope

The Coastal Defence Concept Design currently consists of raised sea defences and Penstock Gates which can be opened or closed at several stream outlet locations including, the outlet of Karaka Stream, the channels north and south of Danby Field and the outlet of Hape Stream. The position of the proposed gates in the design events have been assumed to be open in all events.

Figure 10 in **Appendix B** shows that with the Coastal Defence Concept Design in place including the proposed open gates, minimal impacts are observed in the 10 year ARI event. The existing coastal defences do not overtop and so there is no additional water which now ponds behind the proposed design.

Figure 10, Figure 11 and **Figure 12** in **Appendix B** show that with the Coastal Defence Concept Design in place with open gates, impacts on peak flood level are observed in the 10, 50 and 100 year ARI events, respectively. The impacts are in the vicinity of Albert Street due to the overtopping of the existing coastal defences in the baseline scenario and are between 0.05 – 0.1 m in the 10 year and more significant in the 50 and 100 year ARI events. The proposed Concept Design results in additional water ponding on the land-side since the height of the proposed sea wall does not allow overtopping, whereas in the baseline scenario, the seawall is observed to overtop from catchment flooding in events as frequent as the 10 year ARI. A detailed survey should be conducted on the existing seawall to accurately determine its current level and understand the potential impact on land-side flooding if the seawall is raised the fluvial floodwaters to escape due to overtopping, as they do in the existing case.

Future stages of the project should consider the two options for the major outlets and streams crossing the coastal defences to the ocean. Two options to be considered are:

1. Penstock Gates usually left open but with defined closing trigger levels based on storm tide predictions (e.g. gates that are either programmed to close at defined trigger levels, or that are manually closed at defined trigger levels); and
2. Non-Return “Flap” gates (noting that flap-gates have the potential to increase hydraulic head losses).

Which of these options will be implemented is to be decided at a later stage of the project and will be discussed in consultation with TCDC.

8 Feasibility of Pumping

Since the purpose of the study was to develop a baseline model to investigate pumping options, preliminary pumping options were explored to alleviate flooding in the vicinity of Albert Street, however, it became apparent that pumping would not be feasible. **Figure 8-1** below shows the flow that overtops the Bella Street culvert and flows towards the low point at Albert Street. This flow results in ponding at Albert Street. Pumps such as Hytrans FloodModule pumps, each with a maximum capacity of 0.83 m³/s, were considered.

However, as shown in the figure, even with 4 pumps, the total capacity would be 3.32 m³/s. This would only remove the first 3.32 m³/s of flow from the large amount of overland flow arriving at the Albert Street low point, still leading to significant ponding around Albert Street. The same applies to eight pumps with a capacity of 6.64 m³/s, which would still result in considerable ponding.

Deploying eight pumps would be very expensive and challenging, especially in emergency situations with a catchment with a fast response such as the Karaka Stream catchment. Additionally, such a large pump system would be impractical for permanent deployment due to the site constraints. While this approach would help reduce the duration of inundation, it would not lower the peak flood levels by any significant margin.

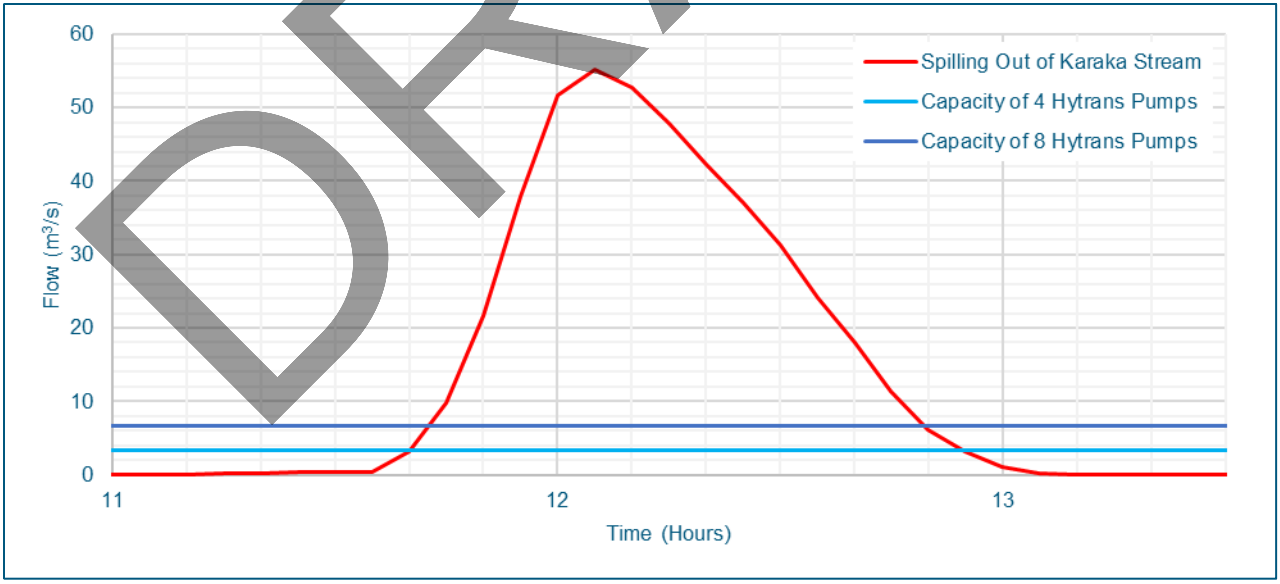


Figure 8-1: Flow Spilling Out of Karaka Stream and Pump Capacity – 50 year ARI

9 Recommendations

Based on the findings of this study, several conclusions and recommendations were identified:

- The modelling results indicated higher design flows in the stream catchments than previously estimated;
- The capacity of the Bella Street Culvert on the Karaka Stream is significantly lower than previously estimated;
- Confidence has been achieved in the calibration of the stream catchments to the drone photography and the Kauaeranga River to the Smiths Cableway Gauge for the February 2023 event;
- Design flows have been estimated with the best available information, including calibrated catchment roughness and infiltration, and design rainfall from the Thames EWS gauge with a long period of record;
- The Coastal Concept Design without additional flood protection measures is estimated to worsen flooding in Thames, particularly in the Northern part of town near Albert Street. Floodwaters that previously overtopped the seawall would now pond behind it, worsening flood conditions during fluvial events. A proper survey of the seawall is required to assess the impact with more certainty, as there is uncertainty in the actual height of the existing seawall(s). Regardless, additional measures should be considered before proceeding with seawall modifications;
- Hazard mapping should be conducted in Thames to identify areas with unacceptable flood risk;
- Pumping alone would not significantly reduce ponding around Albert Street due to the high discharge rate from Karaka Stream overtopping during significant storm events;
- Alternative solutions should be explored, especially given the site constraints at the low point near Victoria Park and Albert Street. Additional engineering options should be investigated, such as stop-banks, culvert / bridge upgrades, channel widening and drainage upgrades;
- The model, which focused on pumping, lacked detailed results outside the focus area and did not include hazard mapping, only depth and impact assessments for various scenarios such as climate change and coastal defences. Additional areas should be modelled in more detail for assessment of drainage improvement options. Specifically, the out-of-scope areas to the South of Thames should be modelled in more detail, including the addition of the Heale Street and Rolleston Street pumping stations, and incorporating the works done on the southern side of the Kauaeranga River (the Kauaeranga Spillway); and
- With future modelling and optioneering, more events should be considered (e.g. the 5, 20 and 250 year ARI).

The results of this investigation perhaps challenge the concept of increasing coastal defences to protect against climate change within Thames, particularly in the Northern part of town around Albert Street, as it appears from the results in this report that the majority of flooding in Thames under existing climate conditions is in fact be driven by catchment runoff processes, rather than coastal processes. Depending on the dominant effects of climate change being either sea level rise or increased catchment runoff frequency and severity (or both), careful consideration of raised coastal defences must be undertaken, to ensure that doing so would not unduly exacerbate future flooding in Thames as a result of catchment runoff processes.

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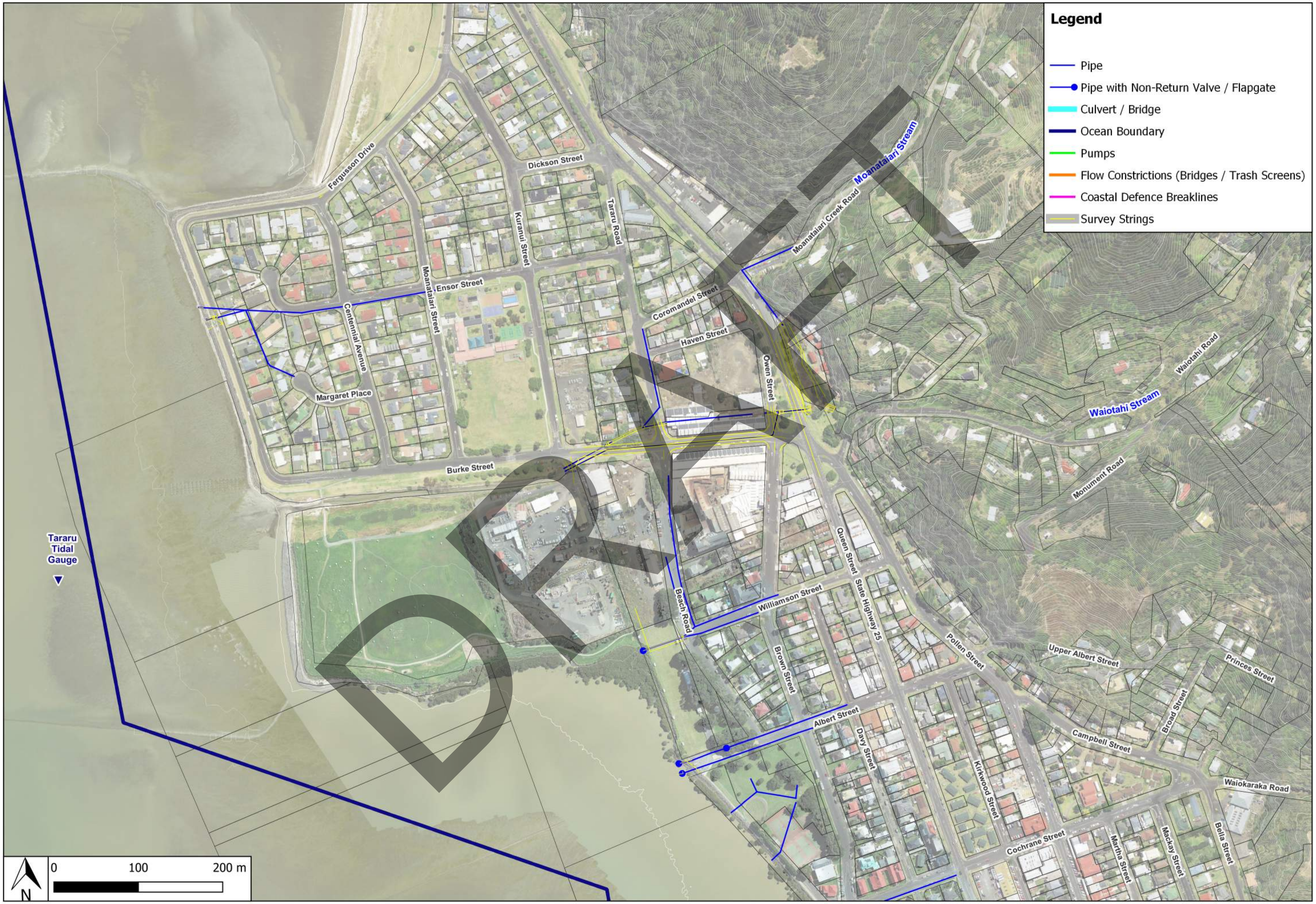
Appendix A – TUFLOW Model Setup


Legend
Pipe
Pipe with Non-Return Valve / Flapgate
Culvert / Bridge
Ocean Boundary
Pumps
Flow Constrictions (Bridges / Trash Screens)
Coastal Defence Breaklines
Survey Strings
Tararu Tidal Gauge
Fergusson Drive
Dickson Street
Kuranui Street
Tararu Road
Moanataiari Stream
Moanataiari Creek Road
Ensor Street
Moanataiari Street
Centennial Avenue
Coromandel Street
Haven Street
Owen Street
Margaret Place
Waiotahi Road
Waiotahi Stream
Burke Street
Monument Road
Queen Street
State Highway 25
Williamson Street
Beach Road
Brown Street
Pollen Street
Upper Albert Street
Princes Street
Broad Street
Campbell Street
Albert Street
Davy Street
Kirkwood Street
Waiokaraka Road
Cochrane Street
Martha Street
Mackay Street
Bella Street
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Legend
Pipe
Pipe with Non-Return Valve / Flapgate
Culvert / Bridge
Ocean Boundary
Pumps
Flow Constrictions (Bridges / Trash Screens)
Coastal Defence Breaklines
Survey Strings
Karaka Stream
Karaka Stream
Beach Road
Albert Street
Campbell Street
Broad Street
Waiokaraka Road
Irishtown Road
Davy Street
Cochrane Street
Kirkwood Street
Martha Street
Bella Street
Redwood Lane
Karaka Road
St Patricks Row
Vanguard Street
Brown Street
Amy Street
Pahau Street
Walter Street
Queen Street
State Highway 25
Pollen Street
Mary Street
Mackay Street
Court Street
Edward Street
Augustus Street North
Sandes Street
Hill Street
Graham Street
Sealey Street
Franklyn Street
The Terrace
Rolleston Street
Lambert Street
Richmond Street
Hape Road
Augustus Street South
Baillie Street
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100
200 m
N


Richmond Street
Willoughby Street
Queen Street
Pollen Street
Mackay Street
Baillie Street
Hape Stream
Clarence Street
Alfred Street
Grey Street
Hape Road
Augustus Street South
Hape Stream
The Terrace
Vernon Street
Danby Street
Mount Pleasant Road
Harvey Crescent
Pleasant Wood Place
Rolleston Street
Tui Place
Hauraki Terrace
Kingsford Place
Oakley Crescent
Fenton Street
Heale Street
State Highway 25
Jellicoe Lane
Jellicoe Crescent
Banks Street
Brunton Crescent
Parawai Road
Mount Sea Road
Ngati Maru Highway
Kaueranga River
Legend
Pipe
Pipe with Non-Return Valve / Flapgate
Culvert / Bridge
Ocean Boundary
Pumps
Flow Constrictions (Bridges / Trash Screens)
Coastal Defence Breaklines
Survey Strings
N
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100
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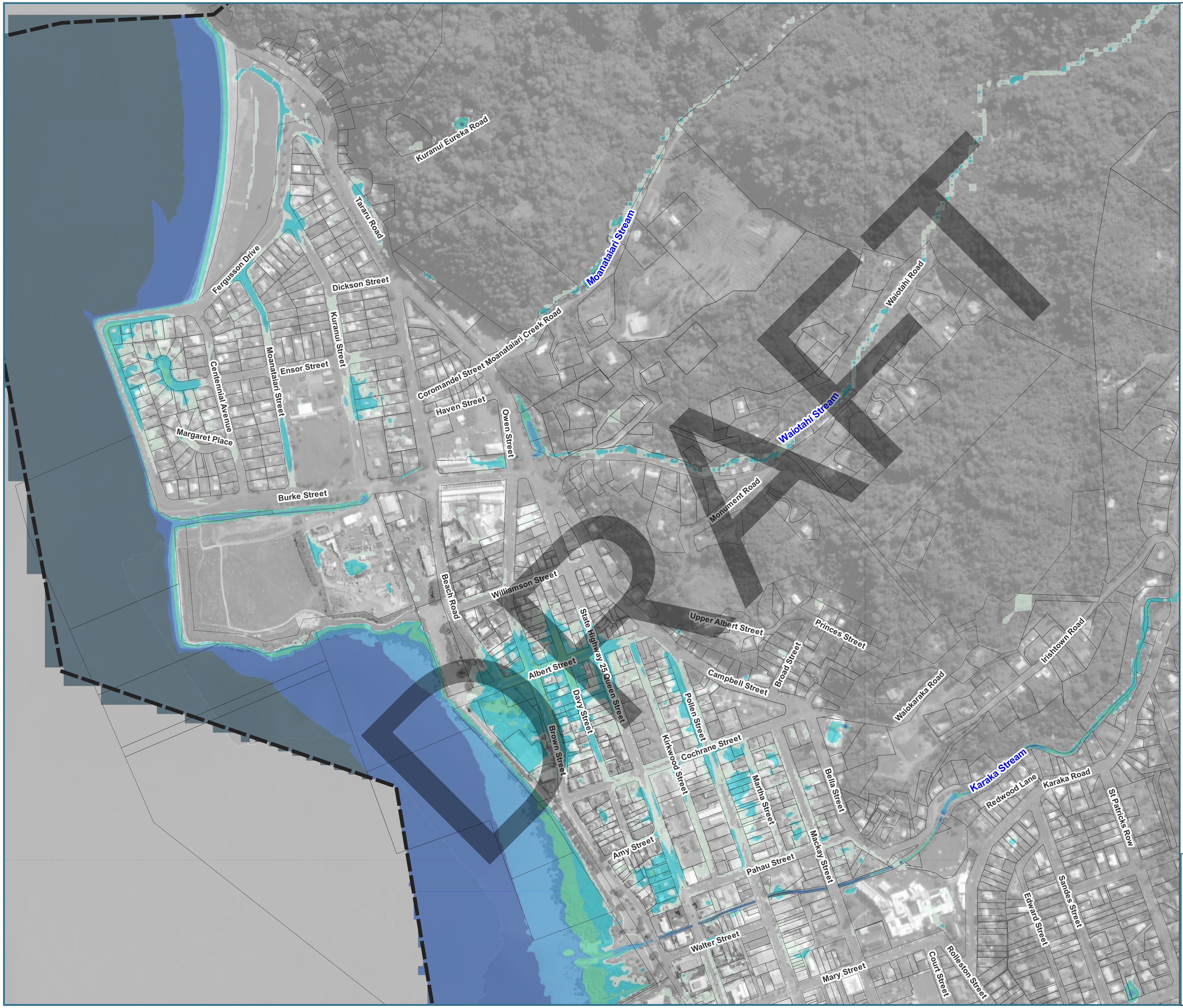
Appendix B – Flood Mapping



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Thames Fluvial Modelling

Figure 1 (Sheet 1)

Scenario: February 2023 Baseline Conditions
Event: February 2023 Event
Results: Peak Water Depth

Legend

Model Boundary ▭

Water Depth
<= 0.1 m ▨
0.1 - 0.25 m ▨
0.25 - 5 m ▨
0.5 - 1 m ▨
1- 1.5 m ▨
1.5 - 2 m ▨
> 2 m ▨

PA3520
NZGD2000 / New Zealand Transverse Mercator 2000
Scale at A3

1:6,000
0 100 200 300 m
N

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Thames Fluvial Modelling

Figure 1 (Sheet 2)

Scenario: February 2023 Baseline Conditions
Event: February 2023 Event
Results: Peak Water Depth

Legend

Model Boundary ⌐

Water Depth

<= 0.1 m	⬜
0.1 - 0.25 m	⬜
0.25 - 5 m	🟦
0.5 - 1 m	🟩
1- 1.5 m	🟦
1.5 - 2 m	🟦
> 2 m	■

PA3520
NZGD2000 / New Zealand Transverse Mercator 2000
Scale at A3

1:6,000

0 100 200 300 m

N

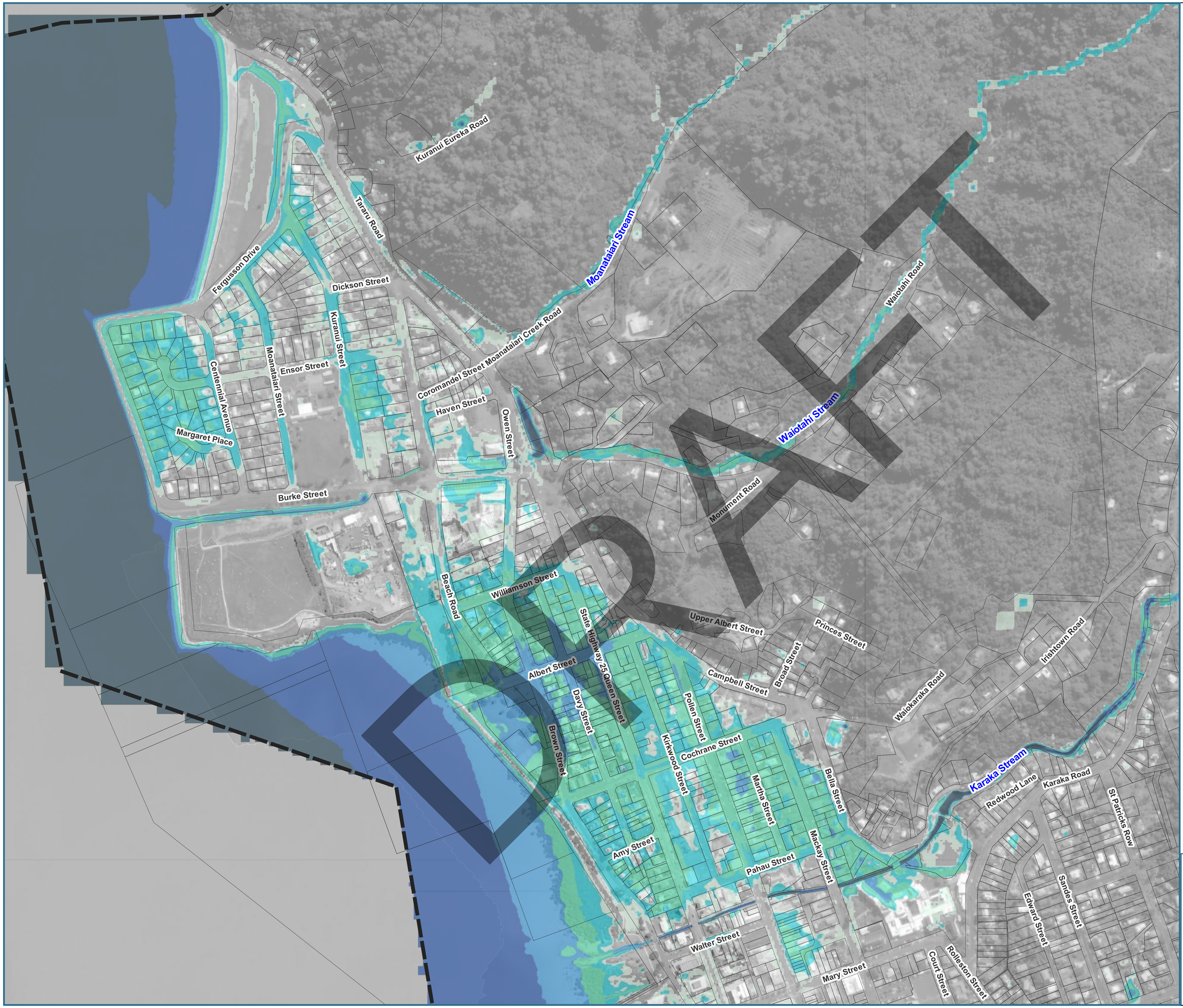

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Figure 2 (Sheet 1)

Scenario: June 2002 Baseline Conditions
Event: June 2002 Event
Results: Peak Water Depth

Legend

Model Boundary	⌐¬
Water Depth	
<= 0.1 m	⬜
0.1 - 0.25 m	⬜
0.25 - 5 m	🟦
0.5 - 1 m	🟩
1- 1.5 m	🟦
1.5 - 2 m	🟦
> 2 m	⬛

PA3520
NZGD2000 / New Zealand Transverse Mercator 2000
Scale at A3

1:6,000

0 100 200 300 m

N

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Figure 2 (Sheet 2)

Scenario: June 2002 Baseline Conditions
Event: June 2002 Event
Results: Peak Water Depth

Legend

Model Boundary ▭

Water Depth
<= 0.1 m □
0.1 - 0.25 m ■
0.25 - 5 m ■
0.5 - 1 m ■
1- 1.5 m ■
1.5 - 2 m ■
> 2 m ■

PA3520
NZGD2000 / New Zealand Transverse Mercator 2000
Scale at A3

1:6,000

0 100 200 300 m

N

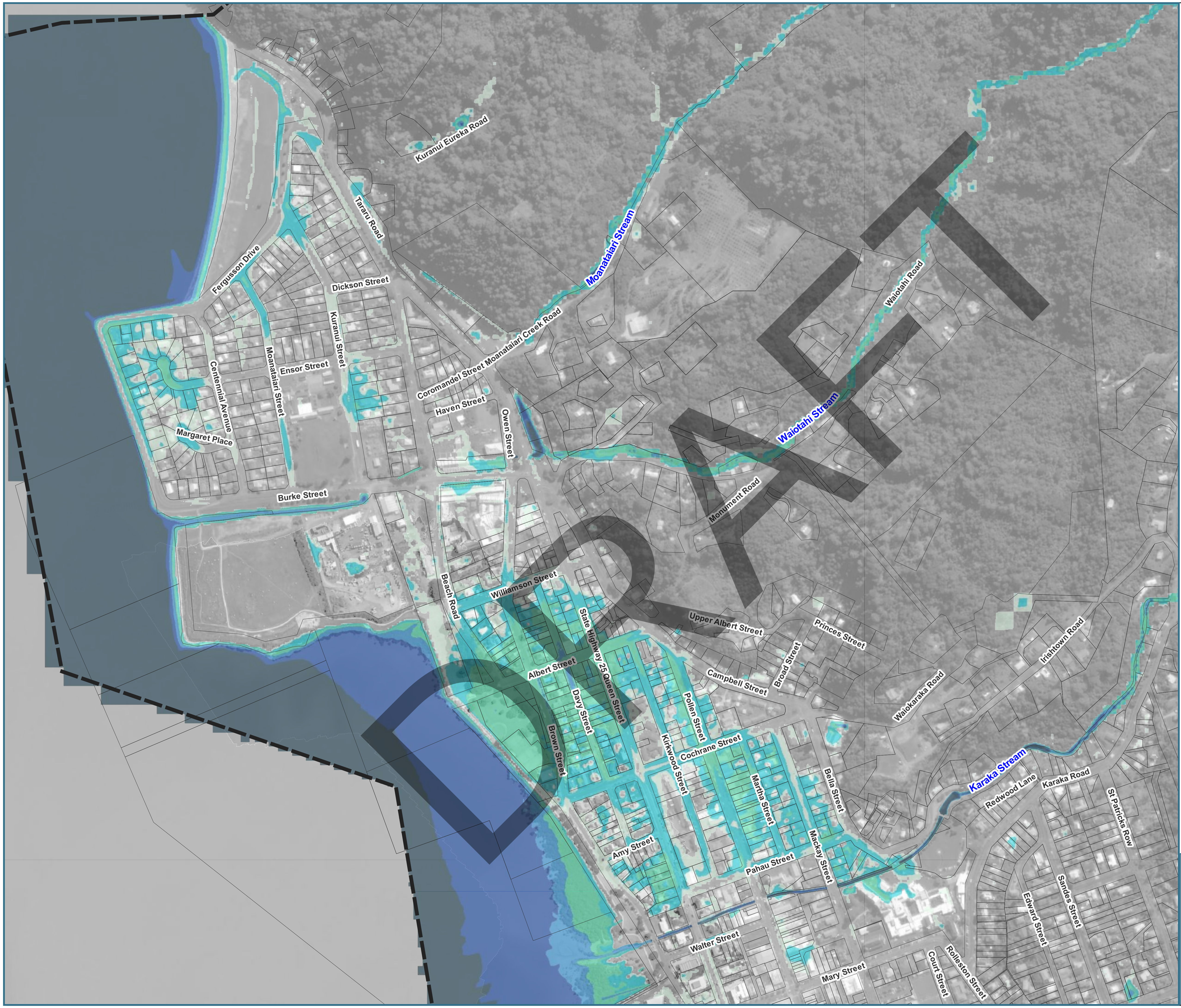

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Figure 3 (Sheet 1)

Scenario: Baseline Conditions
Event: 10 Year ARI Event
Results: Peak Water Depth

Legend

Model Boundary

Water Depth

<= 0.1 m	▨
0.1 - 0.25 m	▨
0.25 - 5 m	▨
0.5 - 1 m	▨
1- 1.5 m	▨
1.5 - 2 m	▨
> 2 m	▨

PA3520
NZGD2000 / New Zealand Transverse Mercator 2000
Scale at A3

1:6,000

0 100 200 300 m

N

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Figure 3 (Sheet 2)

Scenario: Baseline Conditions
Event: 10 Year ARI Event
Results: Peak Water Depth

Legend

Model Boundary

Water Depth

<= 0.1 m	⬜
0.1 - 0.25 m	⬜
0.25 - 5 m	🟦
0.5 - 1 m	🟩
1- 1.5 m	🟦
1.5 - 2 m	🟦
> 2 m	⬛

PA3520
NZGD2000 / New Zealand Transverse Mercator 2000
Scale at A3

1:6,000

0 100 200 300 m

N

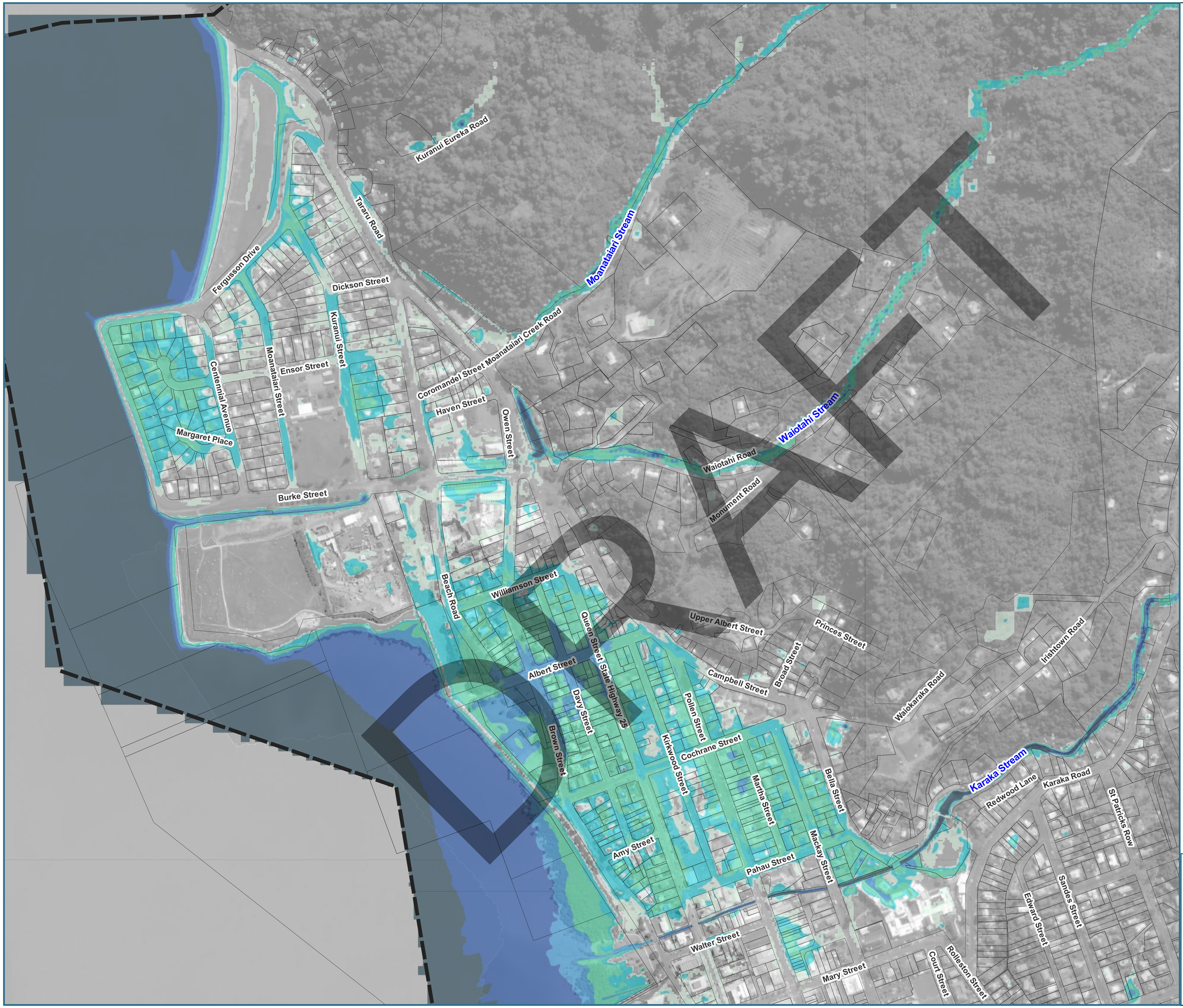

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Figure 4 (Sheet 1)

Scenario: Baseline Conditions
Event: 50 Year ARI Event
Results: Peak Water Depth

Legend
Model Boundary

Water Depth
<= 0.1 m
0.1 - 0.25 m
0.25 - 5 m
0.5 - 1 m
1- 1.5 m
1.5 - 2 m
> 2 m

PA3520
NZGD2000 / New Zealand Transverse Mercator 2000
Scale at A3

1:6,000
0 100 200 300 m
N

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Figure 4 (Sheet 2)

Scenario: Baseline Conditions
Event: 50 Year ARI Event
Results: Peak Water Depth

Legend

Model Boundary	⌐
Water Depth	
<= 0.1 m	⬜
0.1 - 0.25 m	🟩
0.25 - 5 m	🟦
0.5 - 1 m	🟩
1- 1.5 m	🟦
1.5 - 2 m	🟦
> 2 m	⬛

PA3520
NZGD2000 / New Zealand Transverse Mercator 2000
Scale at A3

1:6,000
0 100 200 300 m
N

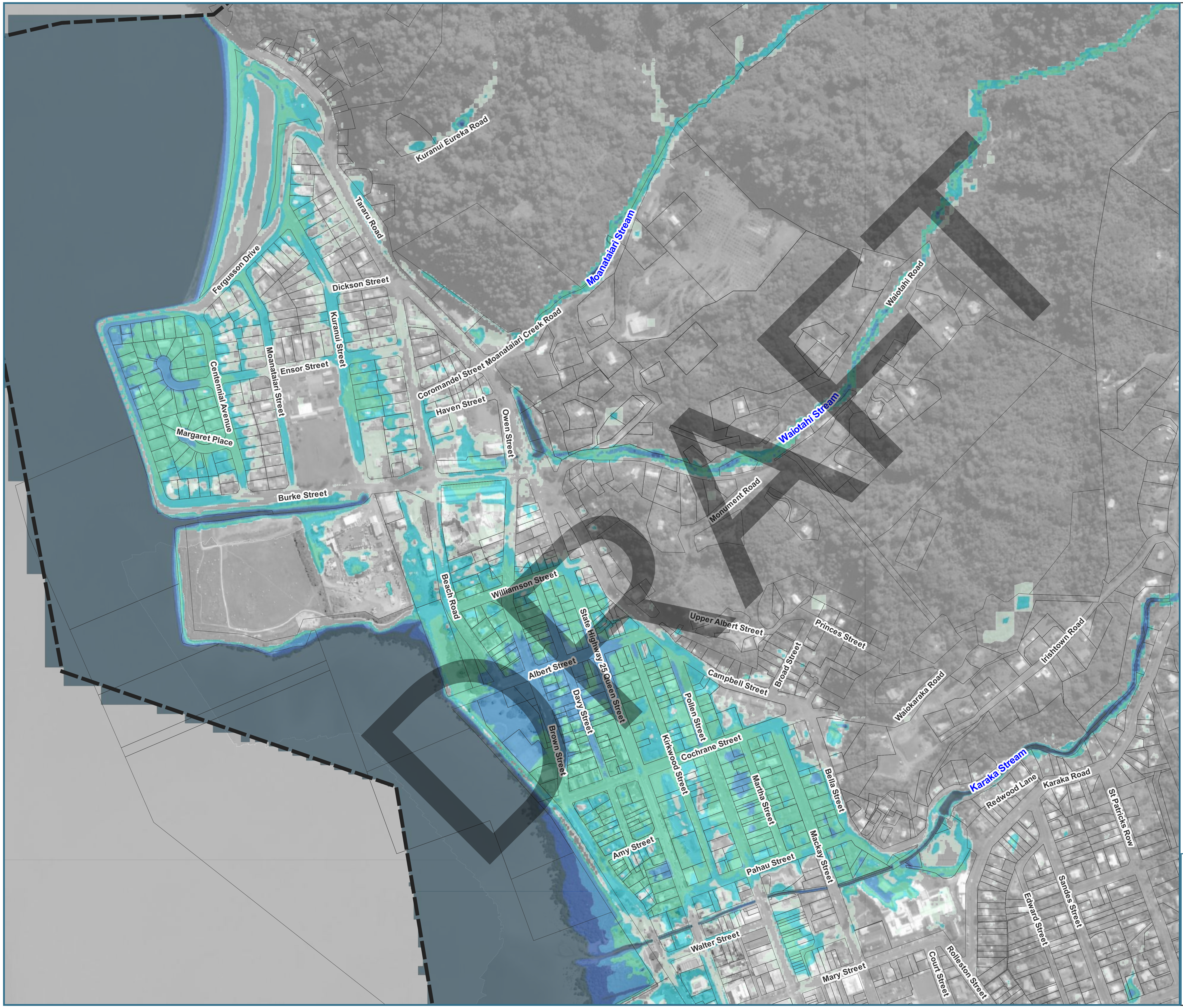

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Figure 5 (Sheet 1)

Scenario: Baseline Conditions
Event: 100 Year ARI Event
Results: Peak Water Depth

Legend

Model Boundary

Water Depth
<= 0.1 m
0.1 - 0.25 m
0.25 - 5 m
0.5 - 1 m
1- 1.5 m
1.5 - 2 m
> 2 m

PA3520
NZGD2000 / New Zealand Transverse Mercator 2000
Scale at A3

1:6,000

0 100 200 300 m

N

Thames Fluvial Modelling

Figure 5 (Sheet 2)

Scenario: Baseline Conditions
Event: 100 Year ARI Event
Results: Peak Water Depth

Legend

Model Boundary	⌐
Water Depth	
<= 0.1 m	□
0.1 - 0.25 m	□
0.25 - 5 m	■
0.5 - 1 m	■
1- 1.5 m	■
1.5 - 2 m	■
> 2 m	■

PA3520
NZGD2000 / New Zealand Transverse Mercator 2000
Scale at A3

1:6,000

0 100 200 300 m

N

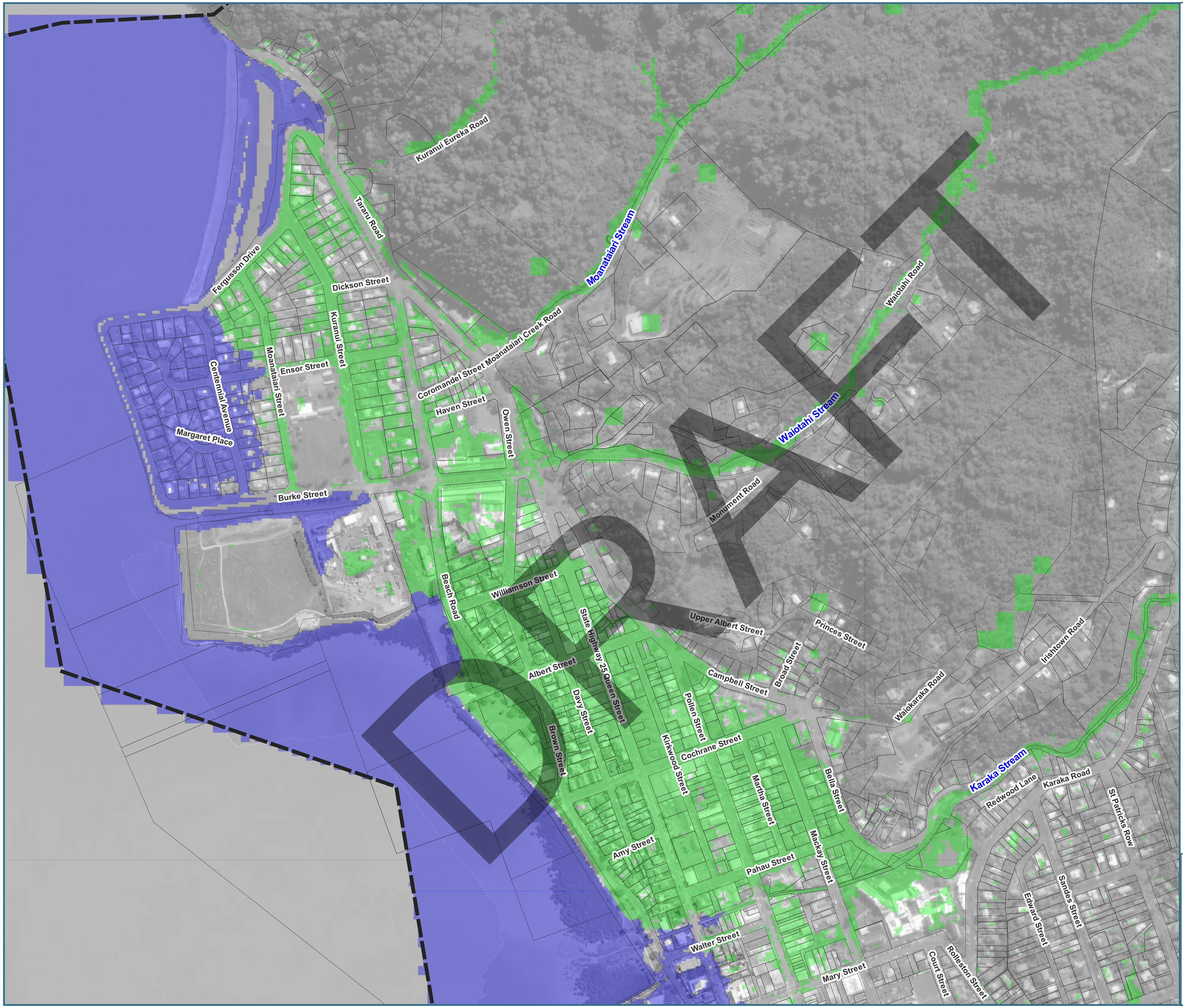

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Figure 6 (Sheet 1)

Scenario: Baseline Conditions
Event: 100 Year ARI Event
Results: Critical Event in Envelope

Legend

Model Boundary

Critical Event

100 year ARI Catchment Event
10 year ARI Ocean Event 🟩

10 year ARI Catchment Event
100 year ARI Ocean Event 🟦

PA3520
NZGD2000 / New Zealand Transverse Mercator 2000
Scale at A3

1:6,000

0 100 200 300 m

N

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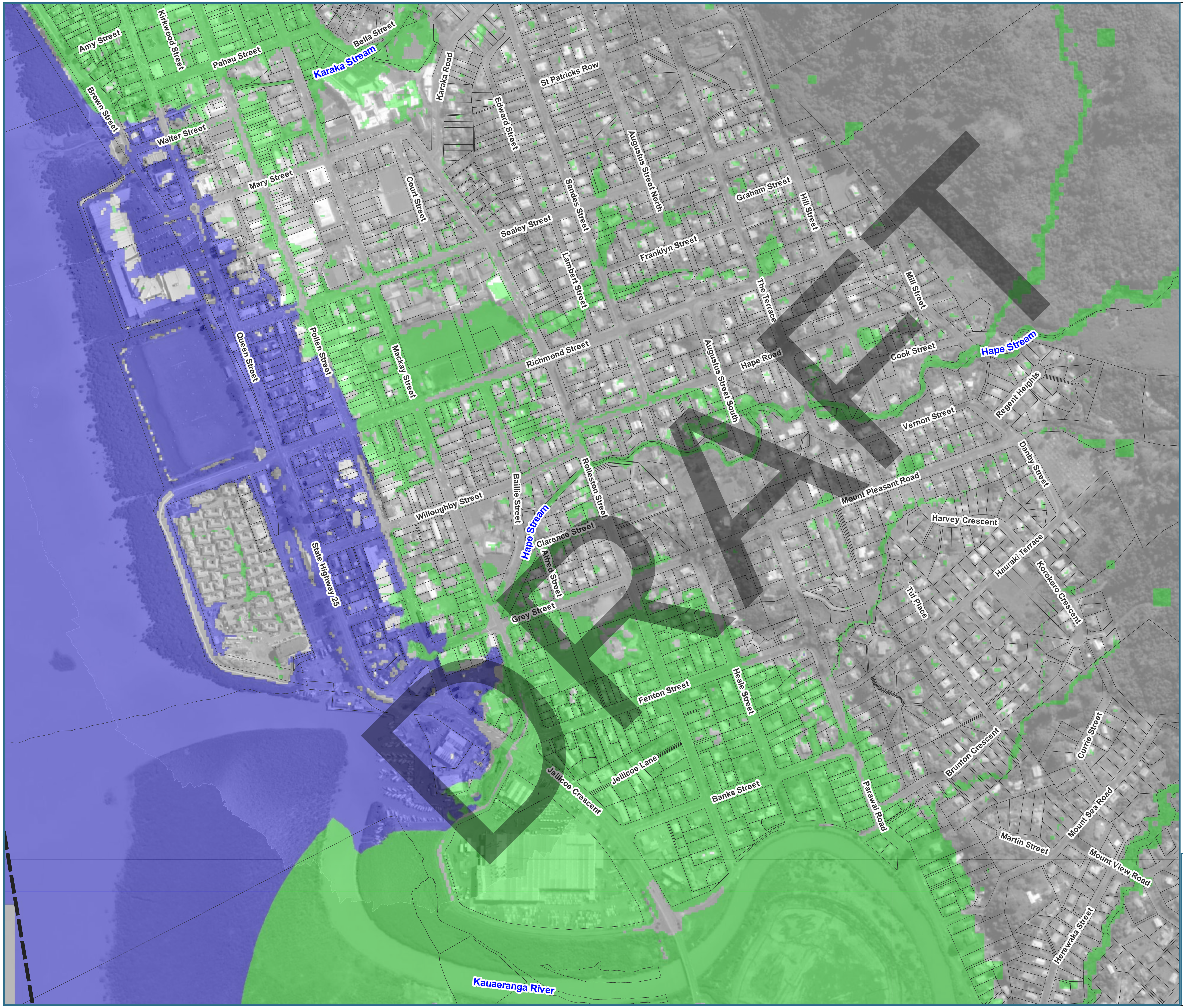

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Figure 6 (Sheet 2)

Scenario: Baseline Conditions
Event: 100 Year ARI Event
Results: Critical Event in Envelope

Legend

Model Boundary

Critical Event
100 year ARI Catchment Event
10 year ARI Ocean Event 🟩

10 year ARI Catchment Event
100 year ARI Ocean Event 🟪

PA3520
NZGD2000 / New Zealand Transverse
Mercator 2000
Scale at A3

1:6,000

0 100 200 300 m

N

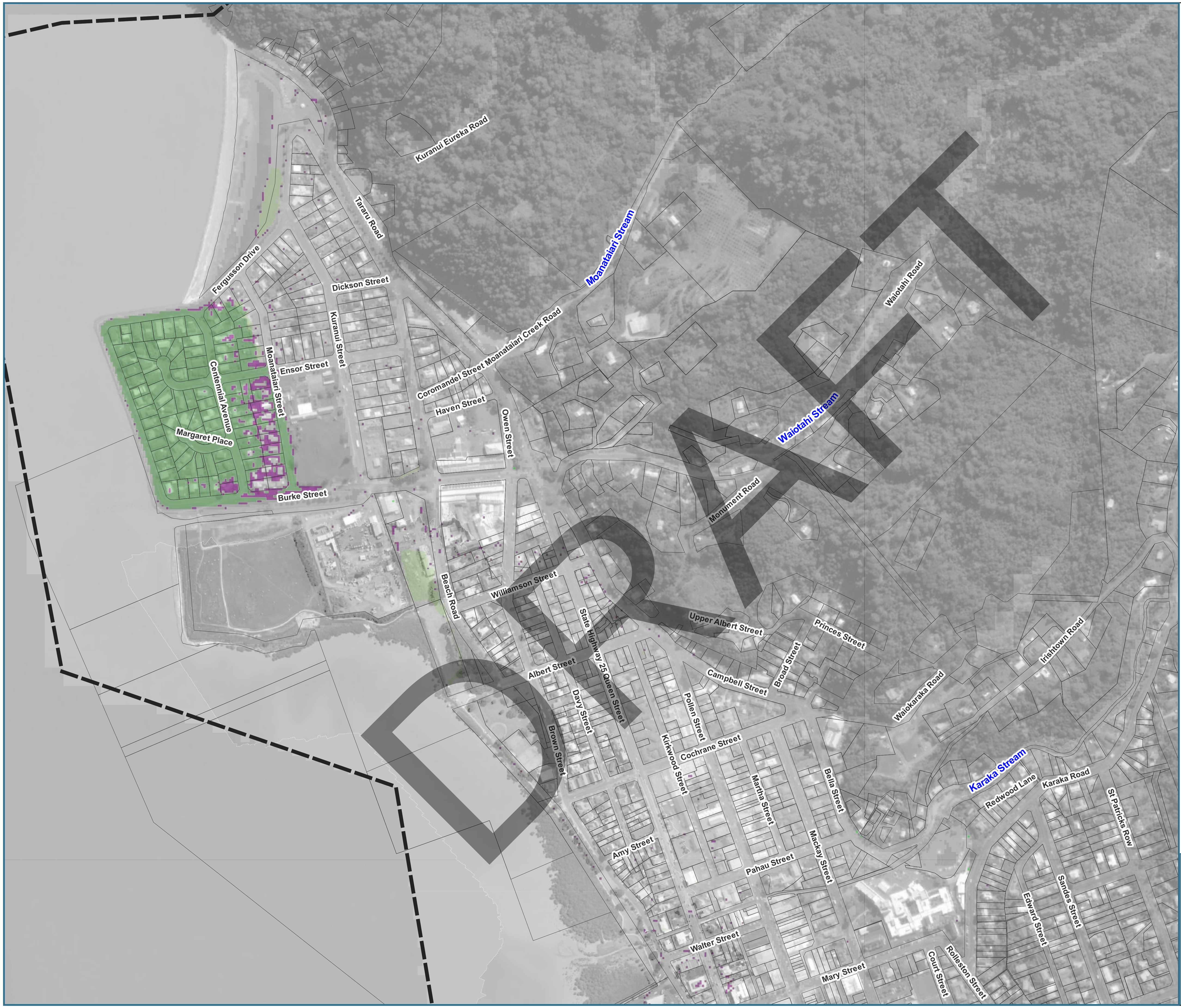

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Figure 7 (Sheet 1)

Scenario: Coincident 100 Year ARI Flood and Ocean Event
Event: 100 Year ARI Event
Results: Impact on Peak Water Depth

Legend

Model Boundary ▬

Depth Difference
> 1 m Lower 🟪
0.7 m to 1 m Lower 🟦
0.5 m to 0.7 m Lower 🟦
0.2 m to 0.5 m Lower 🟦
0.05 m to 0.2 m Lower 🟦
< 0.05 m Difference ⬜
0.05 m to 0.1 m Higher 🟩
0.1 m to 0.2 m Higher 🟩
0.2 m to 0.4 m Higher 🟨
0.4 m to 0.7 m Higher 🟧
0.7 m to 1.0 m Higher 🟧
1.0 m to 1.4 m Higher 🟥
> 1.4 m Higher 🟥

Wet / Dry
Was Wet, Now Dry 🟩
Was Dry, Now Wet 🟪

PA3520
NZGD2000 / New Zealand Transverse Mercator 2000
Scale at A3

1:6,000
0 100 200 300 m
N

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Figure 7 (Sheet 2)

Scenario: Coincident 100 Year ARI Flood and Ocean Event
Event: 100 Year ARI Event
Results: Impact on Peak Water Depth

Legend

Model Boundary

Depth Difference
- > 1 m Lower
- 0.7 m to 1 m Lower
- 0.5 m to 0.7 m Lower
- 0.2 m to 0.5 m Lower
- 0.05 m to 0.2 m Lower
- < 0.05 m Difference
- 0.05 m to 0.1 m Higher
- 0.1 m to 0.2 m Higher
- 0.2 m to 0.4 m Higher
- 0.4 m to 0.7 m Higher
- 0.7 m to 1.0 m Higher
- 1.0 m to 1.4 m Higher
- > 1.4 m Higher

Wet / Dry
- Was Wet, Now Dry
- Was Dry, Now Wet

PA3520
NZGD2000 / New Zealand Transverse Mercator 2000
Scale at A3

1:6,000

0 100 200 300 m

N

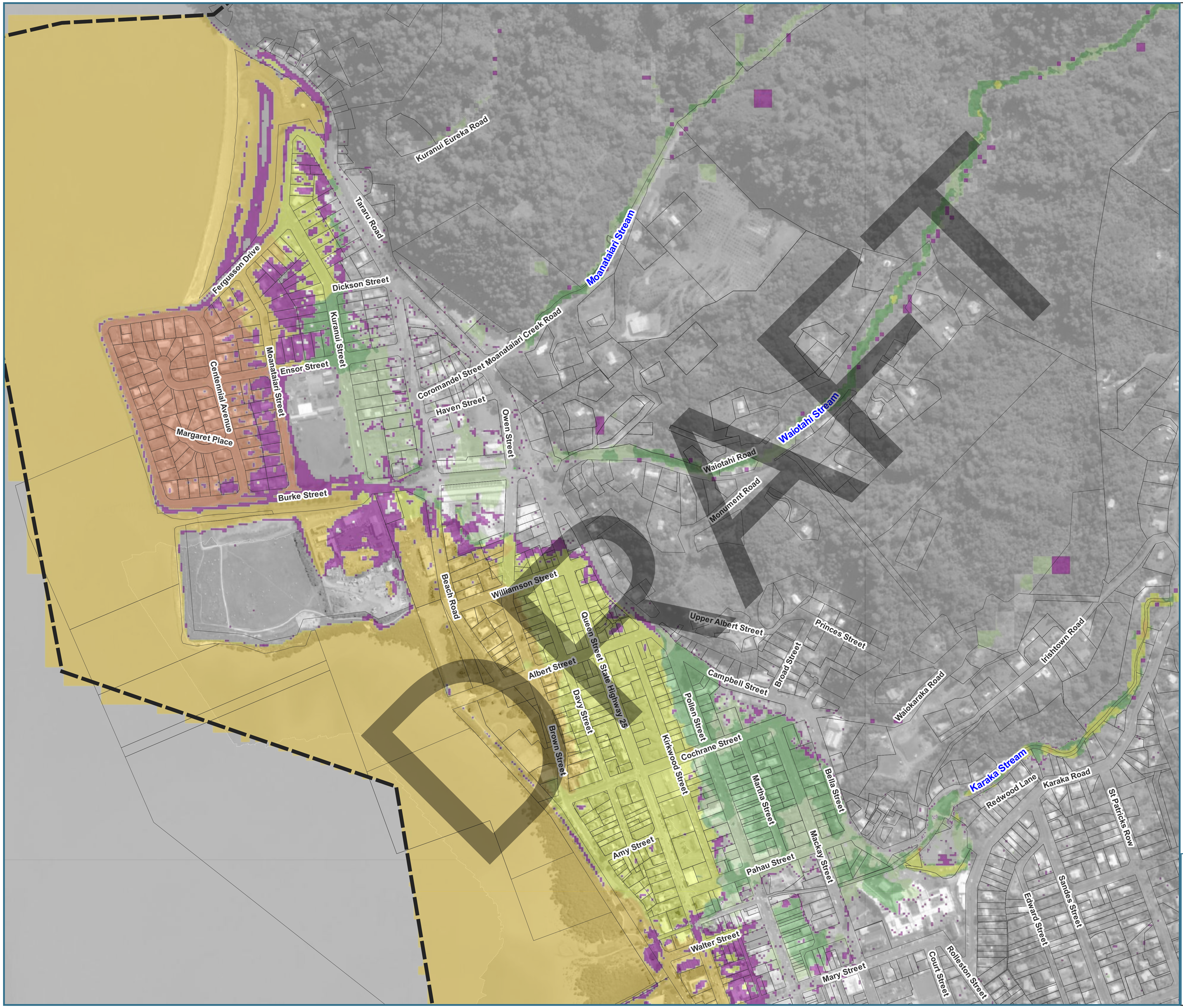

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Figure 8 (Sheet 1)

Scenario: 2080 Climate Change (50 Year Horizon)
Event: 100 Year ARI Event
Results: Impact on Peak Water Depth

Legend

Model Boundary	▭
Depth Difference	
> 1 m Lower	🟪
0.7 m to 1 m Lower	🟦
0.5 m to 0.7 m Lower	🟦
0.2 m to 0.5 m Lower	🟦
0.05 m to 0.2 m Lower	🟦
< 0.05 m Difference	⬜
0.05 m to 0.1 m Higher	🟩
0.1 m to 0.2 m Higher	🟩
0.2 m to 0.4 m Higher	🟨
0.4 m to 0.7 m Higher	🟧
0.7 m to 1.0 m Higher	🟧
1.0 m to 1.4 m Higher	🟥
> 1.4 m Higher	🟥
Wet / Dry	
Was Wet, Now Dry	🟩
Was Dry, Now Wet	🟪

PA3520
NZGD2000 / New Zealand Transverse Mercator 2000
Scale at A3

1:6,000

0 100 200 300 m

N

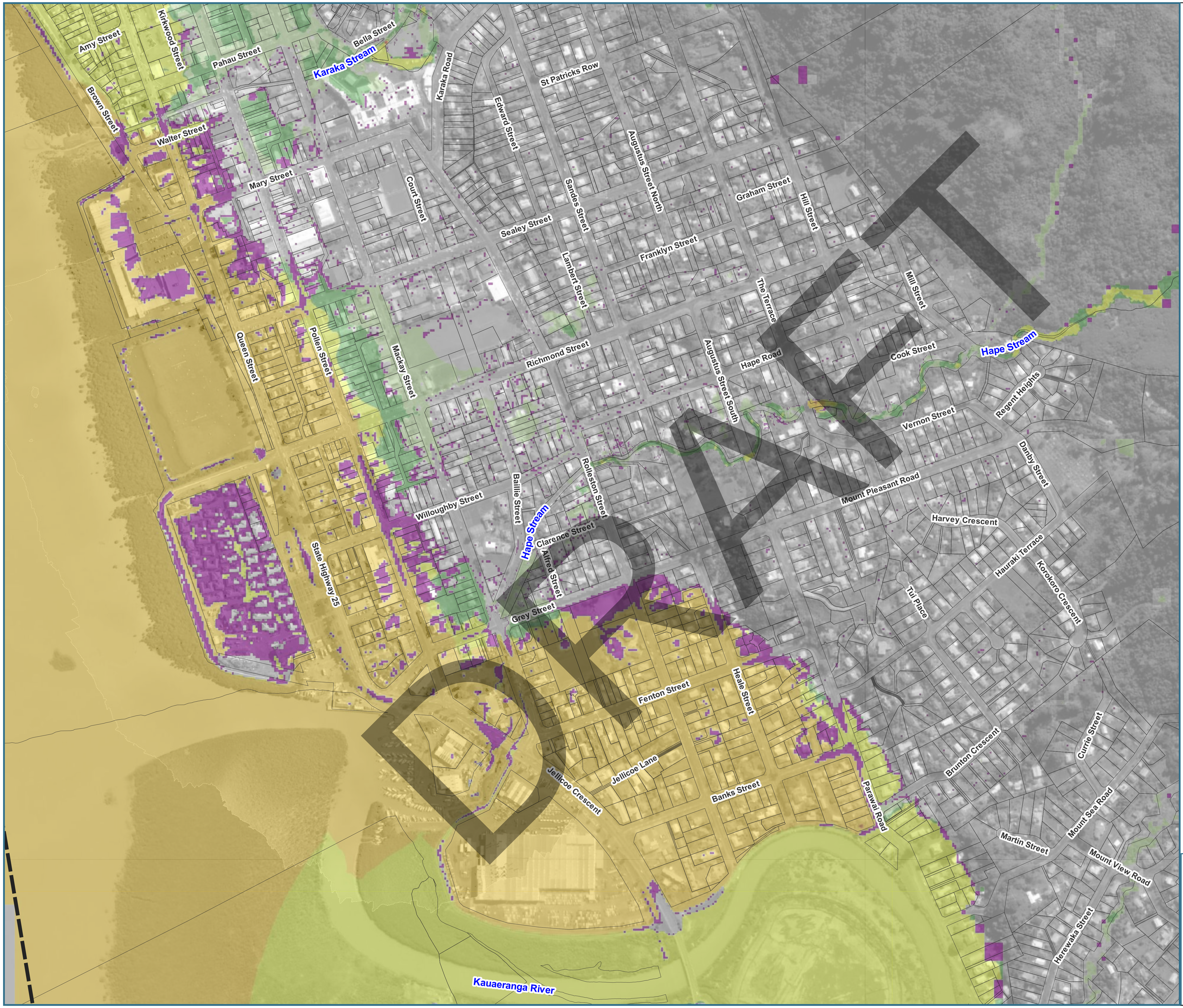

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Figure 8 (Sheet 2)

Scenario: 2080 Climate Change (50 Year Horizon)
Event: 100 Year ARI Event
Results: Impact on Peak Water Depth

Legend

Model Boundary ⊏

Depth Difference
> 1 m Lower 🟪
0.7 m to 1 m Lower 🟦
0.5 m to 0.7 m Lower 🟦
0.2 m to 0.5 m Lower 🟦
0.05 m to 0.2 m Lower 🟦
< 0.05 m Difference ⬜
0.05 m to 0.1 m Higher 🟩
0.1 m to 0.2 m Higher 🟩
0.2 m to 0.4 m Higher 🟨
0.4 m to 0.7 m Higher 🟨
0.7 m to 1.0 m Higher 🟧
1.0 m to 1.4 m Higher 🟥
> 1.4 m Higher 🟥

Wet / Dry
Was Wet, Now Dry 🟩
Was Dry, Now Wet 🟪

PA3520
NZGD2000 / New Zealand Transverse Mercator 2000
Scale at A3

1:6,000

0 100 200 300 m

N

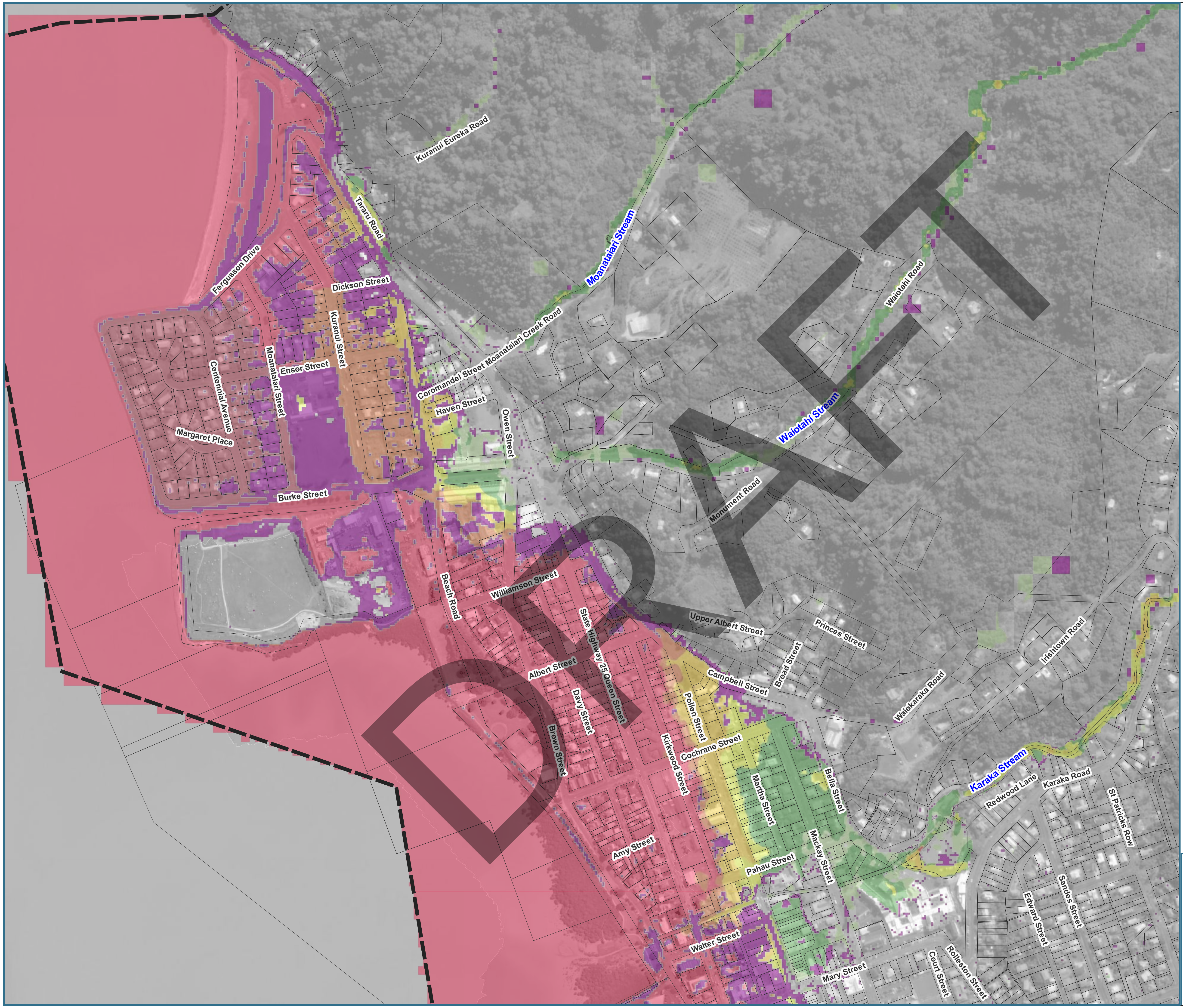

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Figure 9 (Sheet 1)

Scenario: 2130 Climate Change (100 Year Horizon)
Event: 100 Year ARI Event
Results: Impact on Peak Water Depth

Legend

Model Boundary ⌐¬

Depth Difference
> 1 m Lower 🟪
0.7 m to 1 m Lower 🟦
0.5 m to 0.7 m Lower 🟦
0.2 m to 0.5 m Lower 🟦
0.05 m to 0.2 m Lower 🟦
< 0.05 m Difference ⬜
0.05 m to 0.1 m Higher 🟩
0.1 m to 0.2 m Higher 🟩
0.2 m to 0.4 m Higher 🟨
0.4 m to 0.7 m Higher 🟨
0.7 m to 1.0 m Higher 🟧
1.0 m to 1.4 m Higher 🟥
> 1.4 m Higher 🟥

Wet / Dry
Was Wet, Now Dry 🟩
Was Dry, Now Wet 🟪

PA3520
NZGD2000 / New Zealand Transverse Mercator 2000
Scale at A3

1:6,000

0 100 200 300 m

N

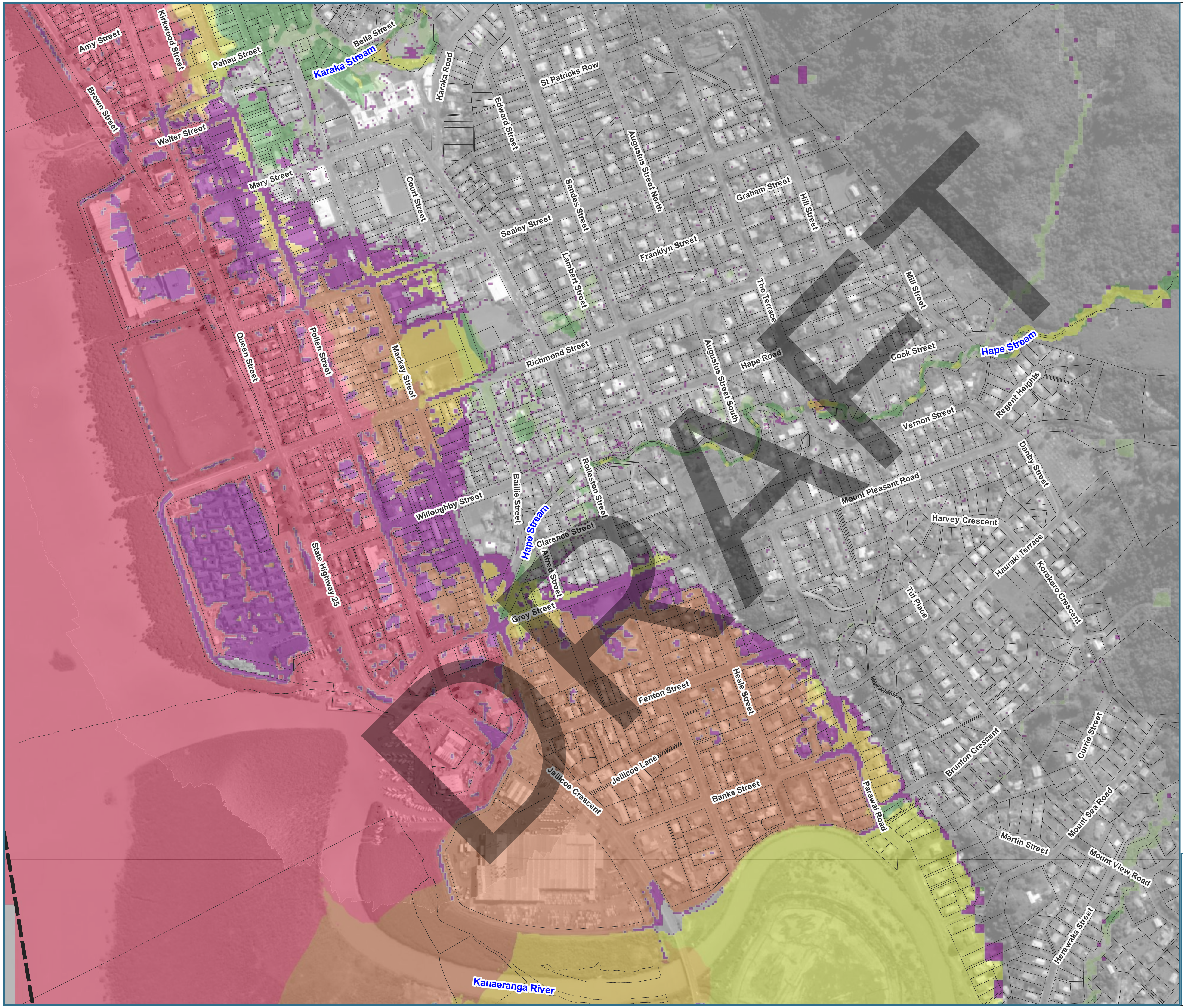

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Figure 9 (Sheet 2)

Scenario: 2130 Climate Change (100 Year Horizon)
Event: 100 Year ARI Event
Results: Impact on Peak Water Depth

Legend

Model Boundary	▭
Depth Difference	
> 1 m Lower	🟪
0.7 m to 1 m Lower	🟦
0.5 m to 0.7 m Lower	🟦
0.2 m to 0.5 m Lower	🟦
0.05 m to 0.2 m Lower	🟦
< 0.05 m Difference	⬜
0.05 m to 0.1 m Higher	🟩
0.1 m to 0.2 m Higher	🟩
0.2 m to 0.4 m Higher	🟨
0.4 m to 0.7 m Higher	🟨
0.7 m to 1.0 m Higher	🟧
1.0 m to 1.4 m Higher	🟥
> 1.4 m Higher	🟥
Wet / Dry	
Was Wet, Now Dry	🟩
Was Dry, Now Wet	🟪

PA3520
NZGD2000 / New Zealand Transverse Mercator 2000
Scale at A3

1:6,000

0 100 200 300 m

N

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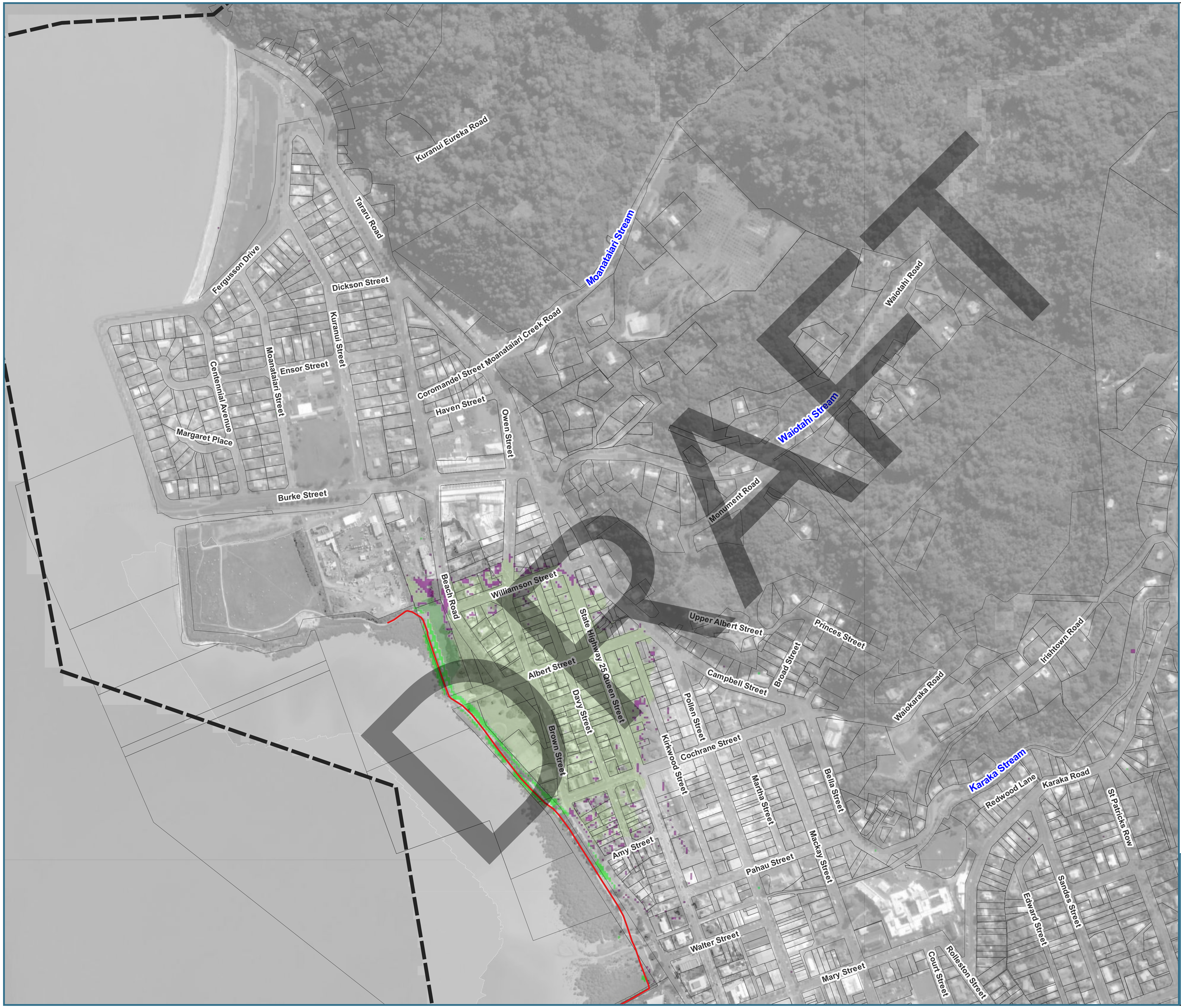

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Figure 10 (Sheet 1)

Scenario: Concept Design Gates Open
Event: 10 Year ARI Event
Results: Impact on Peak Water Depth

Legend
Model Boundary ╍
Coastal Defence Concept Design —

Depth Difference
> 1 m Lower 🟪
0.7 m to 1 m Lower 🟦
0.5 m to 0.7 m Lower 🟦
0.2 m to 0.5 m Lower 🟦
0.05 m to 0.2 m Lower 🟦
< 0.05 m Difference ⬜
0.05 m to 0.1 m Higher 🟩
0.1 m to 0.2 m Higher 🟩
0.2 m to 0.4 m Higher 🟨
0.4 m to 0.7 m Higher 🟨
0.7 m to 1.0 m Higher 🟧
1.0 m to 1.4 m Higher 🟥
> 1.4 m Higher 🟥

Wet / Dry
Was Wet, Now Dry 🟩
Was Dry, Now Wet 🟪

PA3520
NZGD2000 / New Zealand Transverse Mercator 2000
Scale at A3

1:6,000

0 100 200 300 m
N

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Figure 10 (Sheet 2)

Scenario: Concept Design Gates Open
Event: 10 Year ARI Event
Results: Impact on Peak Water Depth

Legend

Model Boundary ▭
Coastal Defence Concept Design —

Depth Difference

> 1 m Lower	🟪
0.7 m to 1 m Lower	🟪
0.5 m to 0.7 m Lower	🟦
0.2 m to 0.5 m Lower	🟦
0.05 m to 0.2 m Lower	🟦
< 0.05 m Difference	⬜
0.05 m to 0.1 m Higher	🟩
0.1 m to 0.2 m Higher	🟩
0.2 m to 0.4 m Higher	🟨
0.4 m to 0.7 m Higher	🟨
0.7 m to 1.0 m Higher	🟧
1.0 m to 1.4 m Higher	🟥
> 1.4 m Higher	🟥

Wet / Dry

Was Wet, Now Dry	🟩
Was Dry, Now Wet	🟪

PA3520
NZGD2000 / New Zealand Transverse Mercator 2000
Scale at A3

1:6,000

0 100 200 300 m N

Disclaimer: While all reasonable care has been taken to ensure the information contained on this output is up to date and accurate, it contains data from a number of sources - no warranty is given that this information is free from error or omission. Any reliance placed on such information shall be at the sole risk of the user. Please verify the accuracy of all information prior to using it. This is not a design document.

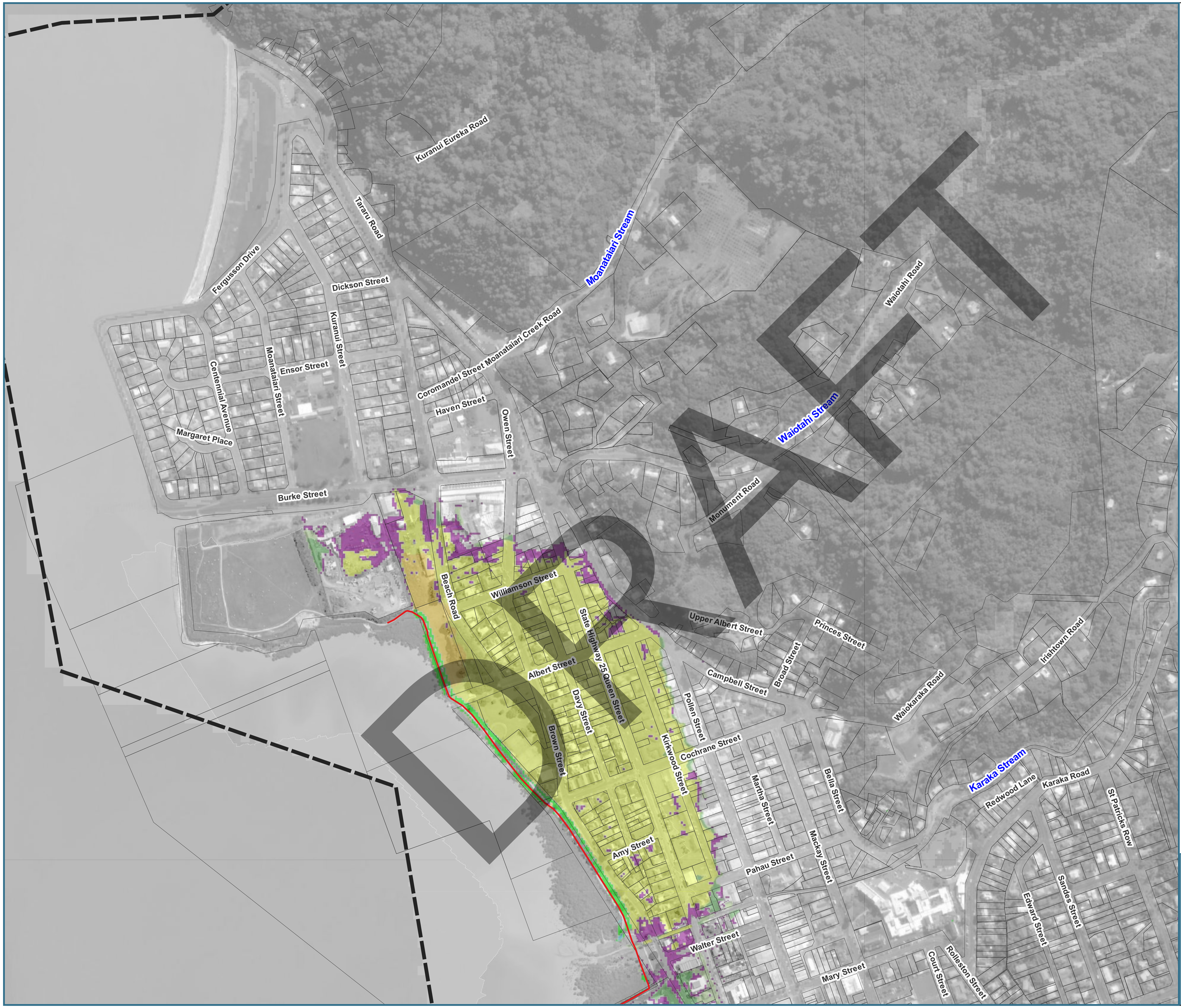

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Figure 11 (Sheet 1)

Scenario: Concept Design Gates Open
Event: 50 Year ARI Event
Results: Impact on Peak Water Depth

Legend

Model Boundary	⌐
Coastal Defence Concept Design	—

Depth Difference

> 1 m Lower	🟪
0.7 m to 1 m Lower	🟦
0.5 m to 0.7 m Lower	🟦
0.2 m to 0.5 m Lower	🟦
0.05 m to 0.2 m Lower	🟦
< 0.05 m Difference	⬜
0.05 m to 0.1 m Higher	🟩
0.1 m to 0.2 m Higher	🟩
0.2 m to 0.4 m Higher	🟨
0.4 m to 0.7 m Higher	🟧
0.7 m to 1.0 m Higher	🟧
1.0 m to 1.4 m Higher	🟥
> 1.4 m Higher	🟥

Wet / Dry

Was Wet, Now Dry	🟩
Was Dry, Now Wet	🟪

PA3520
NZGD2000 / New Zealand Transverse Mercator 2000
Scale at A3

1:6,000

0 100 200 300 m

N

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Figure 11 (Sheet 2)

Scenario: Concept Design Gates Open
Event: 50 Year ARI Event
Results: Impact on Peak Water Depth

Legend

Model Boundary	⌐
Coastal Defence Concept Design	—

Depth Difference

> 1 m Lower	🟪
0.7 m to 1 m Lower	🟦
0.5 m to 0.7 m Lower	🟦
0.2 m to 0.5 m Lower	🟦
0.05 m to 0.2 m Lower	🟦
< 0.05 m Difference	⬜
0.05 m to 0.1 m Higher	🟩
0.1 m to 0.2 m Higher	🟩
0.2 m to 0.4 m Higher	🟨
0.4 m to 0.7 m Higher	🟨
0.7 m to 1.0 m Higher	🟧
1.0 m to 1.4 m Higher	🟥
> 1.4 m Higher	🟥

Wet / Dry

Was Wet, Now Dry	🟩
Was Dry, Now Wet	🟪

PA3520
NZGD2000 / New Zealand Transverse Mercator 2000
Scale at A3

1:6,000
0 100 200 300 m
N

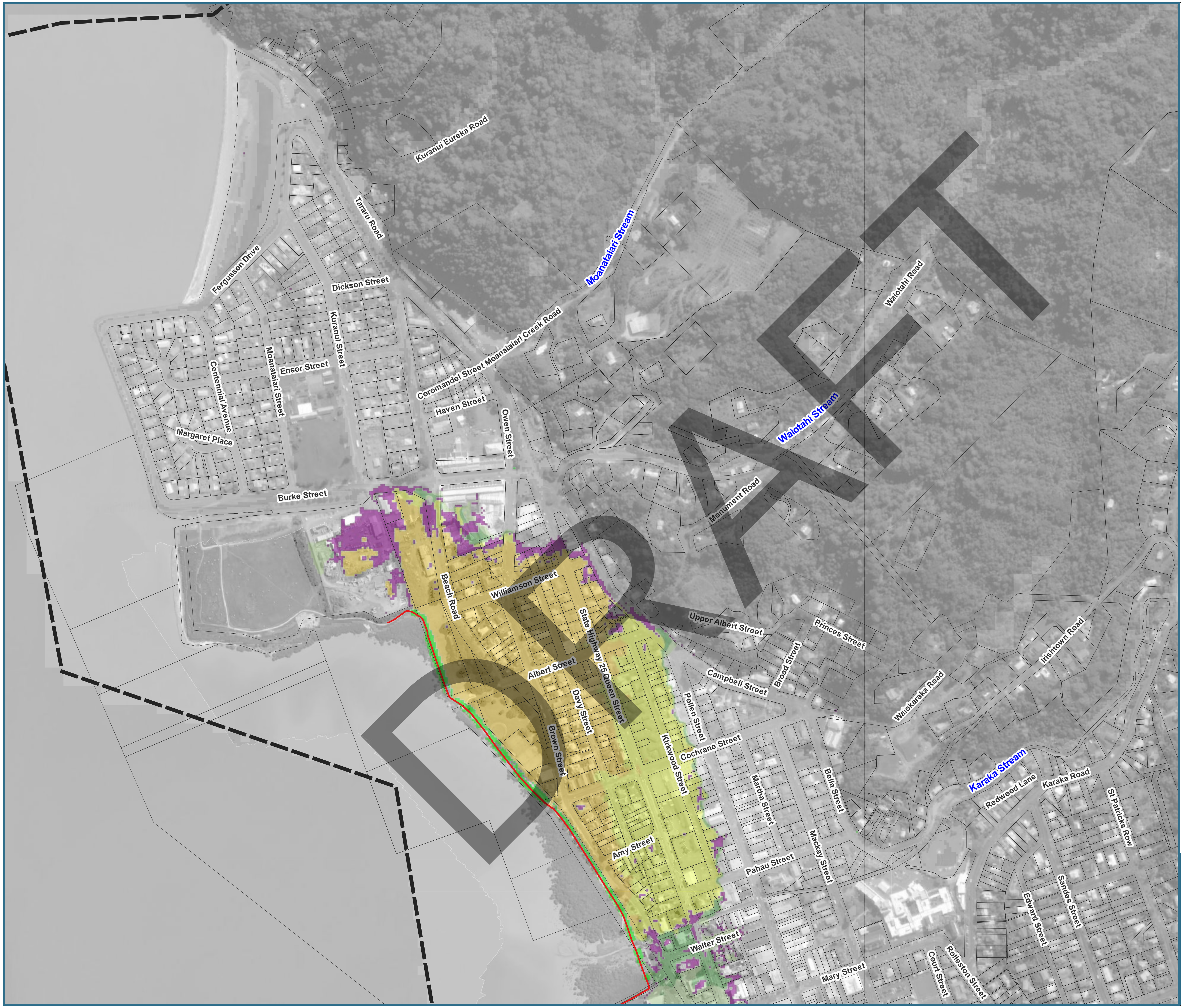

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Figure 12 (Sheet 1)

Scenario: Concept Design Gates Open
Event: 100 Year ARI Event
Results: Impact on Peak Water Depth

Legend
Model Boundary
Coastal Defence Concept Design

Depth Difference
> 1 m Lower 🟪
0.7 m to 1 m Lower 🟦
0.5 m to 0.7 m Lower 🟦
0.2 m to 0.5 m Lower 🟦
0.05 m to 0.2 m Lower 🟦
< 0.05 m Difference ⬜
0.05 m to 0.1 m Higher 🟩
0.1 m to 0.2 m Higher 🟩
0.2 m to 0.4 m Higher 🟨
0.4 m to 0.7 m Higher 🟨
0.7 m to 1.0 m Higher 🟧
1.0 m to 1.4 m Higher 🟥
> 1.4 m Higher 🟥

Wet / Dry
Was Wet, Now Dry 🟩
Was Dry, Now Wet 🟪

PA3520
NZGD2000 / New Zealand Transverse
Mercator 2000
Scale at A3

1:6,000
0 100 200 300 m
N

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Figure 12 (Sheet 2)

Scenario: Concept Design Gates Open
Event: 100 Year ARI Event
Results: Impact on Peak Water Depth

Legend	
Model Boundary	▭
Coastal Defence Concept Design	—
Depth Difference	
> 1 m Lower	🟪
0.7 m to 1 m Lower	🟦
0.5 m to 0.7 m Lower	🟦
0.2 m to 0.5 m Lower	🟦
0.05 m to 0.2 m Lower	🟦
< 0.05 m Difference	⬜
0.05 m to 0.1 m Higher	🟩
0.1 m to 0.2 m Higher	🟩
0.2 m to 0.4 m Higher	🟨
0.4 m to 0.7 m Higher	🟨
0.7 m to 1.0 m Higher	🟧
1.0 m to 1.4 m Higher	🟥
> 1.4 m Higher	🟥
Wet / Dry	
Was Wet, Now Dry	🟩
Was Dry, Now Wet	🟪

PA3520
NZGD2000 / New Zealand Transverse Mercator 2000
Scale at A3

1:6,000

0 100 200 300 m

N