Hihi Wastewater Treatment Plant

Hydrodynamic Modelling Study

Report prepared for Far North District Council

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MetOcean SOLUTIONS

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MetOcean Solutions is a Division of Meteorological Services of New Zealand Ltd, MetraWeather (Australia) Pty Ltd [ACN 126 850 904], MetraWeather (UK) Ltd [No. 04833498] and MetraWeather (Thailand) Ltd [No. 0105558115059] are wholly owned subsidiaries of Meteorological Service of New Zealand Ltd (MetService).

Executive Summary

Far North District Council (FNDC) is in the process of renewing its consent (CON20100739901) for the Hihi Wastewater Treatment Plant (WWTP) operation. MetOcean Solutions (MOS) has been commissioned by FNDC to provide a hydrodynamic study of the Hihi Stream/Hihi Beach to support the Quantitative Microbiological Risk Assessment (QMRA), which will assess the public health risk resulting from discharge downstream of the Hihi WWTP.

The release of pollutants into the river system is generally continuous over time, but is often subject to fluctuations within the released quantities. The fate of these pollutants can be assessed based on the hydrodynamic modelling of various flow conditions, thereby allowing estimations of the expected general dispersion of pollutants.

Hydrodynamic modelling

A SCHISM hydrodynamic model of Doubtless Bay and Hihi Beach and stream was created for this study. The model resolution was optimised to ensure replication of the relevant hydrodynamic processes.

Four scenarios were modelled to understand the extent of variability within the dispersal of pollutants from the WWTP::

Scenario 1 - Mean flow; Low WWTP Discharge rate (40 m^3/day -30days average).

Scenario 2 - Mean flow; Consent WWTP Discharge rate (40 m^3/day -30days average).

Scenario 3 - Mean flow; Peak WWTP Discharge rate (40 m^3/day -30days average).

Scenario 4 - Mean Annual Low Flow; Low WWTP Discharge rate (40 m^3/day -30days average).

Scenario 5 - Mean Annual Low Flow; Consent WWTP Discharge rate (40 m^3/day -30days average).

Scenario 6 - Mean Annual Low Flow; Peak WWTP Discharge rate (40 m^3/day -30days average).

Each scenario was simulated for the duration of a spring-neap tidal cycle (15 days) to capture the tidal variability in the analysis.

WWTP discharge simulations

Passive (neutrally buoyant) tracers were discharged within the closest model cell to the WWTP location. A nominated concentration value of 1 mg/L was used so that dilution can be calculated at various distances from the source. Specific contamination levels can then be determined using concentration ratios and the expected, or measured, discharge value.

Results are presented in the form of 50th and 90th percentile dilution maps, and as a time series of tracer concentration at 6 locations near Hihi Beach.

Key Findings

Hihi Stream is a low-flow rate stream and model results show that tracer concentration for the Mean Flow and Mean Annual Low Flow (MALF) are of similar order of magnitude once it reaches Hihi Beach.

Under MALF conditions and the consented WWTP discharge of 250 m^3/day (30-day average) , the tracer concentrations are approximately:

- 10^{-3} to 10^{-4} (dilution of 1,000 to 10,000) at the Hihi Stream outflow location onto Hihi Beach
- 10^{-4} to 10^{-5} (dilution of 10,000 to 100,000) north near Hihi Beach Holiday Park (stations 5 and 6)
- 10^{-5} to 10^{-6} (dilution of 100,000 to 1,000,000) south near Rangitoto Peninsula (stations 3 and 4)

Tracer concentration within and near the entrance of Mangonui Harbour are very low and in the order of 10^{-7} or less (dilution of 10,000,000 or more).

Difference in tracer concentration between the low (40 m^3/day 30-d average), consented (250 m3/day 30-d average) and peak (1600 m^3/day 30-d average) are typically one order of magnitude greater from low to peak, e.g. near Station 2, the tracer concentration is approx. 10^{-5} (dilution of 100,000) for the low WWTP discharge, 10^{-4} (dilution of 10,000) for the consented WWTP discharge and 10^{-3} (dilution of 1,000) for the peak WWTP discharge.

Tracer concentration within and near the entrance of Mangonui Harbour are very low and in the order of 10^{-7} or less (dilution of 10,000,000 or more).

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1.Introduction

Far North District Council (FNDC) is in the process of renewing its consent (CON20100739901) for the Hihi Wastewater Treatment Plant (WWTP) operation. A Quantitative Microbiological Risk Assessment (QMRA) is required to assess the public health risk resulting from the discharge to an unnamed tributary of Hihi Beach known locally as Hihi Stream.

To support the QMRA, a hydrodynamic study covering the Hihi Beach/Stream and Doubtless Bay is required to predict the dilution and dispersion of wastewater discharge from the Hihi Beach WWTP (Figure 1-1).

MetOcean Solutions (a division of the Meteorological Service of New Zealand Ltd) has been commissioned to undertake the hydrodynamic study.

The report is structured as follows: a description of the model set up and methodology is presented in Section 2, the model results are in Section 3 and a concise summary is provided in Section 4. References to literature cited in the text are given after Section

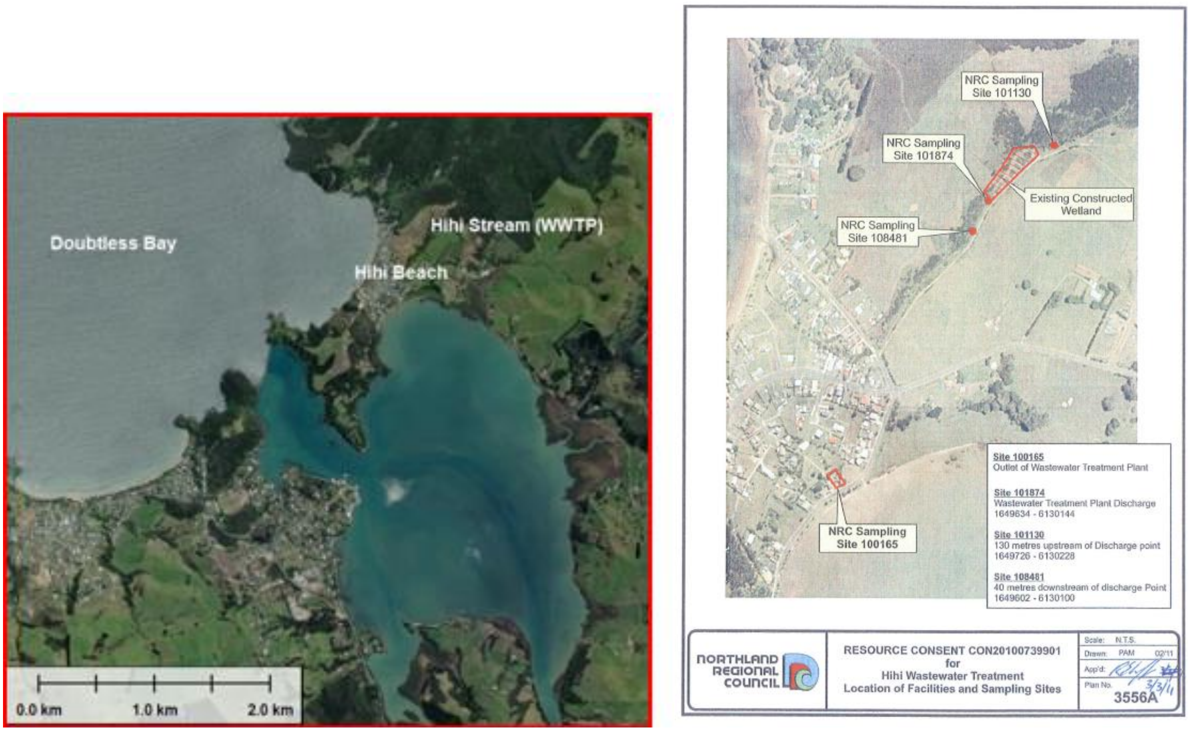

Figure 1-1: Location of the WWTP discharge at Hihi Beach/Stream.

2. Methodology

2.1 Bathymetry data

For this project the MetOcean Solutions bathymetry database, derived predominantly from Electronic Navigation Charts (ENC), was supplemented by LiDAR data supplied by the Far North District Council in intertidal coastal regions (Figure 2-1).

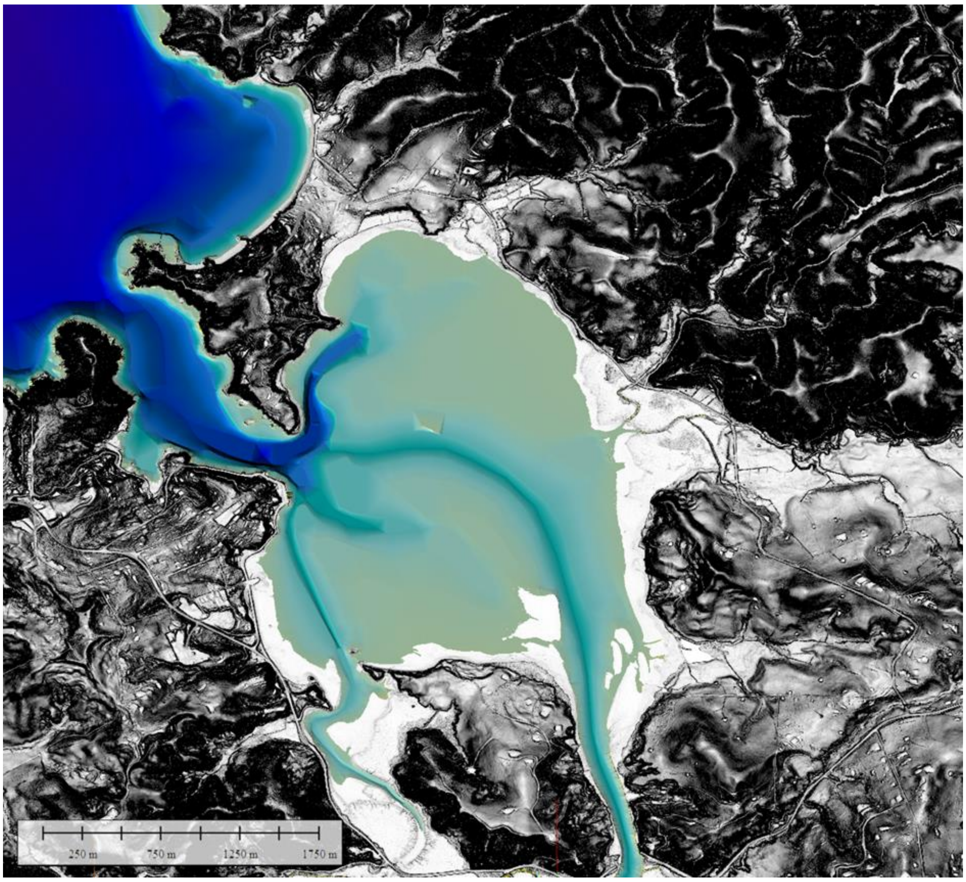

Figure 2-1: High resolution LiDAR data surrounding Mangonui Harbour

2.2 Model Description

The simulation of the far-field dispersion of effluent within a complex estuary system requires high resolution hydrodynamic fields. For the present study, high-resolution modelling of the tidal/river/stream discharge hydrodynamics was simulated using the open-source model SCHISM[1,2].Open-source science models allow full transparency of the code, numerics, boundary conditions and outputs.

SCHISM is a prognostic finite-element unstructured-grid model designed to simulate 3-D baroclinic, 3-D barotropic or 2-D barotropic circulation. The barotropic mode equations employ a semi-implicit finite-element Eulerian-Lagrangian algorithm to solve the shallow-water equations, forced by relevant physical processes (atmospheric, oceanic and fluvial forcing). A detailed description of the SCHISM model formulation, governing equations and numerics can be found in (Zhang and Baptista 2008). The finite-element grid structure (i.e., triangles) used by SCHISM has resolution and scale benefits over other regular or curvilinear based hydrodynamic models (such as Delft3D).

SCHISM is computationally efficient in the way it resolves the complex topography and bathymetry associated with estuaries, while the governing equations are similar to other open-source models such as Delft3D. SCHISM has been used extensively within the scientific community[3], and forms the backbone to operational systems used to predict nowcast and forecast estuarine water levels, currents, water temperature and salinity[4].

2.3 Model domain

The grid used for the Hihi Stream discharge assessment is based on the grid used for the previous project for the Parapara WWTP (MetOcean Solutions 2019). However, some parts of the previous grid were suppressed to lightweight the grid (e.g. Parapara Stream).

The model domain covers Hihi Stream, Hihi Beach, Mangonui Harbour and extends out into Doubtless Bay. The model resolution was optimised to ensure the relevant hydrodynamic processes were accurately captured. Offshore, the spatial resolution ranges between 20-300 m, refining to a resolution of <10 m inside the rivers and small

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[1] http://ccrm.vims.edu/schism/

[2] http://www.ccrm.vims.edu/w/index.php/Main_Page#SCHISM_WIKI

[3] http://ccrm.vims.edu/schism/schism_pubs.html

[4] https://tidesandcurrents.noaa.gov/ofs/creofs/creofs_info.html

streams (Figure 2-2). Offshore tidal elevation and velocity data was prescribed from MetOcean Solutions NZ ROMS hindcast model.

Hihi stream was designed in the grid according to orthorectified aerial images from LINZ and LIDAR data from Far North Regional Council. Stream width was made in order to have 3 cells in width with a minimum of 3 m resolution. This width was made to fulfil the requirement of at least 2 nodes within the width of the stream. The LiDAR land level data shows that the stream has a significant downhill slope from the WWTP discharge to the shoreline. The stream slope was artificially reduced in order for the model to be stable and prevent any hydraulics jumps and other instability occurring in the model. Whilst this may affect and reduce the velocity in the stream itself this is not expected to have any effect on the concentration assessment within Hihi Beach.

The model was run in 2D as it is not expected for baroclinic forcing (salinity and Temperature) and three-dimensional currents to have a significant effect on the distribution of the tracer concentration within the stream and inter-tidal regions.

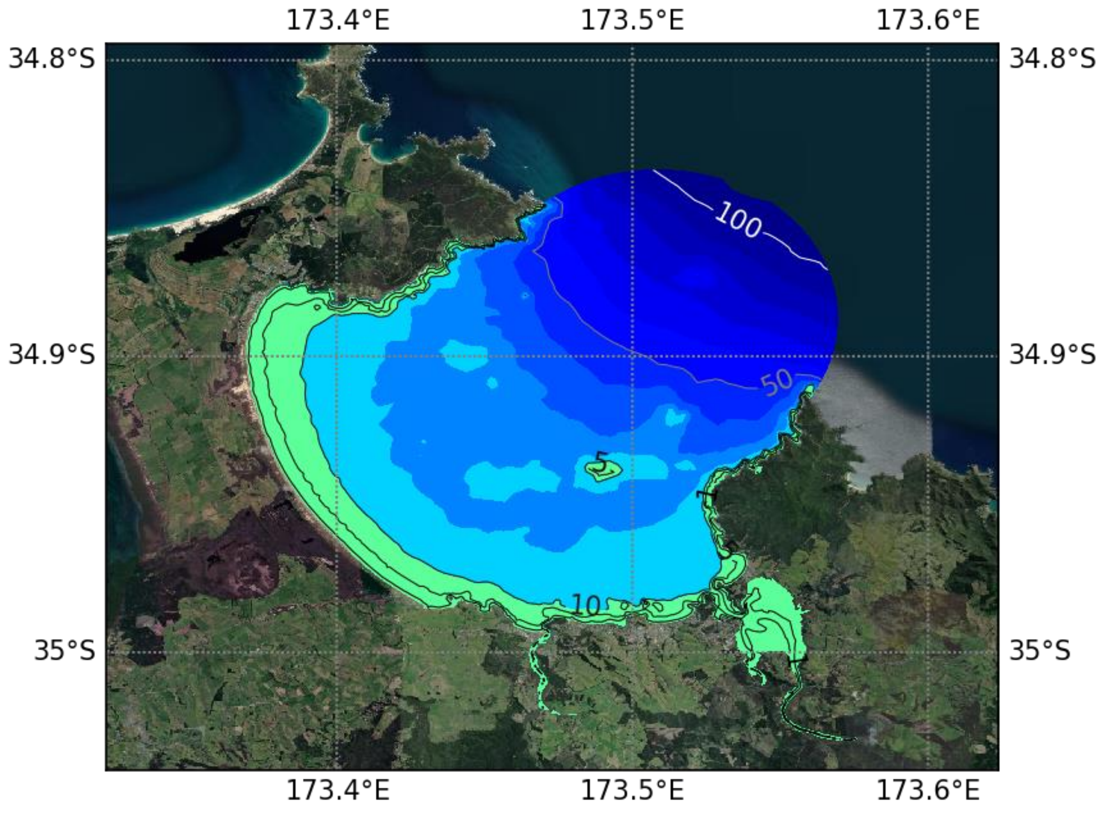

Figure 2-2: General view of the computational domain and bathymetry. Colour scale shows the bathymetry, also indicated by the contour lines.

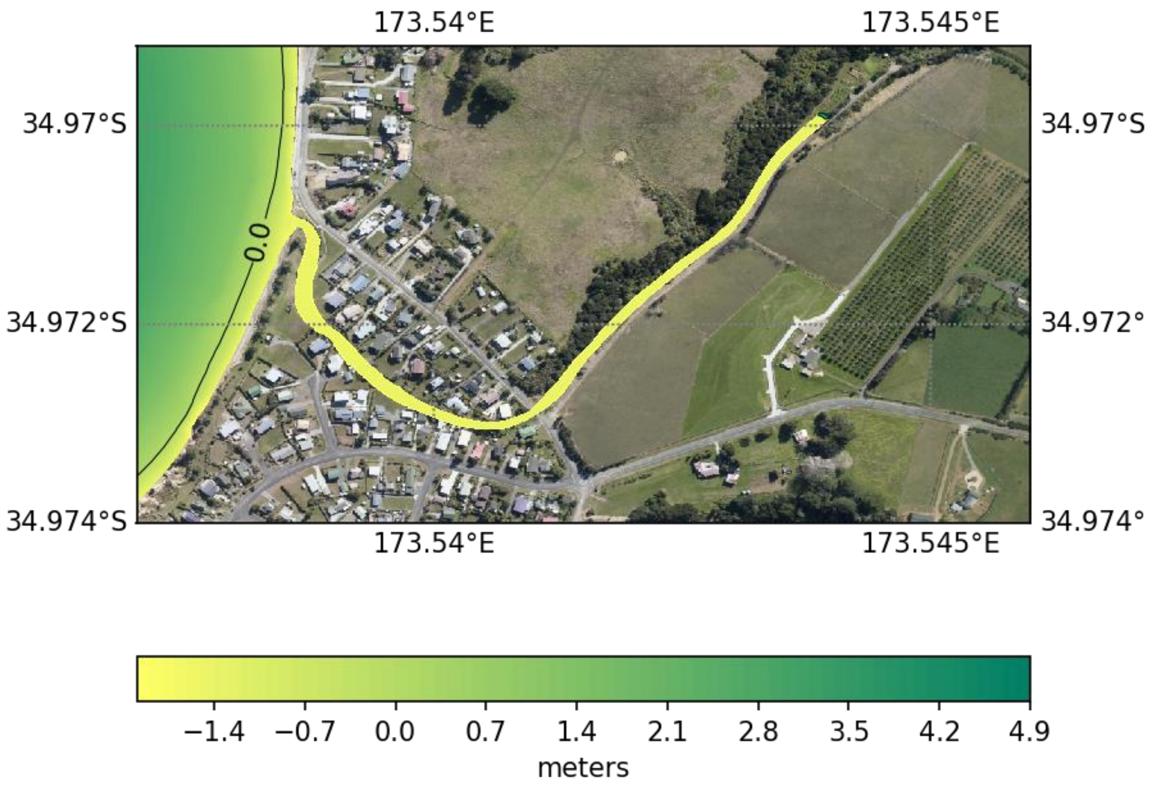

Figure 2-3: Grid bathymetry details near Hihi Stream.

2.4 Model boundary conditions

2.4.1 Hydrodynamic forcing

Tidal elevation and velocity boundary conditions for the SCHISM model were derived from constituents generated by a POM tidal model which covers the NZ region at approximately 6 km resolution. The tidal velocities were interpolated in the 3-D assuming a logarithmic profile.

For the scenario-based modelling, salinity and temperature were given the constant values of 35 ppt and 15 °C, respectively.

2.4.2 River forcing

River discharge data at, or near, the boundary of the main rivers discharging into Doubtless Bay and Mangonui Harbour (e.g. Oruaiti River) were sourced from NIWA's NZ River Maps (Booker and Whitehead 2017).

River discharge was kept constant for the duration of each simulation. The different scenarios simulated used the values for either the Mean Flow (m^3/s) and the Mean Annual Low Flow (MALF; m^3/s). MALF is defined as the mean of the annual low flow data-series after applying a 7-day running average (Booker and Woods 2014).

The rivers were given a salinity and temperature of 0 ppt and 12 °C, respectively.

For Hihi Stream, the following discharge flow were used:

- Mean Flow = 0.0082 m^3/s
- Mean Annual Low Flow (MALF)= 0.0016 m^3/s

2.5 Wastewater outflow trajectory modelling

2.5.1 WWTP Discharge rate

The existing resource consent CON20100739901 indicate that the 30-day rolling average of dry weather discharge shall not exceed 250 m^3/day.

Analysis of the Hihi WWTP discharge rate data available from 2019-2021 shows that the 30-day rolling average is quite variable and typically around 20-40 m^3/day with a peak at 1600 m^3/day in June 2021 (with an associated 2900 m^3 discharge on one day) .

To provide a sensitivity assessment on the effect of the discharge rate, the three following scenarios were considered for this modelling study:

- Low WWTP discharge rate of 40 m^3/day
- Consent WWTP discharge rate of 250 m^3/day
- Peak WWTP discharge rate of 1600 m^3/day

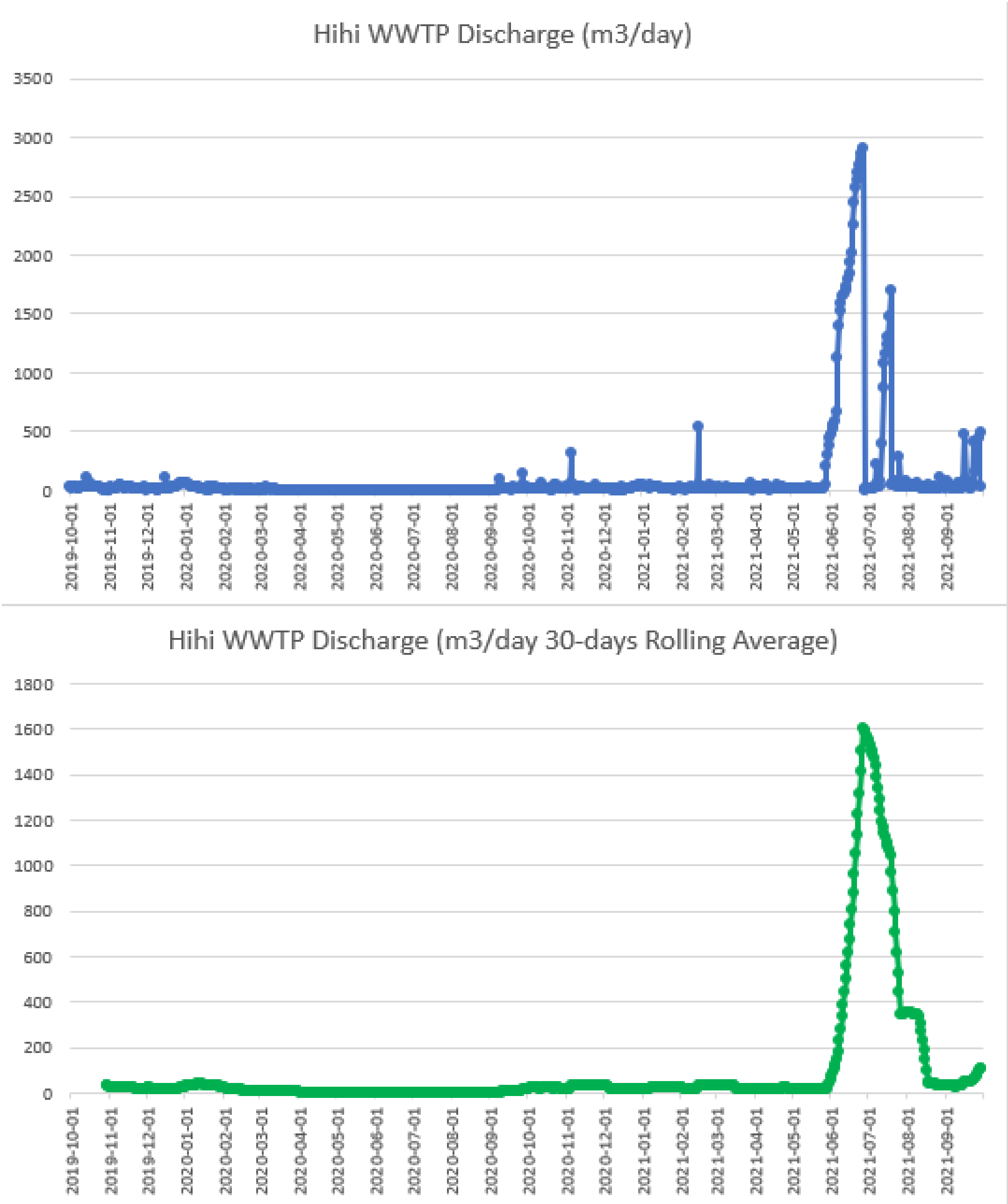

Figure 2-4: Hihi WWTP recorded discharge (October 2019 to September 2021) , daily discharge in m^3/day (top) and 30-days rolling average in m^3/day (bottom)

2.5.2 Eulerian modelling

Eulerian tracers are a concentration field which obeys a classical advection-diffusion equation driven by the current velocities generated by the hydrodynamic model (Meier and Höglund 2013). Sources, sinks and initial boundary conditions are specified for the tracer under consideration.

A detailed description of the Eulerian tracer technique to obtain dilution is presented in Zhang, Wilkin, and Schofield (2010), where the authors examined the time-scales associated with the dispersal of the Hudson River plume into the coastal waters of the New York Bight. The Eulerian tracer method differs from the common Lagrangian tracer approach, where multiple tracers are released, and time-scale information is extracted from their differential transport and is computationally much more efficient. The Eulerian approach is appropriate for the dispersal of outflow from the WWTP given the high model resolution of the receiving environment.

Passive Eulerian tracers (neutrally buoyant, with no decay) were released in the numerical model at the location of the WWTP discharge within the Hihi Stream. The discharge and concentration of the tracer was treated as constant over the length of the model simulation. Three different rates of discharge were used:

- Low (Summer) Discharge = 40 m^3/day (0.000463 m^3/s 30-days rolling average)
- Consent Discharge rate = 250 m^3/day (0.002893 m^3/s 30-days rolling average)
- Peak Discharge rate = 1600 m^3/day (0.018518 m^3/s 30-days rolling average)

The concentration of the tracer discharged from the WWTP remained constant for all scenarios and the entire simulation period, with a nominated concentration value of 1 mg/L to enable specific contaminant levels to be determined using concentration ratios along with the expected or measured discharged value.

2.6 Model Simulations

Six scenarios have been simulated, based on selected river flow discharge scenarios:

Scenario 1 - Mean flow; Low Discharge rate.

Scenario 2 - Mean flow; Consent Discharge rate.

Scenario 3 - Mean flow; Peak Discharge rate.

Scenario 4 - Mean Annual Low Flow; Low Discharge rate.

Scenario 5 - Mean Annual Low Flow; Consent Discharge rate.

Scenario 6 - Mean Annual Low Flow; Peak Discharge rate.

The simulations were run over a full month (two spring-neap tidal cycles) to describe the tidal flow variation effect on the plume within Doubtless Bay and near Hihi Beach.

Timeseries of tracer concentration were extracted at 6 selections locations along Hihi Beach shoreline (Figure 2-5 and Table 2-1) and provided at data files to be used for the QMRA .

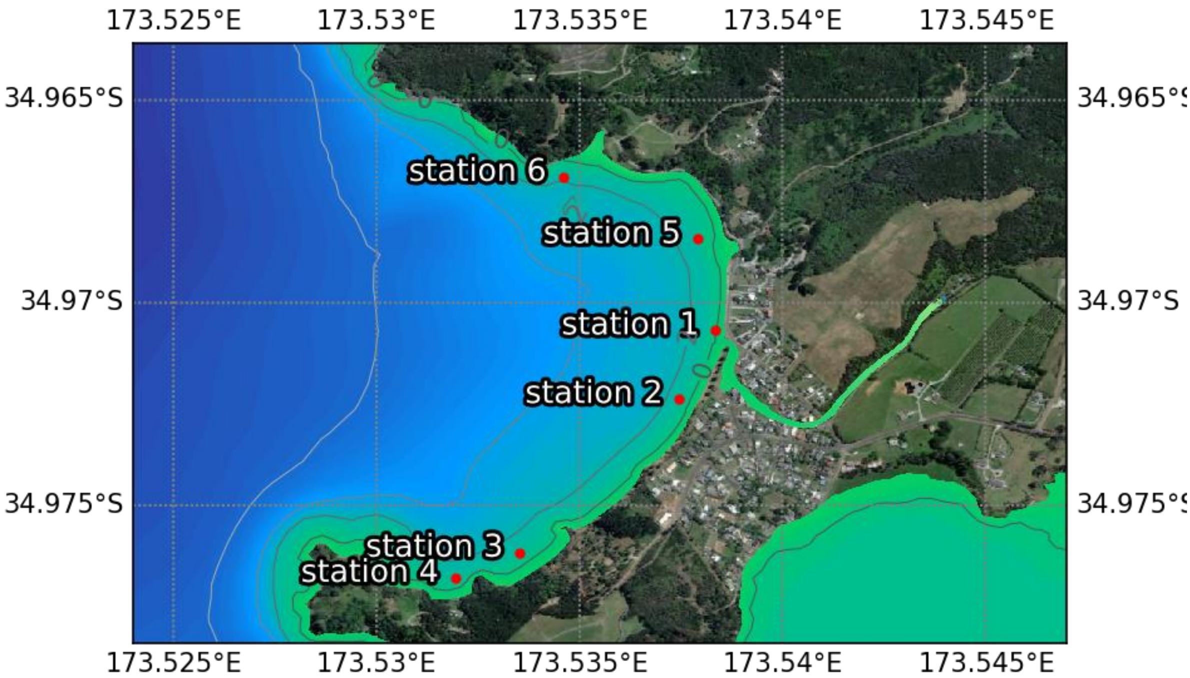

Figure 2-5: Locations of stations for model output timeseries extraction.

Table 2-1: Coordinates of output locations.

	x (m) NZD epsg2193	Y (m) NZD epsg2193	Lon (deg TN)	Lat (deg TN)
Station 1	1649137.27	6130075.41	173.5382862	-34.97068628
Station 2	1649049.90	6129871.75	173.5373411	-34.97252694
Station 3	1648671.22	6129444.42	173.5332178	-34.97639849
Station 4	1648527.66	6129400.34	173.5316477	-34.97680286
Station 5	1649116.97	6130306.32	173.5380502	-34.96860513
Station 6	1648845.85	6130520.68	173.5350678	-34.96668535

3.Hydrodynamic Model Results

Results from the model are presented in terms of maps and time-series of tracer concentration at selected locations along the Hihi Beach shoreline (Figure 2-5) .

Few instantaneous snapshots of the plume shape for the MALF and consent WWTP discharge rate are presented in Figure 3 2. The maps illustrate the effect of the tidal currents in transporting the plume north and south around Rangitoto Peninsula.

Timeseries of concentration (mg/L) of WWTP discharge for the MALF and Mean Flow simulations are presented in Figure 3-2 and Figure 3-3, respectively. The results are over a month period at the 6 selected locations near Hihi Beach. For the purposes of plotting, the Y-axis values have been plotted on a log10 scale.

To illustrate the spatial distribution of the tracer concentration, percentiles were calculated using the hourly output from the model over the full month simulation.

The 50^{th} percentile (P50) concentration, is the concentration of tracer expected to be exceeded 50 % of the time.

The 90^{th} percentile (P90), is more extreme and represents the concentration factors expected to be exceeded only 10 % of the time (or not exceeded 90 % of the time).

Geo-referenced maps showing the 50^{th} and 90^{th} percentiles spatial distribution of concentration for the MALF and consent WWTP discharge rate are presented in Figure 3-4. Concentration outside Hihi Beach embayment are lower than 10^{-7} (dilution of 10,000,000 or more) for the 50^{th} percentile, however for the 90^{th} percentile concentration of that order may extend towards and within Mangonui Harbour.

It should be noted that the tracer (e.g. contaminants) estimates may be conservative as no decay was considered for the passive tracer used in the simulations.

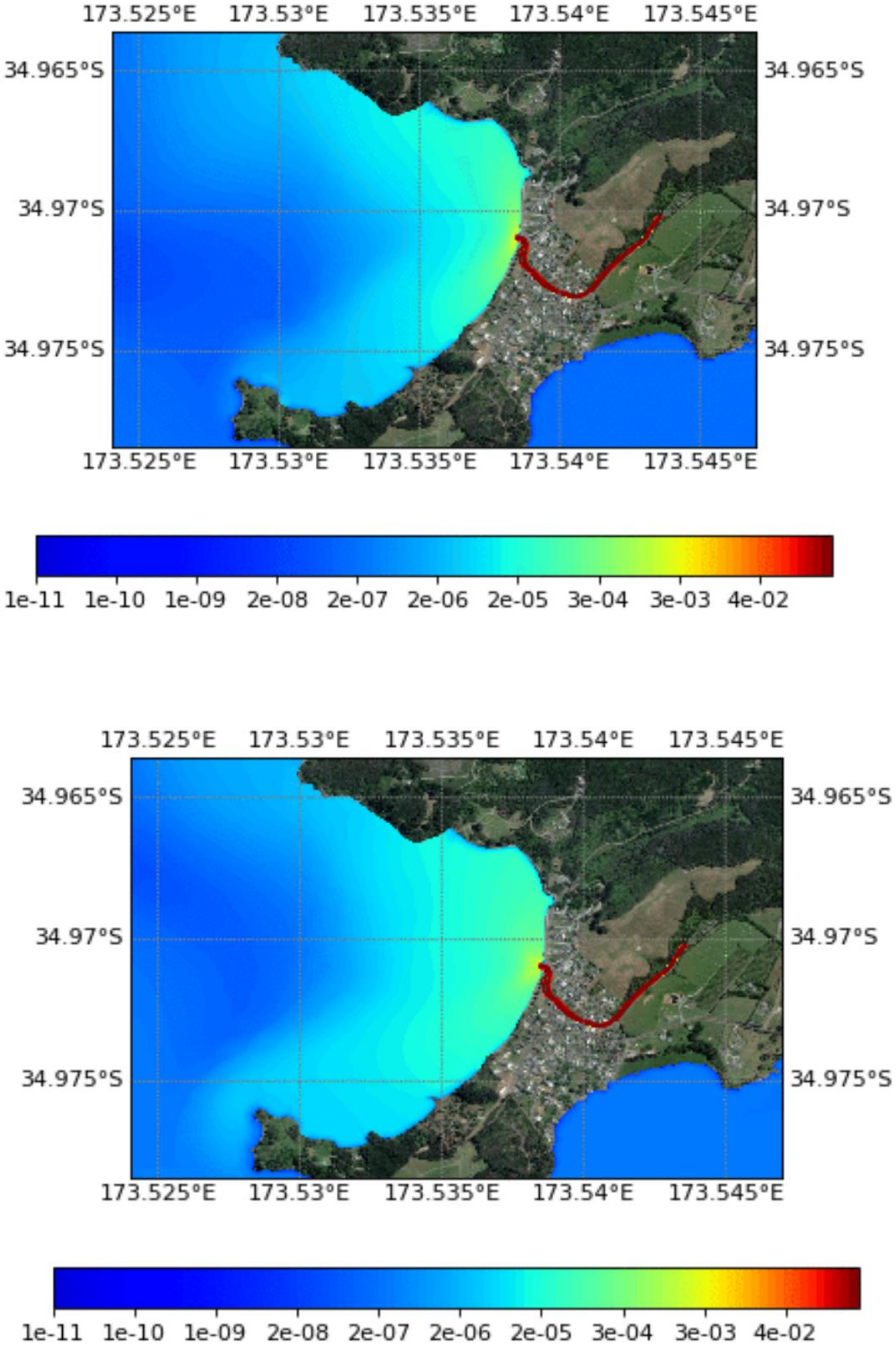

Figure 3-1: Snapshot of tracer concentration during Hihi WWTP Consent discharge and MALF stream flow. Showing two different time step and the influence of tide and current in transporting the plume north and south around Rangitoto Peninsula.

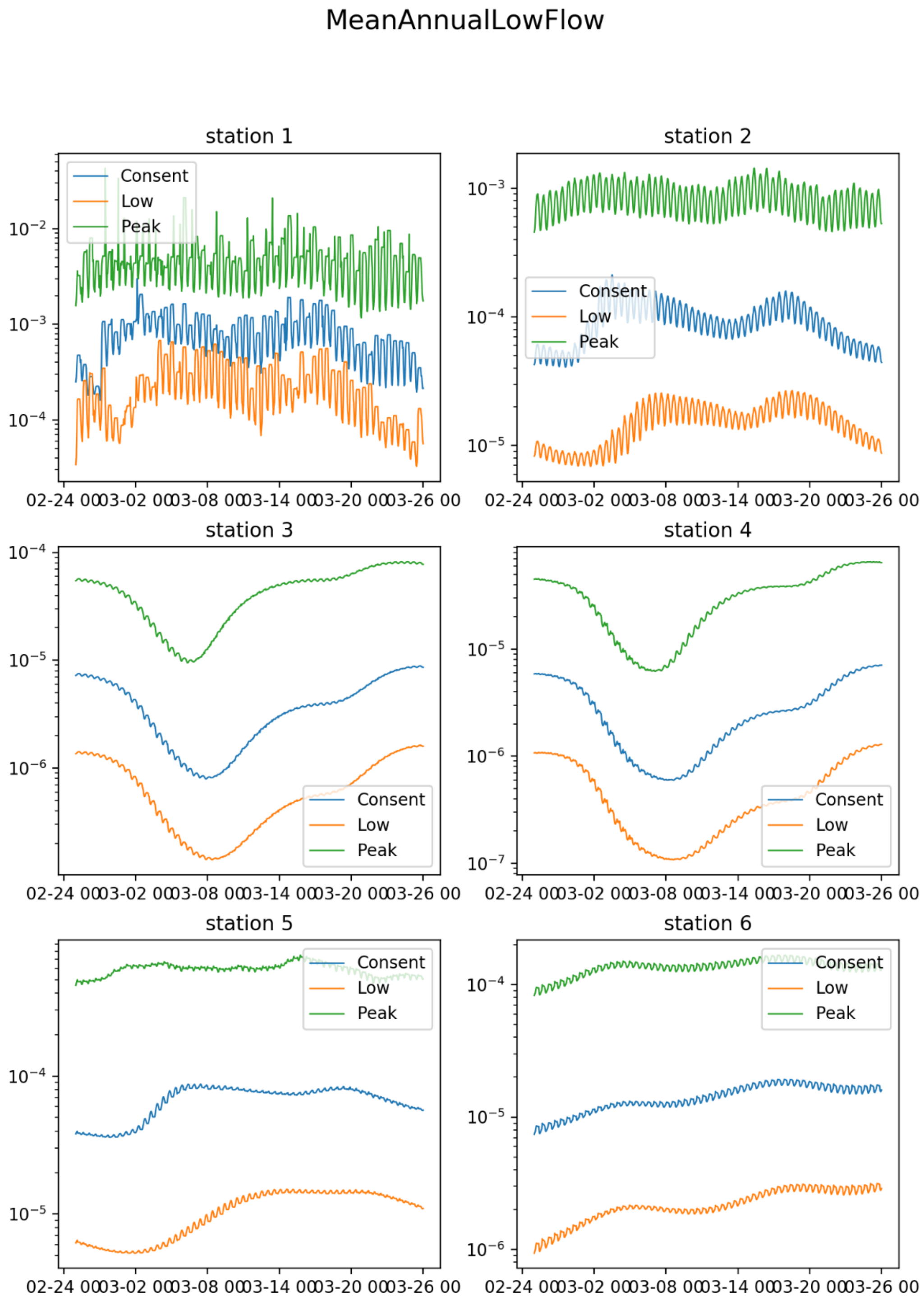

Figure 3-2: Timeseries of concentration (mg/L) of WWTP discharge over a month period considering Hihi Stream MALF and low (40 m^3/day 30-d ave), consented (250 m^3/day 30-d ave) and peak (1600 m^3/day 30-d ave) WWTP discharges. For the purposes of plotting, the Y-axis values have been plotted on a log10 scale.

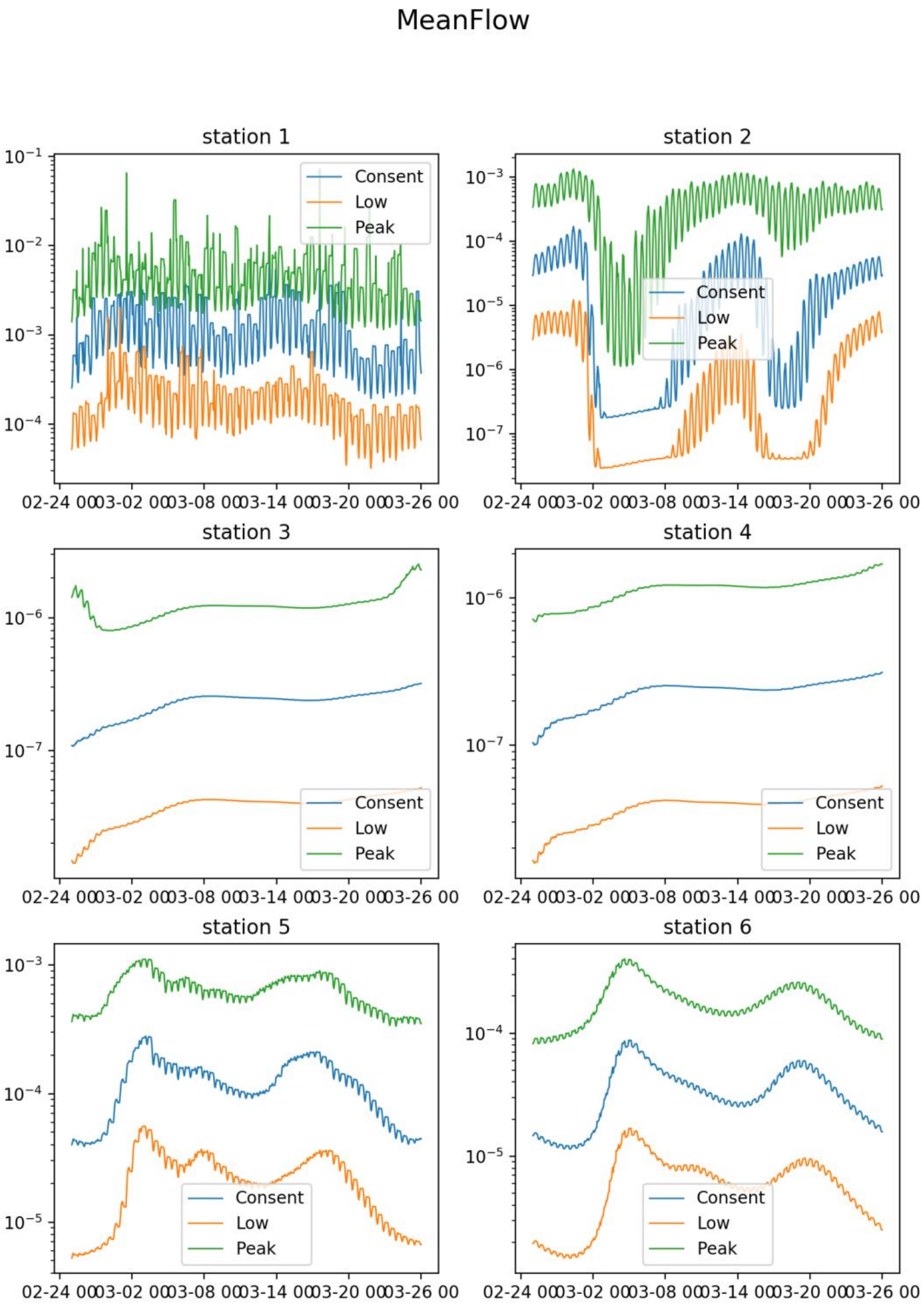

Figure 3-3: Timeseries of concentration (mg/L) of WWTP discharge over a month period considering Hihi Stream Mean Flow and low (40 m^3/day 30-d ave), consented (250 m^3/day 30-d ave) and peak (1600 m^3/day 30-d ave) WWTP discharges. For the purposes of plotting, the Y-axis values have been plotted on a log10 scale.

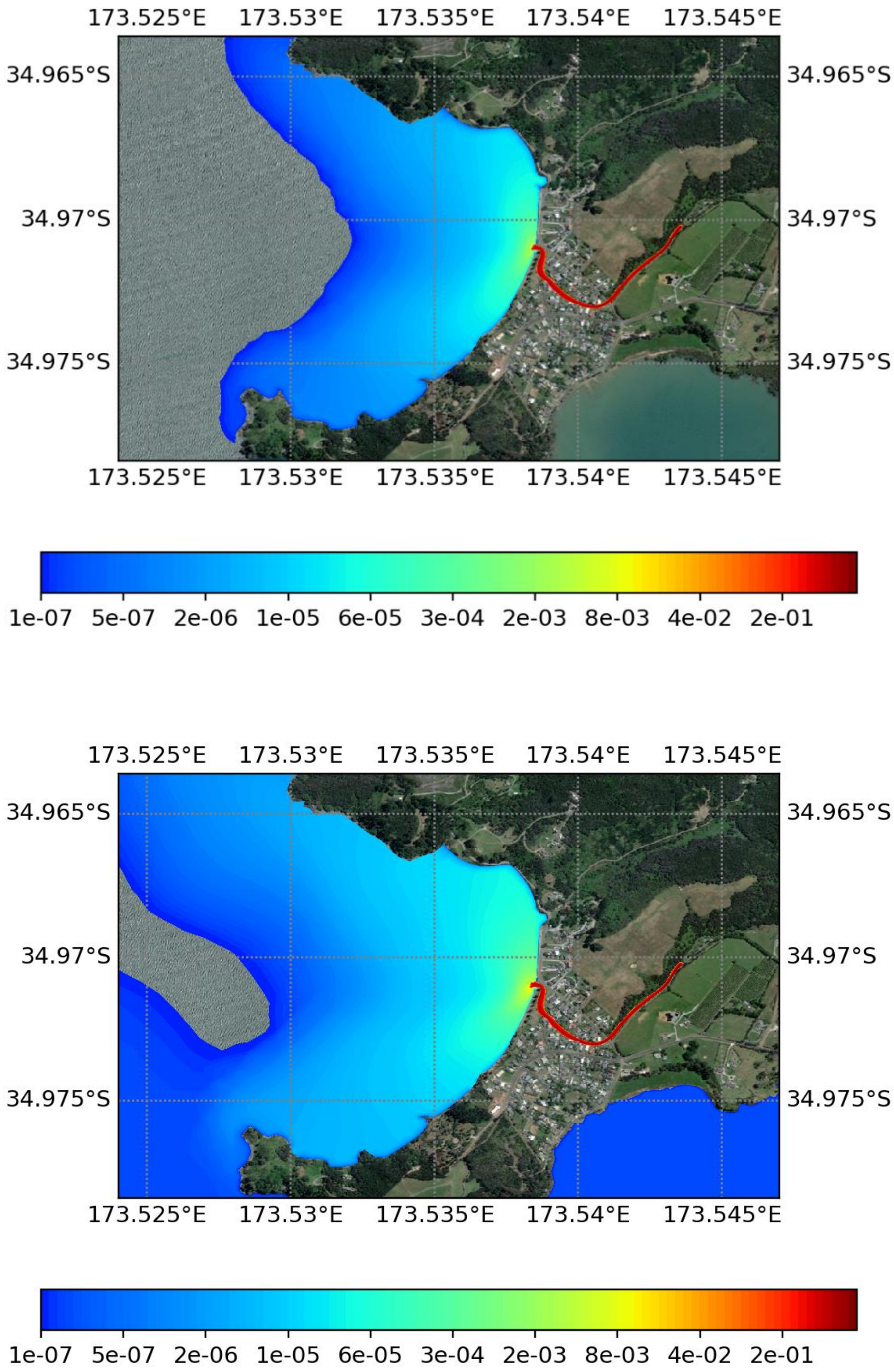

Figure 3-4: Map presenting the 50th (top) and 90th (bottom) percentile tracer concentration for the MALF and Consented WWTP discharge rate.

4.Summary

A hydrodynamic modelling study was undertaken to investigate dispersion of wastewater discharge from the Hihi WWTP into Hihi Stream and Hihi Beach area.

To quantify the hydrodynamics of Doubtless Bay, Mangonui Harbour and Hihi Stream, a 3D, high-resolution, finite element SCHISM model of the region was established, including main fluvial inputs.

Tracer dispersion simulations were undertaken for two river flow scenarios (Mean Flow and Mean Annual Low Flow - MALF), and three discharge rate levels (Low, Consented and Peak). The discharged tracers were released continuously over the model simulation and were given a concentration of 1 mg/L. The tracers do not decay over time and are neutrally buoyant within the river system.

The modelled results were processed in terms of the spatial distribution of tracer concentration within the model domain. Timeseries of concentration were extracted at selected locations within the Hihi Beach area. Results were also presented in terms of the 50th and 90th percentile concentration maps.

The below points provide a summary of the key outcomes:

- Hihi Stream is a low-flow rate stream and results from the dispersion of tracer concentration for mean flow and MALF are of similar order of magnitude once it reaches Hihi Beach (Station 1 and 2).
- Due to the greater rivers flow discharge under the mean flow conditions the concentrations further away from the Hihi Beach are reduced compared to the simulations under MALF conditions: e.g., north near Hihi Beach Holiday Park and south near Rangitoto Peninsula.
- Difference in tracer concentration between the low (40 m^3/day 30-d ave), consented (250 m^3/day 30-d ave) and peak (1600 m^3/day 30-d ave) are typically one order of magnitude greater from low to peak, e.g. near Station 2 the tracer concentration is approx. 10^{-5} (dilution of 100,000) for the low WWTP discharge, 10^{-4} (dilution of 10,000) for the consented WWTP discharge and 10^{-3} (dilution of 1,000) for the peak WWTP discharge.
- Under MALF conditions and the consented WWTP discharge of 250 m^3/day 30-d ave, the tracer concentrations are approximately:
  - 10^{-3} to 10^{-4} (dilution of 1,000 to 10,000) at the Hihi Stream outflow location onto Hihi Beach

- 10^{-4} to 10^{-5} (dilution of 10,000 to 100,000) north near Hihi Beach Holiday Park (stations 5 and 6)
- 10^{-5} to 10^{-6} (dilution of 100,000 to 1,000,000) south near Rangitoto Peninsula (stations 3 and4)

- Tracer concentration within and near the entrance of Mangonui Harbour are very low and in the order of 10^{-7} or less (dilution of 10,000,000 or more).

5.References

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