Kāeo 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 CON20100720501 (AUT.007205.01.03 water discharge) for the Kāeo Wastewater Treatment Plant (WWTP) water discharge operation. MetOcean Solutions (MOS) has been commissioned by FNDC to provide a hydrodynamic study of the Kāeo River and Whangaroa Harbour to support the Quantitative Microbiological Risk Assessment (QMRA), which will assess the public health risk resulting from discharge downstream of the Kāeo 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 Whangaroa Harbour and Kāeo River 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 (48 m^3/day).

Scenario 2 - Mean flow; Consent WWTP Discharge rate (360 m^3/day -30days average).

Scenario 3 - Mean flow; Peak WWTP Discharge rate (927 m^3/day).

Scenario 4 - Mean Annual Low Flow; Low WWTP Discharge rate (48 m^3/day).

Scenario 5 - Mean Annual Low Flow; Consent WWTP Discharge rate (360 m^3/day -30days average).

Scenario 6 - Mean Annual Low Flow; Peak WWTP Discharge rate (927 m^3/day).

Each scenario was simulated for the duration of full month (2 spring neap tidal cycle) 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 50^{th} and 90^{th} percentile dilution maps, and as a time series of tracer concentration at 7 locations within the Kāeo River and Whangaroa Harbour.

Key Findings

- The Kāeo River is a large river with a strong tidal influence between Whangaroa Harbour and the township of Kāeo. The mixing rate is then highly dependent on the river flow. High mixing rate (i.e. tidal mixing due to water intrusion from the harbour into the river) therefore occurs when the river flow is low (MALF).
- Due to the tidal influence, tracer concentration is higher upstream of the WWTP discharge with the MALF than the Mean Flow. However, concentration downstream of the discharge is higher with the Mean Flow than the MALF which can be interpreted as higher mixing rate with lower flow (MALF) rather than higher flow (Mean Flow). It is expected that there is a flow threshold between MALF and Mean Flow where the trend reverses.
- Difference in tracer concentration between the low (48 m^3/day), consented (360 m^3/day 30-d ave) are typically one order of magnitude greater from low to consented, e.g., near Station 3 the tracer concentration is approx. 10^{-3} -10^{-4} (dilution of 1,000 to 10,000) for the low WWTP discharge, 10^{-2} -10^{-3} (dilution of 100 to 1,000) for the consented WWTP discharge and 10^{-3} (dilution of 1,000). For the peak discharge of 927 m^3/day) concentration at Station 3 is about 10^{-1} -10^{-2} (dilution of 10 to 100) .
- Tracer concentration within Whangaroa Harbour is very low and in the order of 10^{-2} to 10^{-6} (dilution of 100 to 1,000,000) depending on the proximity to the Kāeo River mouth.
- Tracer concentration further offshore in Whangaroa Bay are very low and in the order of 10^{-8} or less (dilution of 100,000,000 or more).

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1.Introduction

Far North District Council (FNDC) is in the process of renewing its consent (AUT.007205.01.03) for the Kāeo Wastewater Treatment Plant (WWTP) water discharge operation. A Quantitative Microbiological Risk Assessment (QMRA) is required to assess the public health risk resulting from the discharge to Kāeo River and Whangaroa Harbour.

To support the QMRA, a hydrodynamic study covering the Kāeo River and Whangaroa Harbour is required to predict the dilution and dispersion of wastewater discharge from the Kāeo 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 Kāeo.

2. Methodology

2.1 Bathymetry data

For this project the MetOcean Solutions bathymetry database was supplemented by LiDAR data supplied by the Northland Regional Council (NRC) in intertidal coastal regions and high resolution multibeam data collected and supplied by LINZ, ENCs were used in areas without high resolution coverage, data sources and coverage and the final bathymetry are shown in (Figure 2-1).

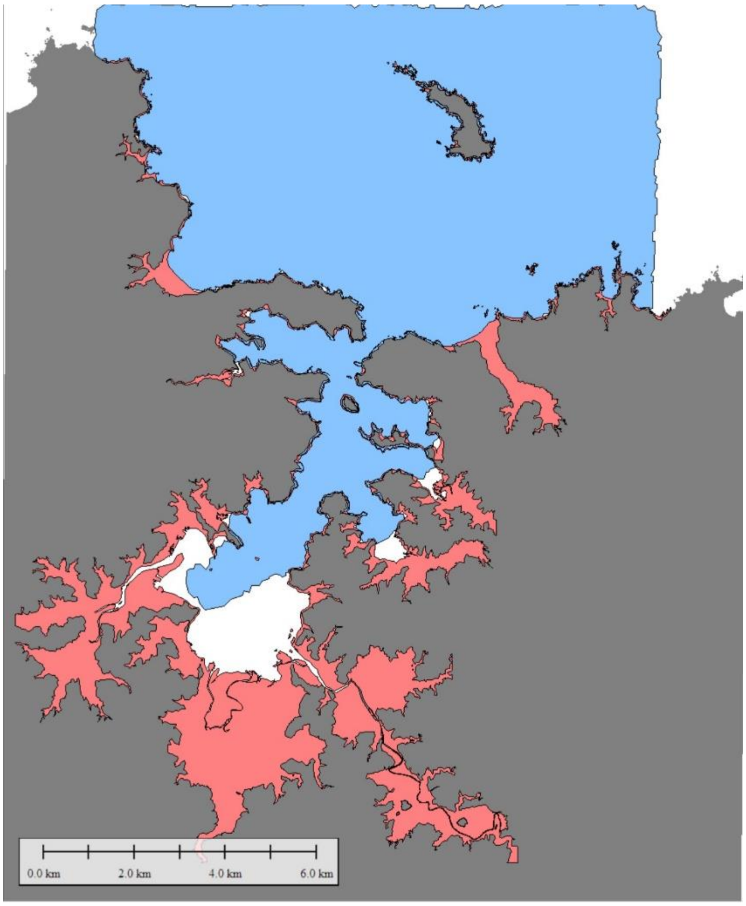

Figure 2-1: Bathymetry data sources : ENC (white), Multibeam survey (Blue), LIDAR (pink)

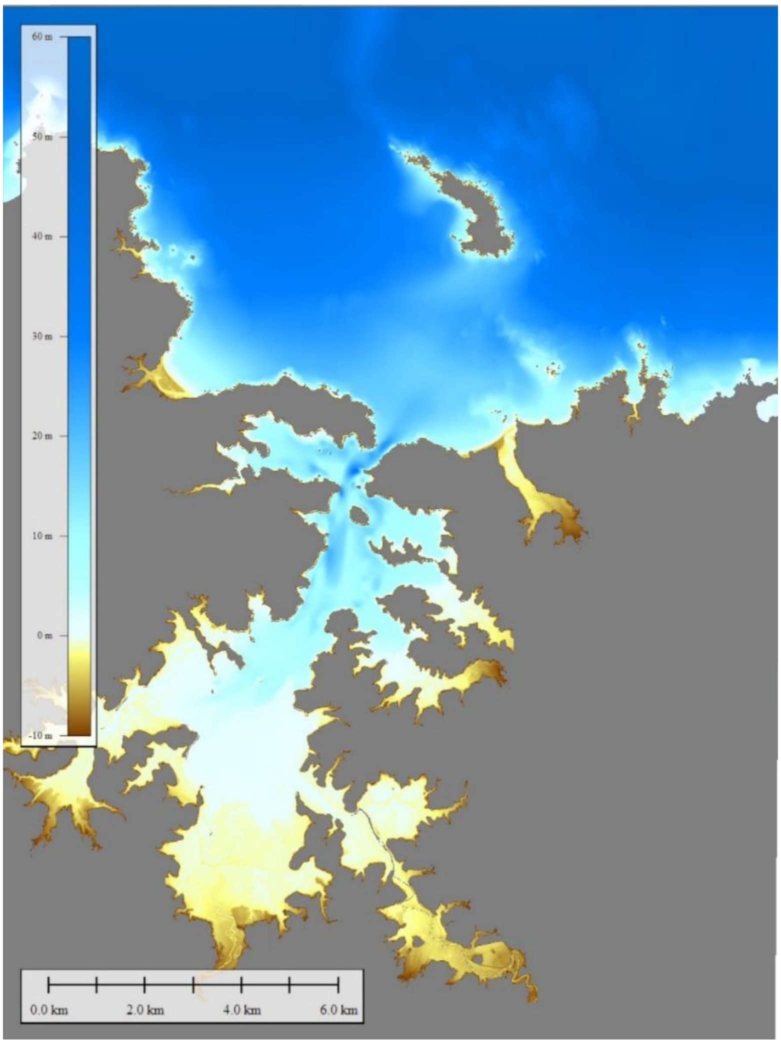

Figure 2-2: Combined bathymetry for Whangaroa Harbour and Kāeo area.

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 model domain covers Kāeo River and Whangaroa Harbour and extends out into Whangaroa 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 streams (Figure 2-3). Offshore tidal elevation and velocity data was prescribed from MetOcean Solutions NZ ROMS hindcast model.

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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

Kāeo River was designed in the grid according to orthorectified aerial images from LINZ and LIDAR data from Northland Regional Council (NRC). River width was made in order to have 4 cells in width with a minimum of 5 m resolution.

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.

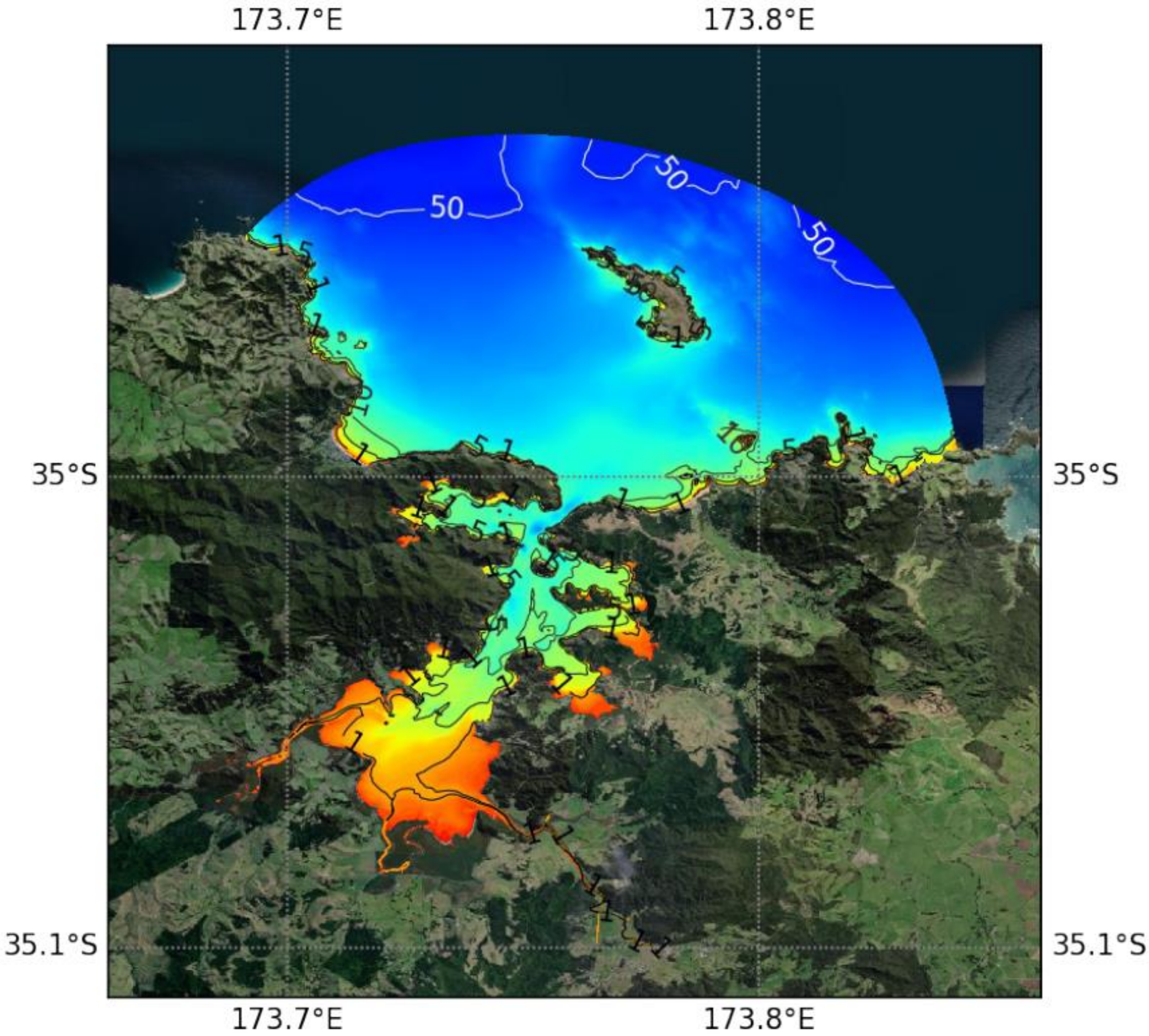


Figure 2-3: General view of the computational domain and bathymetry. Colour scale shows the bathymetry, also indicated by the contour lines.

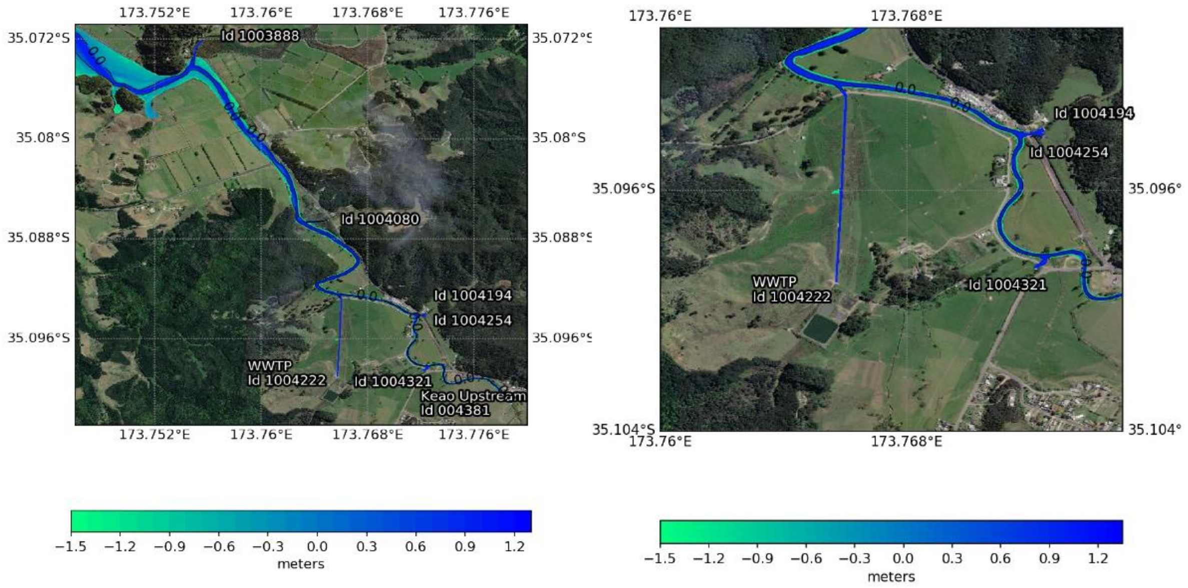


Figure 2-4: Grid bathymetry details near Kāeo River and tributaries.

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 Kāeo River and Whangaroa Harbour 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 5 ppt and 15 °C, respectively.

Details of the river flow rate for each tributaries are presented in Table 2-1.

Table 2-1: Discharge rate in $m^3.s^{-1}$ for the Kāeo River and tributaries (from NIWA's NZ River Maps, Booker and Whitehead 2017).

NIWA segment id	MALF ($m^3.s^{-1}$)	Mean Flow ($m^3.s^{-1}$)
1004222	0.002746	0.01770
1004321	0.029134	0.20555
1004381	0.328100	2.28000
1004254	0.000499	0.00426
1004194	0.010311	0.05989
1004080	0.010871	0.06315
1003888	0.027540	0.17069

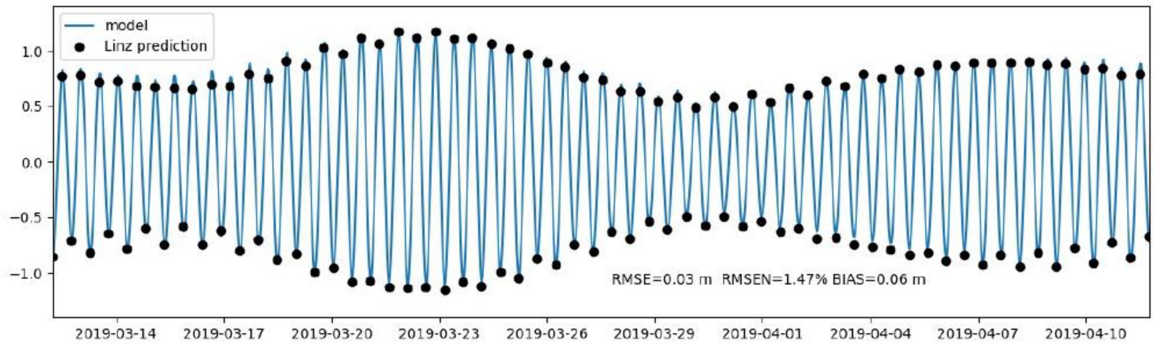
For Kāeo River (ID1004381), the following discharge flow were used:

- Mean Flow = 2.280 m^3/s
- Mean Annual Low Flow (MALF)= 0.328 m^3/s

2.4.3 River forcing

The SCHISM model was validated for water level against predicted tides as shown on Figure 2-5.

Figure 2-5: Comparison of modelled water level with predicted LINZ tide levels.



2.5 Wastewater outflow trajectory modelling

2.5.1 WWTP Discharge rate

The existing resource consent CON20100720501 (AUT.007205.01.03 water discharge), indicate that the 30-day rolling average of dry weather discharge shall not exceed 360 m^3/day.

Analysis of the Kāeo WWTP discharge rate data has been undertaken by Jacobs (2022) and is provided in Table 2-1.

Table 2-2: Kāeo WWTP – Effluent Discharge Rate (Jacobs 2022 – Far North District Council)

Kāeo WWTP - Effluent	Discharge Rate (m3/day)
Average	141
Median	62
Peak (90th Percentile)	439
Maximum	927
Average Dry Weather Discharge	54
Average 30-day Average Dry Weather Discharge	61
Consented 30-day Average Dry Weather Discharge	360

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: 48 m^3/day (0.00055 $m^3.s^{-1}$). This value was a preliminary estimate of averaged low discharge provided by Jacobs/FDNC, which is representative of a low discharge level similar to the Average Dry Weather Discharge.
- Consent WWTP discharge: 30-day Average rate of 360 m^3/day 30-day average (0.004166 $m^3.s^{-1}$)
- Maximum WWTP discharge: Maximum of 927 m^3/day (0.01073 $m^3.s^{-1}$)

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 Kāeo River. The discharge and concentration of the tracer was treated as constant over the length of the model simulation.

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 Whangaroa Harbour and Kāeo River.

Timeseries of tracer concentration were extracted at 7 locations along Kāeo River and Whangaroa Harbour (Figure 2-6 and Table 2-3) and provided at data files to be used for the QMRA .

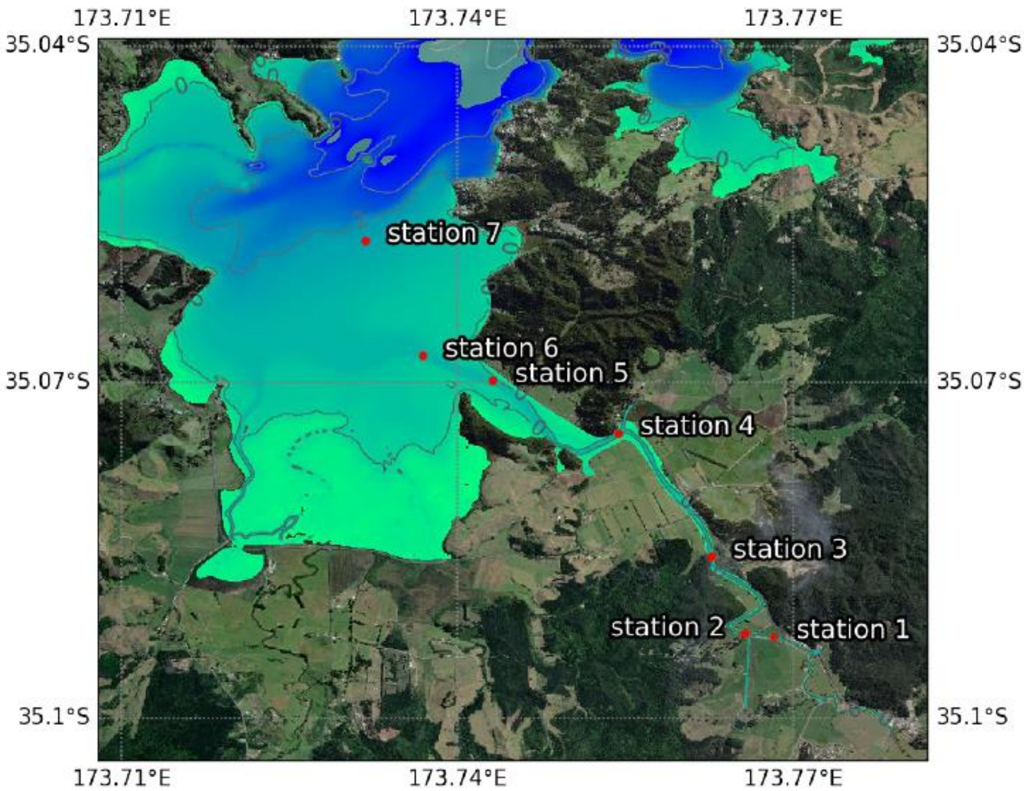


Figure 2-6: Locations of stations for model output timeseries extraction.

Table 2-3: Coordinates of output locations.

	Lon (deg TN)	Lat (deg TN)	x (m) NZD epsg2193	y (m) NZD epsg2193
Station 1	173.7682674	-35.09277186	1670027.17	6116398.89
Station 2	173.7656787	-35.09248057	1669791.46	6116433.01
Station 3	173.7626549	-35.08567193	1669521.61	6117190.21
Station 4	173.7543757	-35.07457584	1668776.2	6118426.52
Station 5	173.7431091	-35.06994282	1667752.83	6118948.04
Station 6	173.7365711	-35.06744006	1667158.77	6119230.02
Station 7	173.7308864	-35.05736755	1666648.63	6120350.88

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 Kāeo River and Whangaroa Harbour (Figure 2-6) .

Overall results show that the tide is the dominant process for the mixing and transport of the tracer. Results show that the tracer concentration is generally lower for the MALF than Mean Flow within the river and harbour which can be a bit counter intuitive. However, whilst this is the case at station 2 to 7 downstream of the discharge , concentration at Station 1, upstream of the discharge, is typically higher for the MALF than the Mean Flow indicating that the MALF is not strong enough against the tide and the tracer is pushed or held up upstream until it mixed with the tidal prism.

A simulation test was undertaken without tidal forcing and showed that without tides the concentration downstream of the discharge is higher with the MALF than with the Mean Flow (Figure 3-1) .

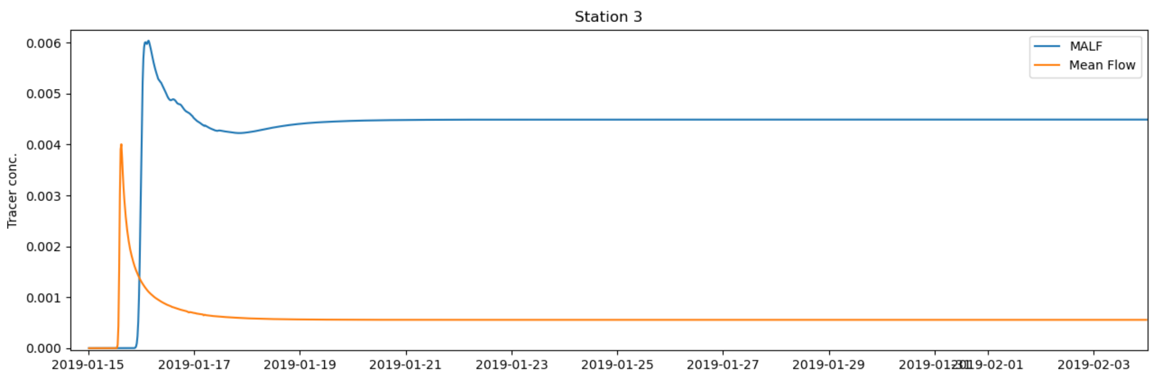


Figure 3-1: Model test – Tracer concentration at Station 3 (downstream of WWTP discharge) with River Discharge only – No tidal Forcing

Timeseries of concentration (mg/L) of WWTP discharge for the MALF and Mean Flow simulations are presented in Figure 3-3 to Figure 3-6. The results are presented over a 2-week period at the 7 selected locations within the Kāeo River and Whangaroa Harbour. 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 2 spring-neap cycle (see Figure 3-2).

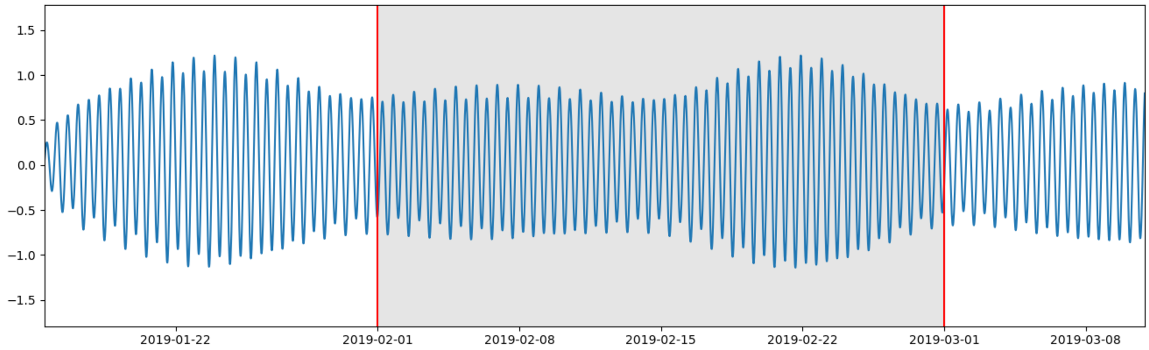


Figure 3-2: Period used for the 50^{th} and 90^{th} percentile calculation.

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 consent WWTP discharge rate are presented in Figure 3-7 and Figure 3-8 for the MALF and Mean Flow, respectively.

Overall results shows that concentration within the Kāeo River is lower than 10^{-2} (dilution of 100 or more) and 10^{-3} (dilution of 1000 or more) within Whangaroa Harbour for the 50^{th} percentile. For the 90^{th} percentile concentration within the Kāeo River is lower than 10^{-1} (dilution of 10 or more) and 10^{-2} (dilution of 100 or more) within Whangaroa 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.

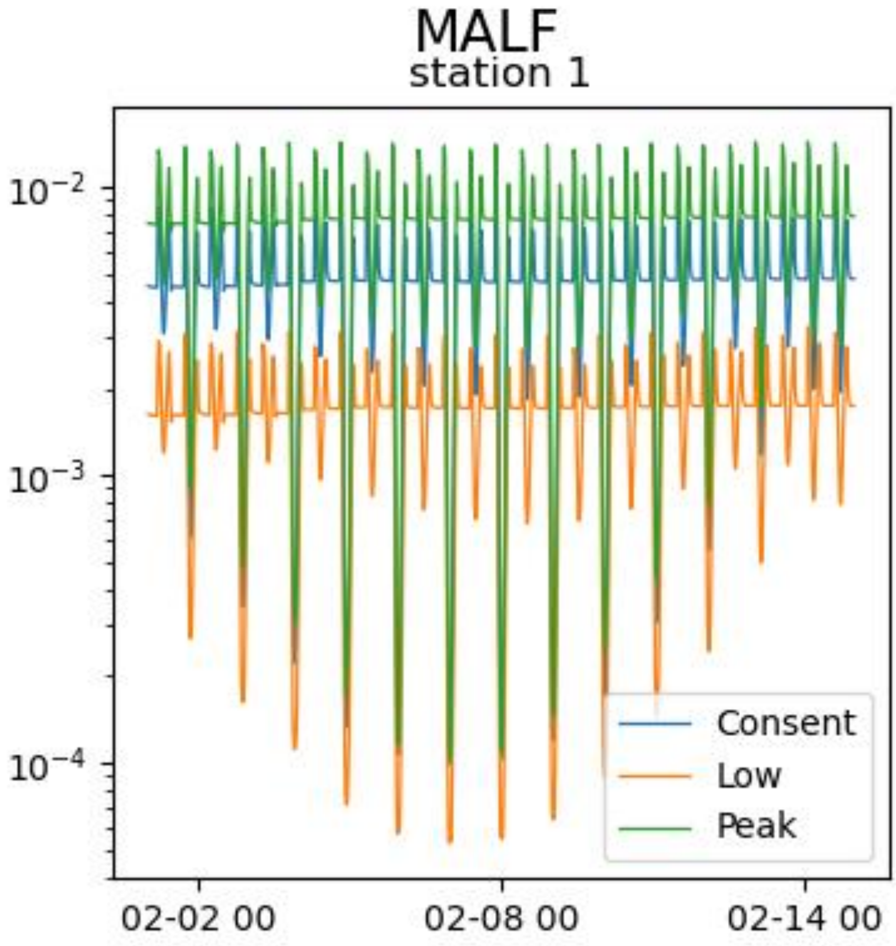


Figure 3-3: Timeseries of concentration (mg/L) at Station 1 of WWTP discharge over a month period considering Kāeo River MALF and low (48 m^3/day 30-d ave), consented (360 m^3/day 30-d ave) and peak (927 m^3/day) WWTP discharges. For the purposes of plotting, the Y-axis values have been plotted on a log10 scale.

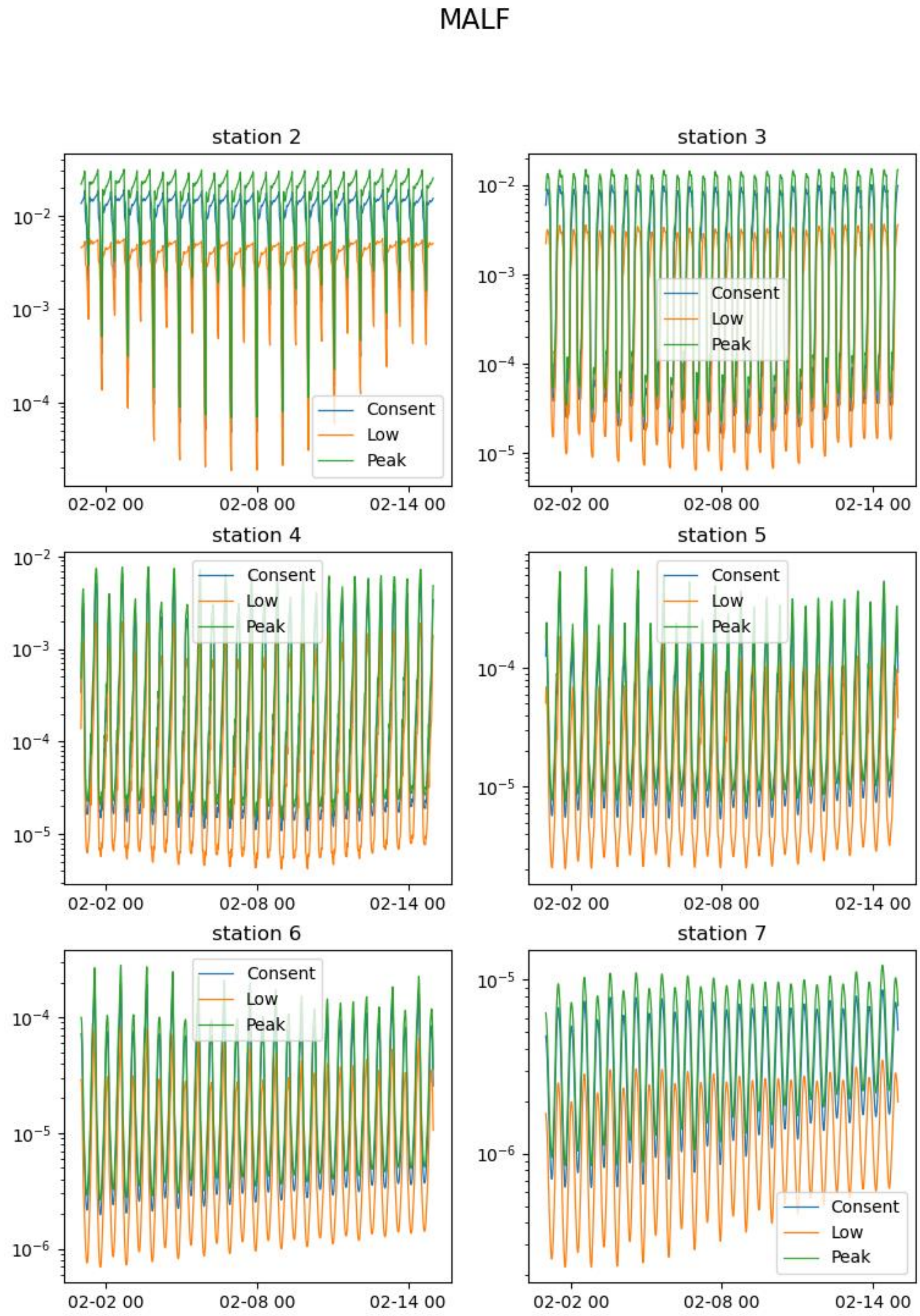


Figure 3-4: Timeseries of concentration (mg/L) of WWTP discharge over a month period considering Kāeo River MALF and low (48 m^3/day 30-d ave), consented (360 m^3/day 30-d ave) and peak (927 m^3/day) WWTP discharges. For the purposes of plotting, the Y-axis values have been plotted on a log10 scale.

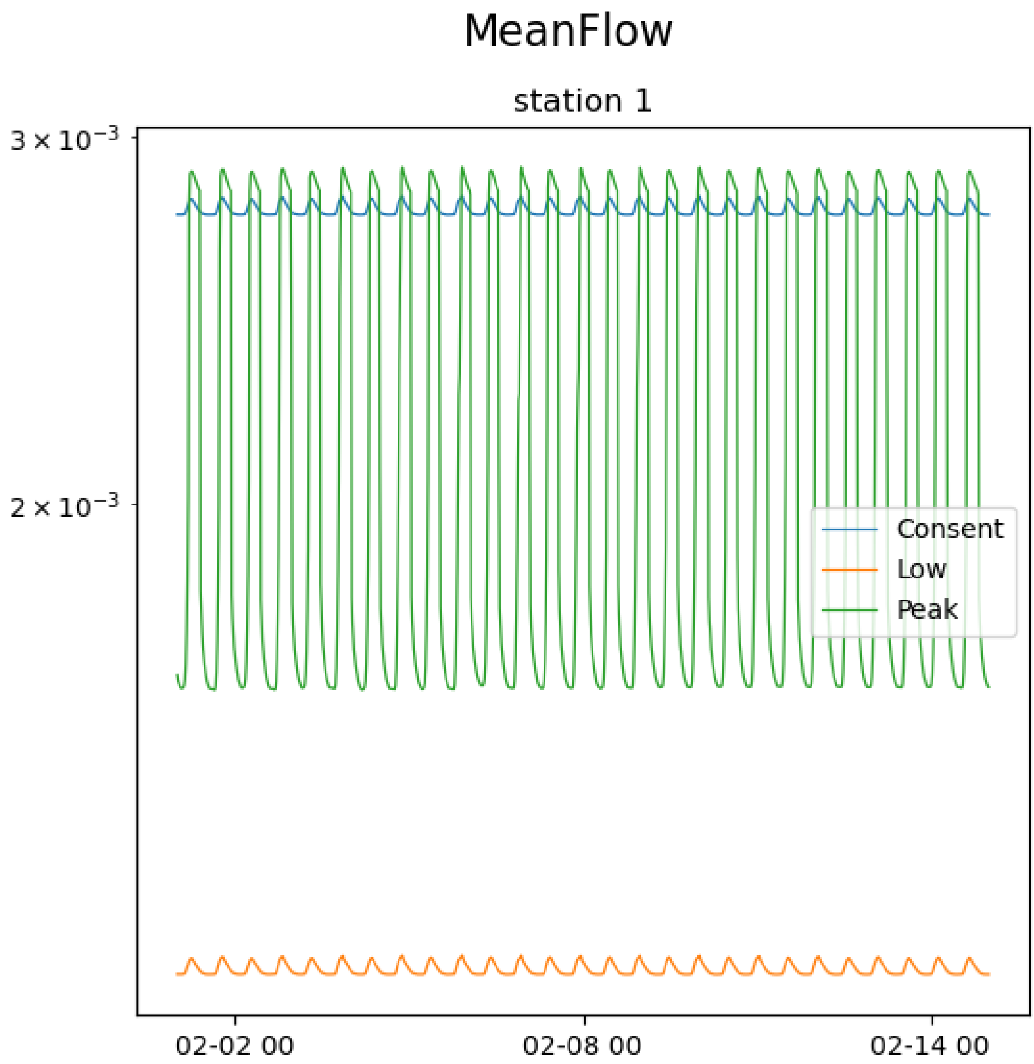


Figure 3-5: Timeseries of concentration (mg/L) at Station 1 of WWTP discharge over a month period considering Kāeo River Mean Flow and low (48 m^3/day 30-d ave), consented (360 m^3/day 30-d ave) and peak (927 m^3/day) WWTP discharges. For the purposes of plotting, the Y-axis values have been plotted on a log10 scale..

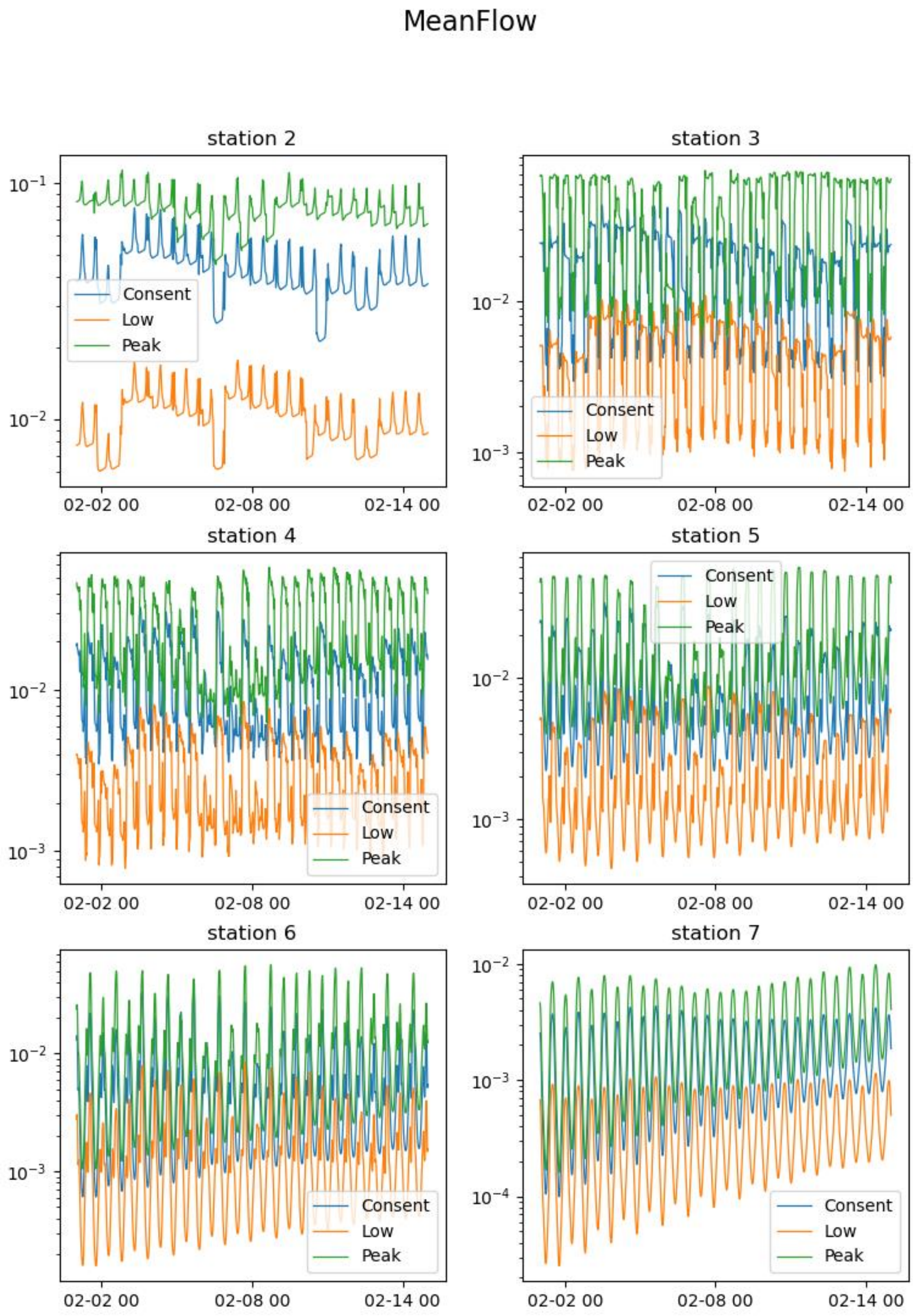


Figure 3-6: Timeseries of concentration (mg/L) at Station 1 of WWTP discharge over a month period considering Kāeo River Mean Flow and low (48 m^3/day 30-d ave), consented (360 m^3/day 30-d ave) and peak (927 m^3/day) WWTP discharges. For the purposes of plotting, the Y-axis values have been plotted on a log10 scale.

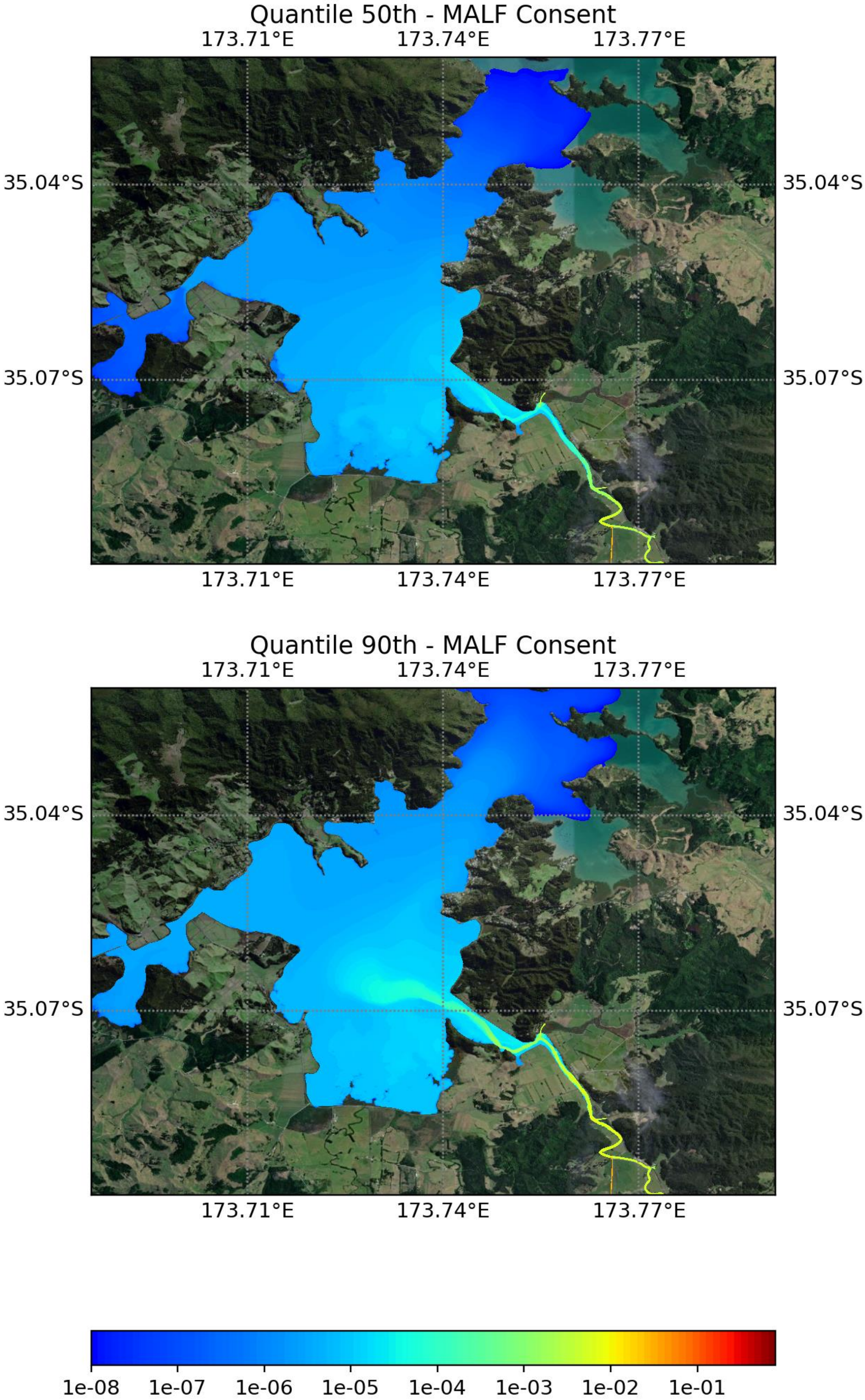


Figure 3-7: Map presenting the 50th (top) and 90th (bottom) percentile tracer concentration for the MALF and Consented WWTP discharge rate.

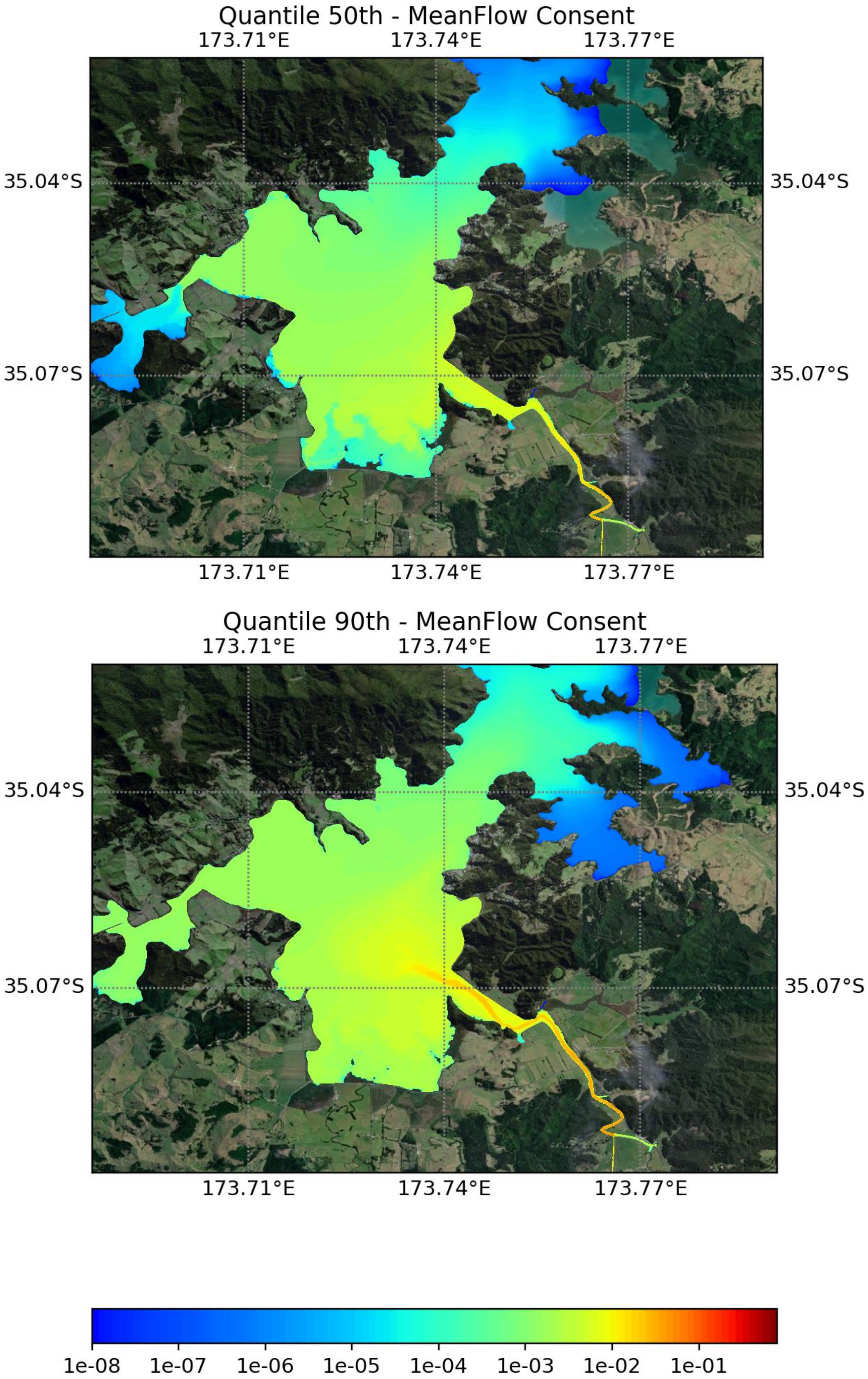


Figure 3-8: Map presenting the 50th (top) and 90th (bottom) percentile tracer concentration for the Mean Flow and Consented WWTP discharge rate.

4.Summary

A hydrodynamic modelling study was undertaken to investigate dispersion of wastewater discharge from the Kāeo WWTP into Kāeo River and Whangaroa Harbour.

To quantify the hydrodynamics of Whangaroa Harbour and the Kāeo River, 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 Kāeo River and Whangaroa Harbour. Results were also presented in terms of the 50th and 90th percentile concentration maps.

The below points provide a summary of the key outcomes:

- The Kāeo River is a large river with a strong tidal influence between Whangaroa Harbour and the township of Kāeo. The mixing rate is then highly dependent on the river flow. High mixing rate (i.e. tidal mixing due to water intrusion from the harbour into the river) therefore occurs when the river flow is low (MALF).
- Due to the tidal influence, tracer concentration is higher upstream of the WWTP discharge with the MALF than the Mean Flow. However, concentration downstream of the discharge is higher with the Mean Flow than the MALF which can be interpreted as higher mixing rate with lower flow (MALF) rather than higher flow (Mean Flow). It is expected that there is a flow threshold between MALF and Mean Flow where the trend reverses.
- Difference in tracer concentration between the low (48 m^3/day 30-d ave), consented (360 m^3/day 30-d ave) are typically one order of magnitude greater from low to consented, e.g., near Station 3 the tracer concentration is approx. 10^{-3} -10^{-4} (dilution of 1,000 to 10,000) for the low WWTP discharge, 10^{-2} -10^{-3} (dilution of 100 to 1,000) for the consented WWTP discharge and 10^{-3} (dilution of 1,000). For the peak discharge of 927 m^3/day) concentration at Station 3 is about 10^{-1} -10^{-2} (dilution of 10 to 100) .

- Tracer concentration within Whangaroa Harbour is very low and in the order of 10^{-2} to 10^{-6} (dilution of 100 to 1,000,000) depending on the proximity to the Kāeo River mouth.
- Tracer concentration further offshore in Whangaroa Bay are very low and in the order of 10^{-8} or less (dilution of 100,000,000 or more).

5. References

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