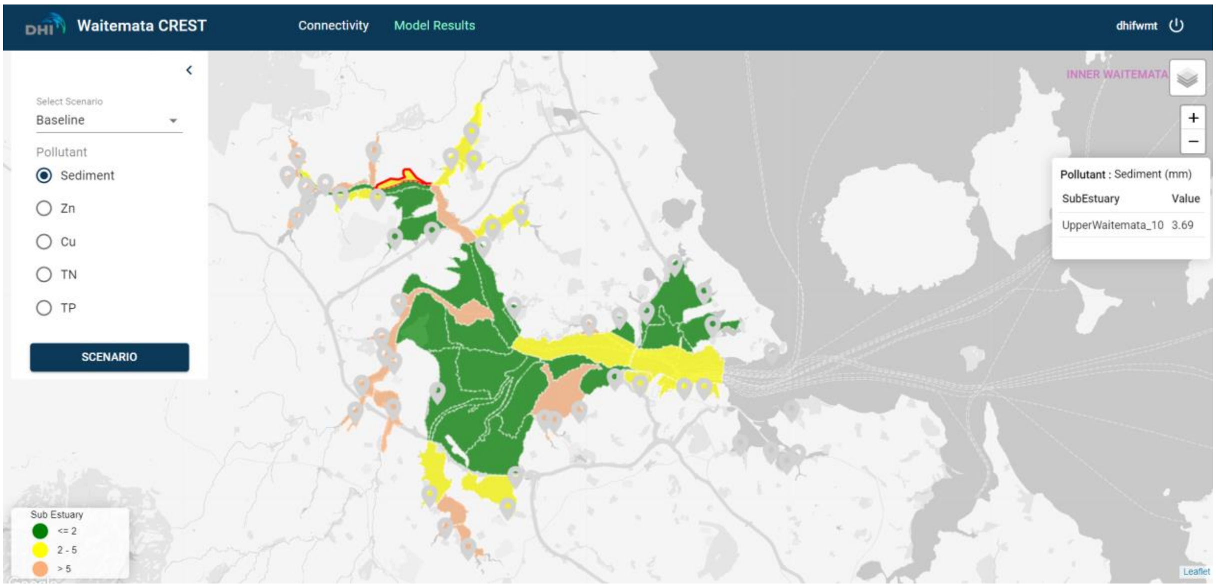
Freshwater Management Tool – Coastal Receiving Environment Scenario Tool

Inner and Outer Waitematā Harbour - Pilot



Report

June 2022

The expert in **WATER ENVIRONMENTS**

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Freshwater Management Tool – Coastal Receiving Environment Scenario Tool

Inner and Outer Waitematā Harbour - Pilot

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Project number	44801679
Approval date	28/06/2021
Revision	Draft .20
Classification	Open

CONTENTS

1 Executive Summary

DHI on behalf of Healthy Waters, Auckland Council has undertaken a geochemical contaminant assessment of the inner and outer Waitematā Harbour, by coupling Auckland Council's Freshwater Management Tool (FWMT) to DHI's numerical hydrodynamic model of Waitematā Harbour to predict transport and fate of Total Nitrogen (TN), Total Phosphorus (TP), Total Suspended Solids (TSS), Total Copper (TCu) and Total Zinc (TZn).

A connectivity matrix was developed between FWMT inflows and defined sub-estuaries within the model domain. With this approach the contribution of freshwater-derived contaminants to the estuarine receiving environment could be estimated at 86 sub-estuaries within the inner and outer Waitematā Harbour.

The FWMT coastal receiving environment model is process-based, with wave and tide hydrodynamic processes coupled to deposition and resuspension processes for sediment. Conservative or decaying tracers for total nutrients in suspension and metals in deposition were also used, combined with the hydrodynamic processes affecting flow and concentration.

The coastal model received daily time-step inputs from the 334 FWMT outputs (including 69 terminal freshwater nodes), that were aggregated to 72 coastal inputs. The coastal model disaggregated daily inputs to 30 second timestep prior to operating on a 30 second timestep over an annual period. The annual period of inputs was 2015 (chosen as a representative contaminant year) whilst the annual period of wave/tidal configuration was 2018. Results are therefore indicative of coastal water quality for a mix of recent boundary conditions.

The integrated FWMT- coastal receiving environment model simulates the fate of freshwater-derived contaminant inputs from all land draining to the Waitematā Harbour. Outputs are intended as proof-of-concept for the value of integrated freshwater-coastal accounting frameworks and highlighted:

An online Coastal Receiving Environment Scenario Tool (CREST) system was developed to allow Auckland Council to view the baseline model results and to evaluate the impact of load reductions on the receiving environment.

2 Introduction

The Auckland region is dominated by the marine environment consisting of two oceans, three major harbours and estuaries totalling about 75% of regional extent. The quality and health of this environment is largely impacted by discharges from land including rivers, stormwater and overland flows and point source discharges. Although it is also expected that natural cycles such seasonal, decadal as well as climate change could influence the quality of the marine environment.

New Zealand is facing ongoing pressure from historic and continuing decline of water quality (PCE, 2013; Larned et al., 2016). New Zealanders are engaged and concerned by water quality issues. This has led to the development of national policies for freshwater management and a coastal policy (MfE, 2020). Whereas the national policy for freshwater has a national objective framework outlining the attributes of freshwater and the various states that could be attained as a consequence of management, the coastal national policy statement lacks the same. There is, however, a universal acknowledgment that freshwater must be managed for ki uta ki tai (integrated management) to give effect to Te Mana o te Wai (National Policy Statement for Freshwater Management [NPS-FM], Clause 3.2). In addition, limits on resource use require regional councils must have regard to the foreseeable impacts of climate change and results or information from freshwater accounting systems (Clause 3.14). Auckland Council has developed the Freshwater Management Tool (FWMT), a process-based and continuous model to account for water quality contaminants, regionwide from mountains to sea.

An integrated understanding of water quality and the distribution of contaminants from freshwater to coast is added by process-based modelling. Process-based models allow transport of contaminants to be traced back to land or stream sources and forecast the effects of marked changes to boundary conditions (e.g., climate change, farming intensification, development, management interventions). Continuous, process-based models also offer detailed information on acute and chronic effects instream through to event-scale and long-term coastal loading.

To help implement the NPS-FM, Healthy Waters requested DHI to couple the FWMT to DHI’s numerical coastal model for the Waitematā Harbour to evaluate the transport and fate of Total Nitrogen (TN), Total Phosphorus (TP), Total Suspended Solids (TSS), Total Copper (TCu) and Total Zinc (TZn) in the harbour. A coupled freshwater-coastal process-based accounting framework can help identify “load targets” for coastal health; event or long-term contaminant mass associated with coastal water quality targets.

The approach adopted here is a pilot which if successful can be expanded to other harbours of Auckland, to identify and manage contaminant loading to the harbours in an integrated manner.

2.1 Approach

DHI has an existing calibrated hydrodynamic model for the Hauraki Gulf (including a wave model) which have been used for the Safeswim programme for the Auckland Council. This model has been expanded to include TN, TP, TZn, TCu and TSS for this current project.

The Waitematā Harbour model domain was divided into two sub-domains (Inner Waitematā and Outer Waitematā) to reduce the model run-time and complexity. These two domains cover two distinct types of receiving environment typical for the Auckland Region, with varying sensitivity to contaminant discharge: a semi enclosed bay with no or limited wave exposure; and more exposed coastline, with minor to moderate wave climate. It also covers the watershed area labelled Waitematā CRE in Figure 2-1.

The coupled model was run for a simulation year (wave and tidal data for 2015, representing an average climatic year for Auckland; using FWMT daily inputs for 2015). Corresponding outputs from the FWMT for this selected year have been processed and included as inputs to the DHI numerical models. Due to the significant number of FWMT outputs, there was aggregation of some of the FWMT node data for different catchments.

The original Safeswim hydrodynamic model and wave models were also refined to fit the purposes of this study. A wave model was required, as waves can play a significant role in the fate of sediment within the receiving environment. The hydrodynamic and wave models were then coupled to the biogeochemical either sediment or advection/dispersion models to understand the fate of the contaminants.

For both sediments and nutrients, a connectivity matrix was developed between FWMT inflows and defined sub-estuaries within the model domain. With this approach the impact on the receiving environment of reducing catchment loads can be estimated, without having to undertake additional simulations.

DHI have developed an online Coastal Receiving Environment Scenario Tool (CREST) system. This allows Auckland Council to view the baseline model results and also to undertake their own investigations into the impact of load reductions on the receiving environment.

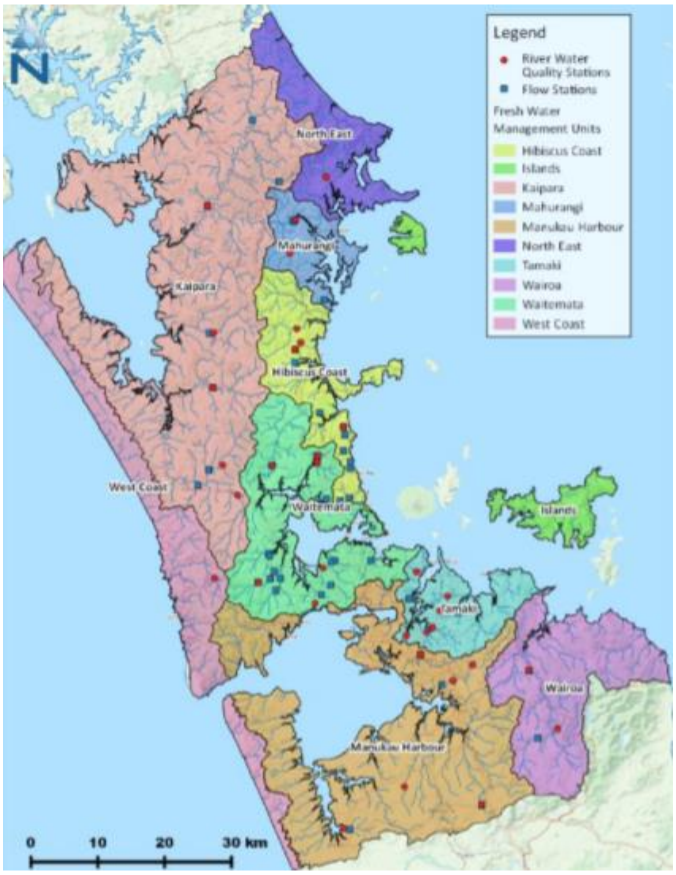


Figure 2-1 Watersheds in Auckland with Integrated Watershed plans.

2.2 Contaminant Thresholds Applied for Study

For each contaminant simulated the following thresholds shown in Table 2-1 to

Table 2-3 (along with reference where applicable) were applied to annualised output for 2015. Thresholds were selected with support of Healthy Waters, Auckland Council. The selected contaminant thresholds were used in the absence of statutory national/regional guidance suited to assessing the effects of sediment, metal and nutrient effects on water quality value(s). Note as per the study purpose being for proof of concept, study findings are not explicitly linked to "ecosystem health" as per the definition in the NPS-FM; a lack of national statutory guidance linking NPS-FM values and objective frameworks to coastal health hinders the development of coupled (integrated) catchment and coastal models.

With regards to sedimentation rates, research to derive appropriate thresholds is still emerging. A threshold typically presented to distinguish marked degradation in aquatic health is 2 mm above the Natural Sedimentation Rate (NSR, akin to "default guidance value") (Green, 2013; Townsend and Lohrer, 2015). However, determining sub-estuary NSR requires sediment sampling, lab analysis and can be site specific. In the interim the following sedimentation rates below have been proposed as a threshold for good, moderate and poor coastal water quality. Notably, the thresholds are intended to be indicative and demonstrate that with objective guidance, improved knowledge, reporting and management of coastal water quality can be achieved with coupled process-models. It is also noted that any NSR attribute does not indicate the full range of sedimentary effects on ecosystem processes and organisms (e.g., other attributes are better able to describe changes in light regime or effects on fish and shellfish behaviour). A final point is that the sediment NSR does not distinguish grain size, whereas typically it is the deposition of cohesive sediment (silts and clay) that have the most significant impact on ecology.

Sediment quality Environmental Response Criteria (ERC) for heavy metal is used to assess whether the measured contaminant concentrations are likely to be causing adverse environmental effects, with threshold impact defined as follows:

- Concentrations in the green zone present a low risk to the biology so the site is unlikely to be impacted;
- Concentrations in the amber zone indicate contaminant levels are elevated and the biology of the site is possibly impacted; and

  Concentrations in the red zone indicate that contaminant levels are high and the biology of the site is probably impacted.

Table 2-1 Sedimentation Thresholds (modified from Townsend and Lohrer, 2015).

Contaminant	**Threshold**		
	Good	**Moderate**	**Poor**
Sedimentation Rate	<2 mm/yr	2 – 5 mm/yr	>5 mm/yr

Table 2-2 TN (Walker and Vaughan, 2013) and TP (Hunt, 2016) Thresholds.

Contaminant	Threshold		
	Excellent	Satisfactory	Unsatisfactory
TN	<= 0.085 mg/l	>0.085 and <=0.238 mg/l	>0.238 mg/l
TP	<= 0.01 mg/l	>0.01 and <=0.03 mg/l	>0.03 mg/l

Table 2-3 Environmental Response Criteria (ERC) for Zinc and Copper in sediments (mg/kg) from Auckland Regional Council (2004).

Contaminant	Threshold		
	Green	Amber	Red
Zn	< 124 mg/kg	124-150 mg/kg	> 150 mg/kg
Cu	< 19 mg/kg	19-34 mg/kg	> 34 mg/kg

2.3 Co-ordinate System and Vertical Datum

For this study, all data is presented using the New Zealand Transverse Mercator projection (NZTM) and the vertical datum is Auckland Vertical Datum (unless otherwise stated).

3 Auckland Council Data

3.1 FWMT Data

FWMT data was provided for 334 outputs as flow-weighted daily average concentration and average daily flow. Among these outputs, 69 were linked to coastal terminal nodes, while the others were related to catchment area sources (see Figure 3-1). FWMT data included TSS (for 3 sediment fractions), TN, TP, Zn and Cu loads.

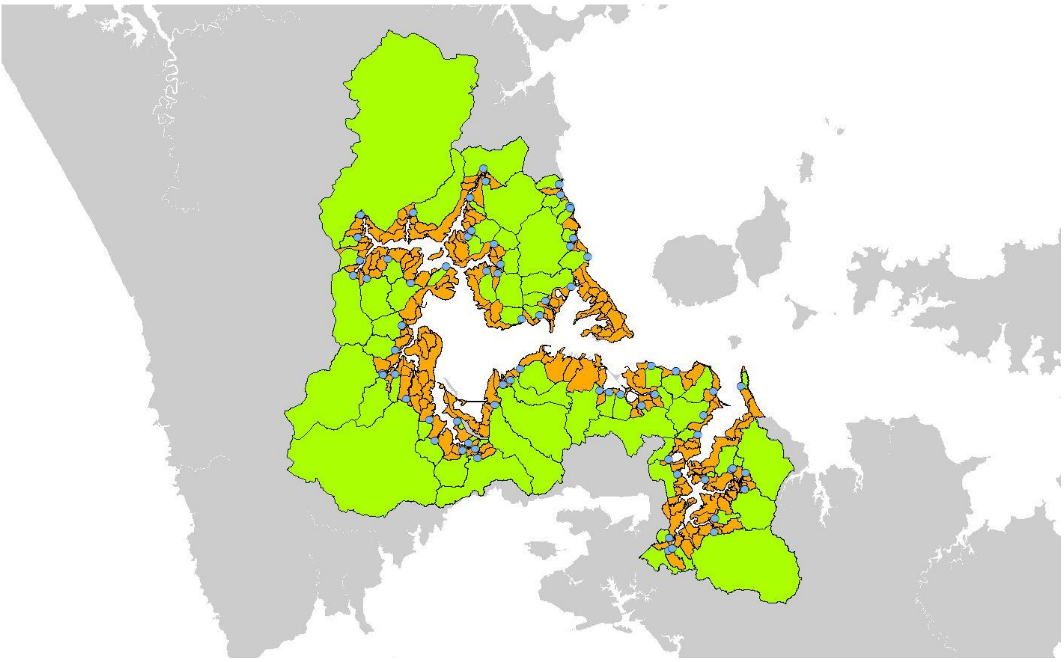


Figure 3-1 FWMT data outputs provided by Auckland Council. The green catchments link to a coastal terminal node, while orange catchments are straight to coast and have no sub-catchments upstream of them.

It was critical to minimise the number of sources to be able to link between sub-catchments and sub-estuary in a meaningful way. The inclusion of too many sources will start to impact the usefulness of this approach.

Catchment area sources were aggregated considering their receiving streams and either merged with the closest downstream coastal terminal node or merged into a new source. Typically sources were moved further downstream into the receiving environment to better suit the resolution of the hydrodynamic model.

This approach resulted in 72 sources, of which it was concluded 50 contribute to the inner Waitematā Harbour receiving environment and 39 sources contribute to the outer Waitematā Harbour receiving environment, for assessing sub-catchment to sub-estuary linkages. Total flows and contaminant concentrations were calculated through adding and weighted-averaging, respectively.

An overview of the merged FWMT sources is provided in Figure 3-2, while Figure 3-3 provides an overview of merged FWMT sources compared with coastal terminal nodes from the FWMT and catchment area sources.

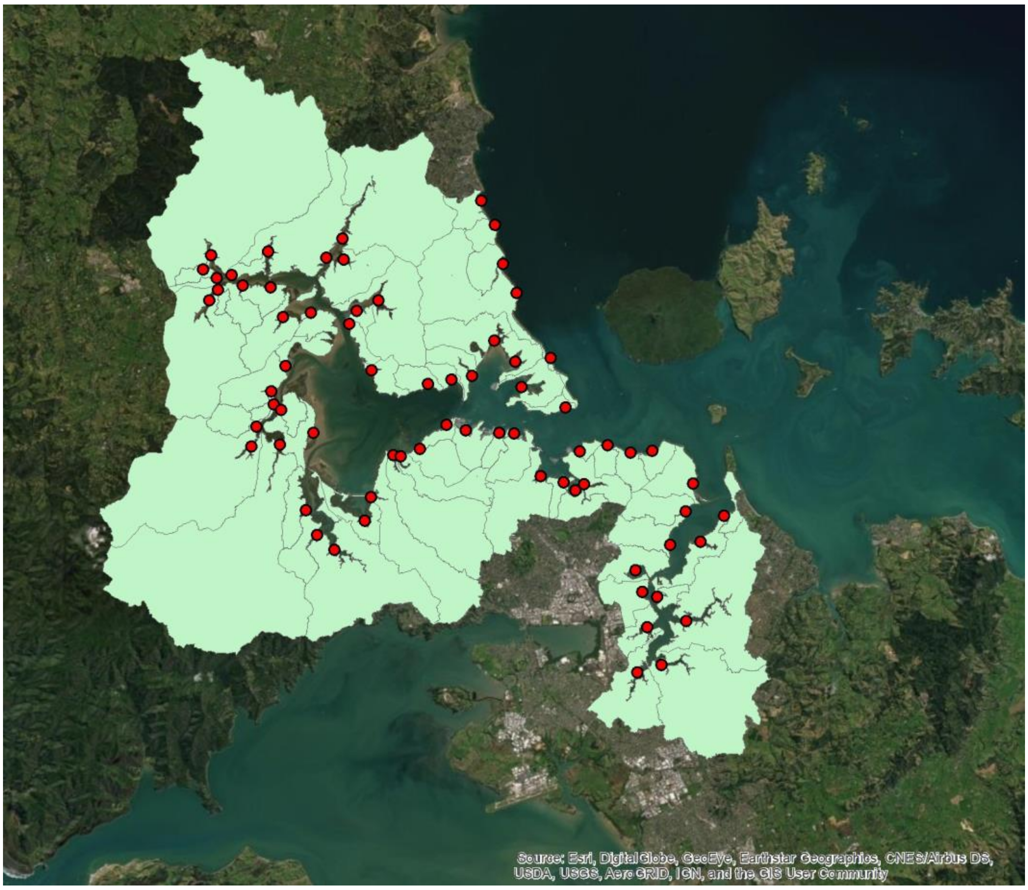


Figure 3-2 Overview of merged FWMT sources and associated catchments.

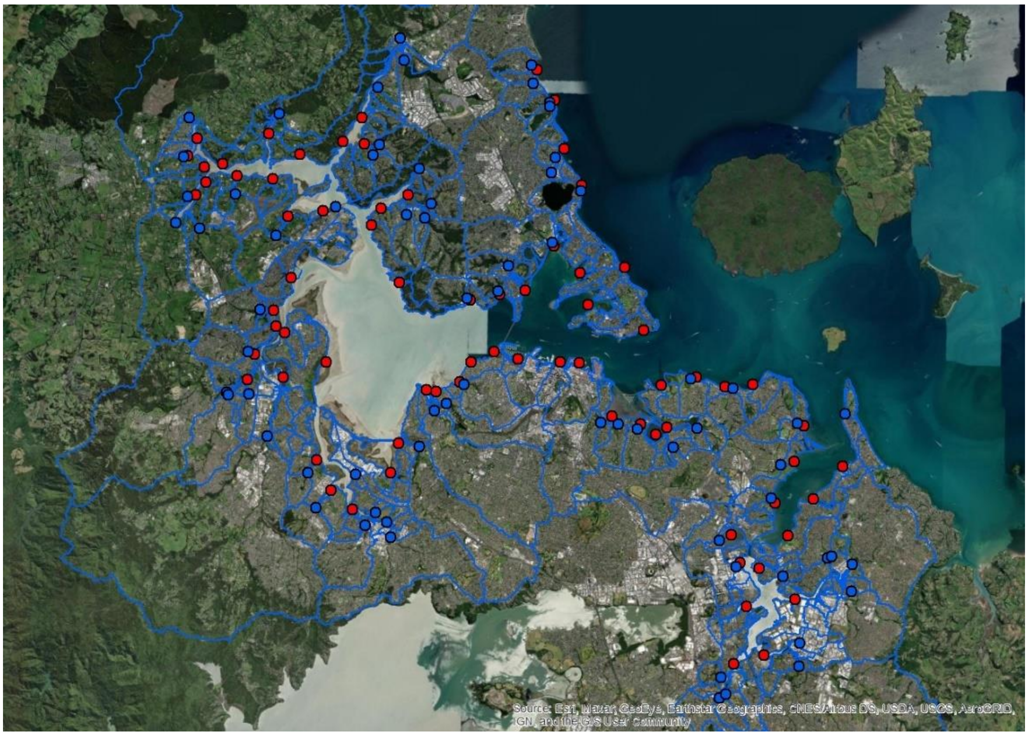


Figure 3-3 Overview of merged FWMT sources (red dot) compared with coastal terminal nodes (blue dot) from FWMT. Catchment outlines indicate both coastal terminal node and catchment area sources.

Following agreement by Healthy Waters, Auckland Council, the year 2015 was selected for the FWMT inflows because it represents a typical climatic year from the FWMT baseline outputs for freshwater quality. Note due to limited availability of spatial wind data (see Section 4.1.4), 2015 FMWT inflows were applied with hydrodynamic and wave forcings from 2018. Consequently, coastal model outputs are not directly representative of 2015.

An overview of total load of TSS (including the different fractions) and other contaminants TN, TP, Zn and Cu is provided in Appendix A.

3.2 Water Quality Data

Auckland Council provided estuarine State of the Environment water quality for a number of locations within the area of interest summarised below. No sedimentation rate data was available for use.

3.2.1 Mud Content Percentage

Mud content percentage data was supplied for the locations indicated in Figure 3-4 for the period 2003 to 2017 at between a 2 monthly to yearly frequency, with the whole period average mud percentage for all samples also provided in Figure 3-4. The same information is presented in Table 3-3 including the minimum and maximum values observed to illustrate possible range observed for each site.

Figure 3-4 Average of percentage mud content.

Table 3-1 Overview of mud content (%) data.

Site	Minimum	Average	Maximum
Brigham Creek	75.80	88.86	97.55
Central Main Channel	18.02	25.95	31.67
Hellyers Creek	31.26	51.44	89.14
Henderson	3.30	7.13	13.81
Herald Island North	0.65	12.82	35.12
Herald Island Waiarohia Inlet	7.04	16.44	28.55
Hobsonville	0.98	3.37	6.58
Hobsonville Opposite	49.97	68.89	87.71
Lucas Creek	14.45	34.49	70.66
Meola Reef	3.02	9.12	21.85
Rangitopuni Creek	91.59	95.82	99.01
Shoal Bay Upper	3.13	7.24	15.80
Upper Main Channel	83.16	89.15	94.88
Whau River	0.00	3.02	8.93

3.2.2 Nutrients

Total Nitrogen (mg/L) data was supplied for the locations indicated in Figure 3-5 for the period 2009 to 2017 at a monthly frequency, with the whole period average Total Nitrogen levels for all samples also provided in Figure 3-5. The same information is presented in Table 3-4, including the minimum, maximum, and median values observed to illustrate possible range observed for each site.

Figure 3-5 Average of Total Nitrogen (mg/L).

Table 3-2 Overview of Total Nitrogen (mg/L) data

Site	Minimum	Average	Median	Maximum
Brigham Creek	0.03	0.37	0.22	1.80
Chelsea	0.01	0.09	0.05	0.69
Henderson Creek	0.01	0.12	0.09	1.10
Hobsonville	0.01	0.08	0.06	0.28
Lucas Creek	0.01	0.2	0.14	1.10
Paremoremo Creek	0.01	0.21	0.14	1.50
Rangitopuni Creek	0.03	0.39	0.26	2.0
Whau Creek	0.01	0.1	0.08	0.40

Total Phosphorous (mg/L) data was supplied for the locations indicated in Figure 3-6 for the period 2003 to 2017 at a monthly frequency, with the whole period average Total Nitrogen levels for all samples also provided in Figure 3-6. The same information is presented in Table 3-3, including the minimum, maximum, and median values observed to illustrate possible range observed for each site.

Figure 3-6 Average of Total Phosphorous (mg/L).

Table 3-3 Overview of Total Phosphorous (mg/L) data

Site	Minimum	Average	Median	Maximum
Brigham Creek	0.01	0.06	0.04	0.59
Chelsea	0.01	0.03	0.03	0.07
Henderson Creek	0.01	0.03	0.03	0.15
Hobsonville	0.01	0.03	0.03	0.08
Lucas Creek	0.01	0.04	0.04	0.12
Paremoremo Creek	0.01	0.04	0.04	0.33
Rangitopuni Creek	0.01	0.05	0.04	0.97
Whau Creek	0.01	0.03	0.03	0.08

3.2.3 Heavy Metals

Zinc (mg/Kg) data was supplied for the locations indicated in Figure 3-5, for the period 2003 to 2017 at a two to five year frequency, with the whole period average Zinc levels for all samples also provided in Figure 3-7. The same information is presented in Table 3-6, including the minimum and maximum values observed to illustrate possible range observed for each site.

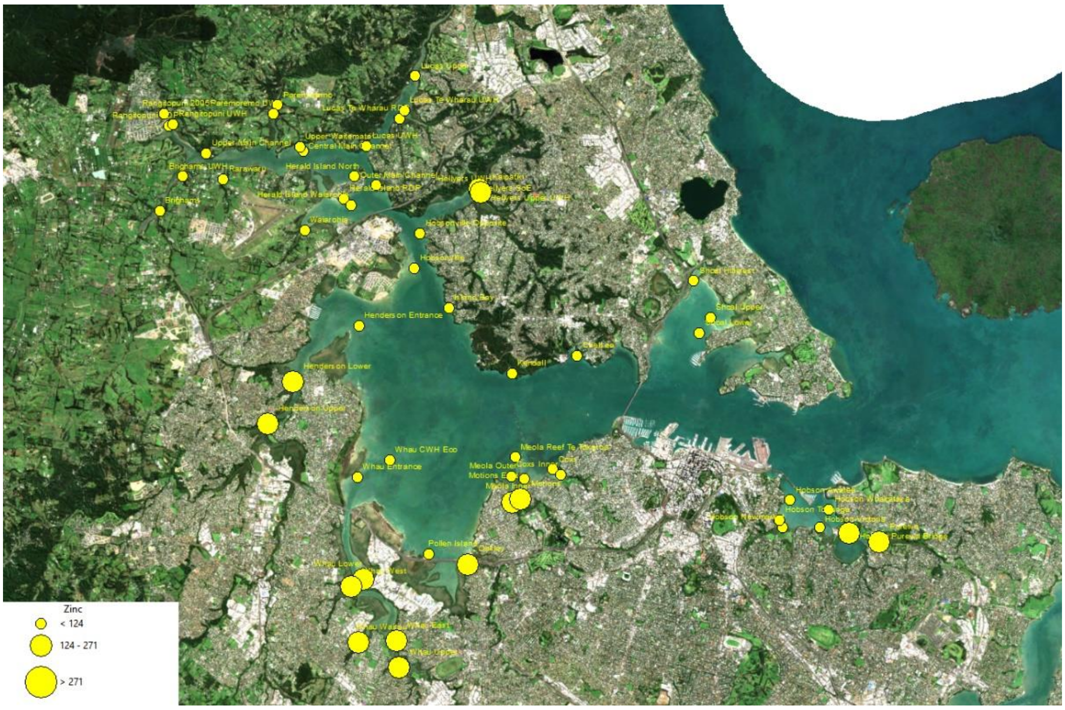


Figure 3-7 Average of Zinc (mg/kg).

Table 3-4 Overview of Zinc (mg/Kg) data.

Site	Minimum	Average	Max
Brighams	88.10	95.92	105.00
Brighams UWH	93.00	101.29	112.00
Central Main Channel	90.60	104.90	122.31
Chelsea	43.70	48.37	56.34
Coxs	58.00	81.72	136.33
Coxs Inner	44.30	44.30	44.30
Hellyers SoE	78.00	95.77	108.08
Hellyers Upper RDP	93.50	95.88	98.40
Hellyers Upper UWH	105.21	124.69	147.00
Hellyers UWH	68.00	87.28	110.00
Henderson Entrance	63.27	72.70	82.00
Henderson Lower	125.00	144.38	170.00
Henderson Upper	140.00	160.22	222.22
Herald Island North	35.00	48.88	68.00
Herald Island RDP	74.00	75.33	76.00
Herald Island Waiarohia	16.00	22.60	35.60
Hobson Awatea	91.00	103.75	124.00
Hobson Newmarket	39.00	41.15	43.43
Hobson Purewa Bridge	156.00	156.00	156.00
Hobson Tohunga	44.50	44.50	44.50
Hobson Victoria	38.00	41.98	46.60
Hobson Whakataka	81.00	89.90	105.00
Hobsonville	20.26	25.31	47.00
Hobsonville Opposite	105.64	109.39	113.35
Island Bay	46.46	51.10	59.00
Kaipatiki	120.00	134.33	150.00
Kendall	30.00	33.29	39.07
Little Shoal Bay	37.40	37.40	37.40
Lucas Te Wharau RDP	85.90	99.79	120.00
Lucas Te Wharau UWH	71.00	82.56	105.00
Lucas Upper	88.40	100.09	112.00
Lucas UWH	75.90	98.14	115.00
Meola Inner	222.22	239.43	265.31
Meola Outer	30.30	36.16	42.00
Meola Reef Te Tokaroa	78.00	91.55	109.18
Motions	210.00	236.48	270.00
Motions East	89.80	89.80	89.80
Oakley	121.77	146.38	184.00
Outer Main Channel	28.40	58.68	86.00
Paremoremo	80.61	91.42	98.96
Paremoremo UWH	88.80	100.98	112.00
Pollen Island	74.00	78.28	88.70
Purewa	130.00	160.16	185.71
Rangitopuni 2005	90.90	90.90	90.90
Rangitopuni RDP	92.30	96.87	101.00
Rangitopuni UWH	81.30	102.10	112.00
Rarawaru	72.73	81.03	93.00
Shoal Hillcrest	91.45	107.98	130.00
Shoal Lower	34.10	41.55	49.00

Site	Minimum	Average	Max
Shoal Upper	36.00	40.68	46.00
Upper Main Channel	79.30	96.83	111.00
Upper Waitemata	99.50	108.83	117.00
Waiarohia	75.00	87.63	103.00
Whau CWH Eco	24.00	25.59	28.00
Whau East	182.00	182.00	182.00
Whau Entrance	22.60	35.57	48.48
Whau Lower	143.30	160.26	180.00
Whau Upper	224.49	259.74	290.00
Whau Wairau	185.57	221.35	248.48
Whau West	172.00	172.00	172.00

Copper (mg/Kg) data was supplied for the locations indicated in Figure 3-8 for the period 2003 to 2017 at a two to five year frequency, with the whole period average Copper levels for all samples also provided in Figure 3-8. The same information is presented in Table 3-5, including the minimum and maximum values observed to illustrate possible range observed for each site.

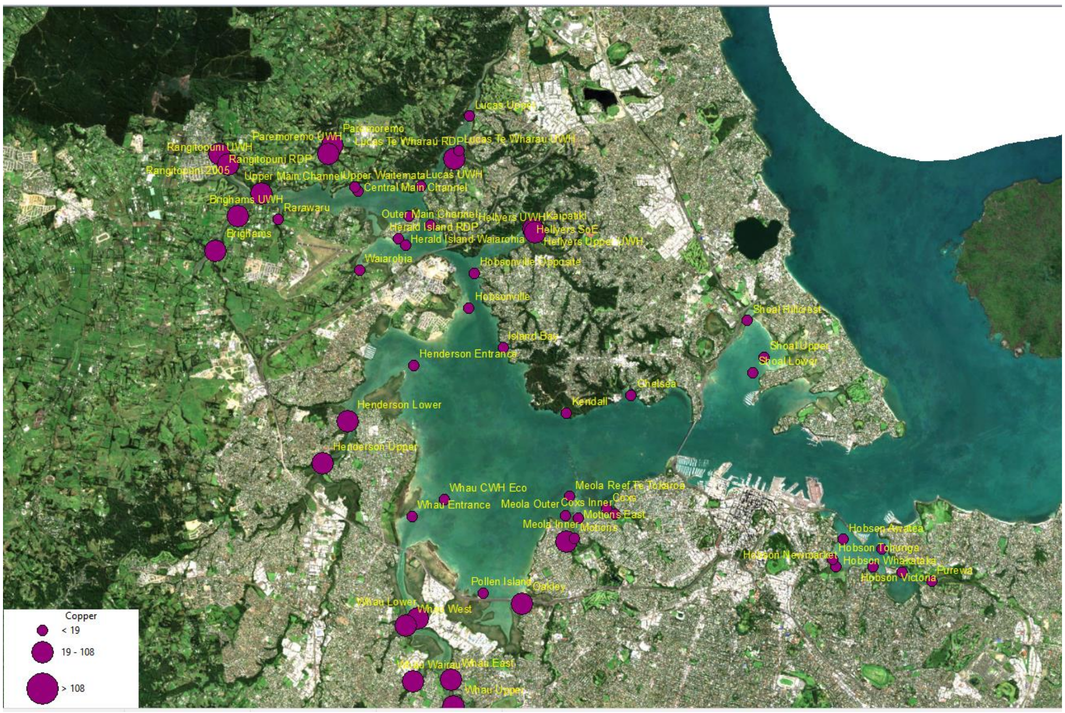


Figure 3-8 Average of Copper (mg/L).

Table 3-5 Overview of Copper (mg/Kg) data.

Site	Minimum	Average	Max
Brighams	19.20	20.78	22.50
Brighams UWH	18.77	21.52	23.90
Central Main Channel	8.89	11.76	14.70
Chelsea	4.80	5.90	8.16
Coxs	3.30	6.12	10.94
Coxs Inner	4.50	4.50	4.50
Hellyers SoE	8.00	13.15	16.00
Hellyers Upper RDP	14.90	16.00	17.70
Hellyers Upper UWH	16.02	21.10	28.10
Hellyers UWH	8.90	12.42	18.80
Henderson Entrance	5.00	6.40	7.30
Henderson Lower	25.30	28.37	36.00
Henderson Upper	26.00	30.31	39.39
Herald Island North	4.80	6.78	14.20
Herald Island RDP	7.60	7.73	7.80
Herald Island Waiarohia	2.50	3.88	7.90
Hobson Awatea	8.85	10.91	14.50
Hobson Newmarket	4.00	5.25	6.00
Hobson Purewa Bridge	14.00	14.00	14.00
Hobson Tohunga	4.40	4.40	4.40
Hobson Victoria	3.30	3.96	4.90
Hobson Whakataka	6.30	7.78	9.70
Hobsonville	2.00	3.02	6.40
Hobsonville Opposite	16.12	16.54	16.95
Island Bay	5.25	5.96	7.40
Kaipatiki	20.00	23.53	28.00
Kendall	3.60	4.38	5.42
Little Shoal Bay	5.20	5.20	5.20
Lucas Te Wharau RDP	16.00	21.28	26.00
Lucas Te Wharau UWH	11.64	15.54	23.00
Lucas Upper	14.68	18.52	22.00
Lucas UWH	10.44	12.56	15.50
Meola Inner	23.20	29.11	33.00
Meola Outer	2.80	3.49	4.30
Meola Reef Te Tokaroa	6.80	10.16	15.41
Motions	14.00	18.23	36.40
Motions East	5.10	5.10	5.10
Oakley	20.27	25.03	31.30
Outer Main Channel	7.60	12.53	26.00
Paremoremo	18.37	20.99	23.96
Paremoremo UWH	21.00	23.57	27.00
Pollen Island	8.00	9.88	12.90
Purewa	11.30	14.39	19.70
Rangitopuni 2005	22.00	22.00	22.00
Rangitopuni RDP	16.80	18.97	21.00
Rangitopuni UWH	21.30	23.24	25.00
Rarawaru	15.48	16.91	18.50
Shoal Hillcrest	14.90	17.07	22.00
Shoal Lower	3.20	4.44	6.10

Site	Minimum	Average	Max
Shoal Upper	3.30	4.12	4.90
Upper Main Channel	18.50	21.66	25.00
Upper Waitemata	6.20	7.60	8.70
Waiarohia	16.00	18.70	21.00
Whau CWH Eco	2.00	2.14	2.42
Whau East	27.30	27.30	27.30
Whau Entrance	2.60	3.94	6.57
Whau Lower	21.65	24.35	28.87
Whau Upper	26.53	32.81	40.00
Whau Wairau	31.63	39.53	46.39

4 Model Overview and Set Up

This section provides an overview of the hydrodynamic, wave, and water quality models which have been set up and applied to assess behaviour of terrestrial sources of sediment, nutrients and heavy metals within the inner and outer Waitematā Harbour.

4.1 Sub-Estuary Delineation

The model domain is divided into broader scale sub-estuaries, as shown in Figure 6-1, with 49 defined for the inner Waitematā and 37 defined for the outer Waitematā.

Delineation was undertaken using the bathymetry as starting point, with judgement calls carried out with the aim of creating sub-estuaries which cover the same broad scale setting. This results in sub- estuaries covering the following types of broad scale settings:

- Main tidal channels;
- Sheltered tidally and stream dominated creeks and intertidal zones;.Intertidal zones exposed to fetch limited wind waves;
- Beaches exposed to more significant wave energy; and
- Nearshore locations byond the intertidal zones.

4.2 2D Hydrodynamic Model

DHI have developed a 2D hydrodynamic model using MIKE 21 FM HD (DHI, 2020) of Hauraki Gulf, with an increased resolution for the Inner and Outer Waitematā Harbour, based on the 3D hydrodynamic model developed for Safeswim (DHI, 2021). The following sections provide an overview of the inputs and forcings applied for this model

4.2.1 Bathymetry and Mesh

Bathymetry data for the models were obtained from three sources:

- C-MAP (digital nautical charts from Jeppesen Norway);
- 2016 LiDAR data from Auckland Council which extends into inter-tidal zone;
- Limited survey data from Ports of Auckland to west of Westhaven.

A flexible mesh allows the computational domain to be discretised into a mixture of triangular and quadrangular elements of various sizes. This enables high-resolution definition where necessary and low-resolution for other areas, reducing computational requirements.

The model extent and bathymetries for the model is presented in Figure 4-1 and Figure 4-2. Model resolution is a balance between resolving the local hydrodynamics and achieving reasonable simulation times. This is important when year-long simulations and multiple simulations are required to develop a connectivity matrix. The smallest mesh size in the tidal creeks was approximately 200m^2.

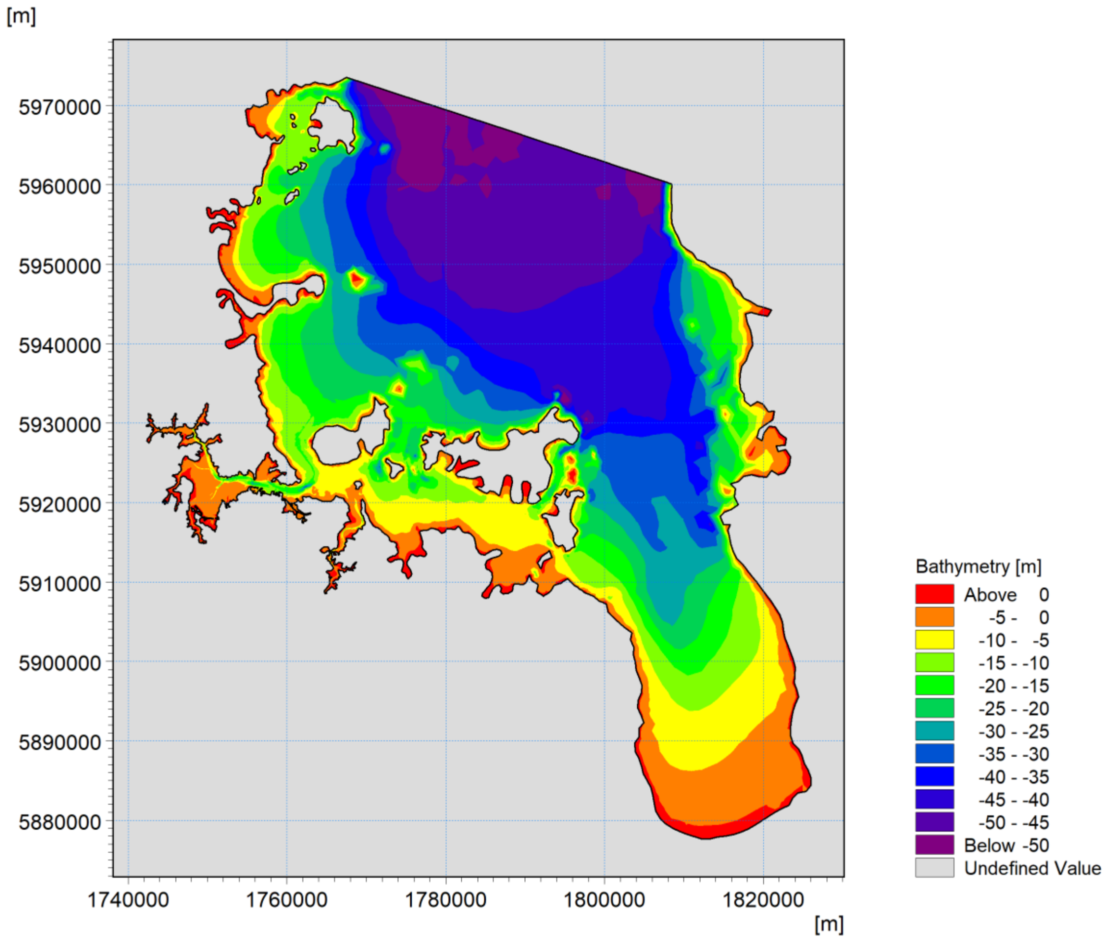


Figure 4-1 Model bathymetry and extent for inner and outer Waitematā Harbour model.

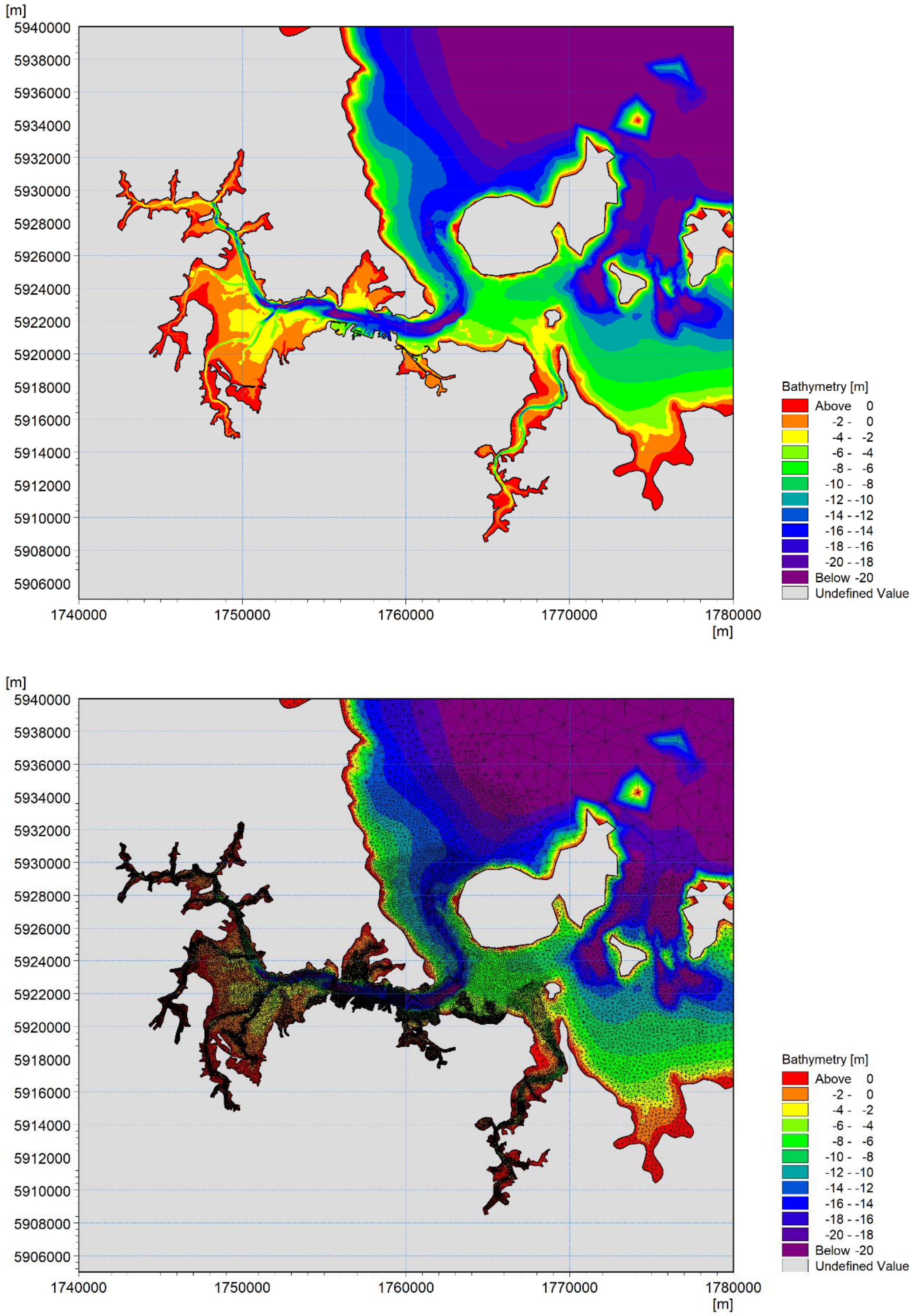


Figure 4-2 Model bathymetry (top) and mesh (bottom) for inner and outer Waitematā harbour model, zoomed into area of interest.

4.2.2 Open Ocean Boundaries

Space-constant water level variations were prescribed along the Inner Hauraki Gulf boundary from corrected TPXO tide model outputs (Egbert et al., 1994). A salinity of 35 PSU is applied at the open ocean boundary.

4.2.3 Freshwater Inflows

Freshwater inflows (i.e. FWMT sources presented in Section 3.1) were assigned a salinity of zero PSU. Inflows were provided at a daily time step, which the model interpolated linearly to the time step of the model (30 seconds).

4.2.4 Wind Data

One hourly spatial wind data is provided to Auckland Council by Weather Radar. The data has an 8 km resolution.

4.3 Wave Model

Waves were simulated using the MIKE 21 Spectral Wave (SW) model (DHI, 2020). MIKE 21 SW is a state-of-the-area third generation spectral wind-wave model developed by DHI. The model simulates the growth, decay and transformation of wind-generated waves and swells in offshore and coastal areas using flexible mesh grid.

Three model domains were nested to capture multi-scale processes controlling the generation and propagation of waves from the Pacific Ocean into the Waitematā Harbour.

The New Zealand domain, which is presented in Figure 4-3, was forced along its open-boundaries using directional spectral data generated from a DHI global wave model. The New Zealand domain has been modified for this study to increase the model resolution at the entrance of the Hauraki Gulf to provide more accurate wave conditions in a complex coastal system that includes multiple islands.

The finest domain (shown in Figure 4-4) covers the entire Hauraki Gulf from Port Jackson to Thames. Similar to the hydrodynamic model, the wave model bathymetry has been generated combining chart data, multi-beam survey data and LIDAR data.

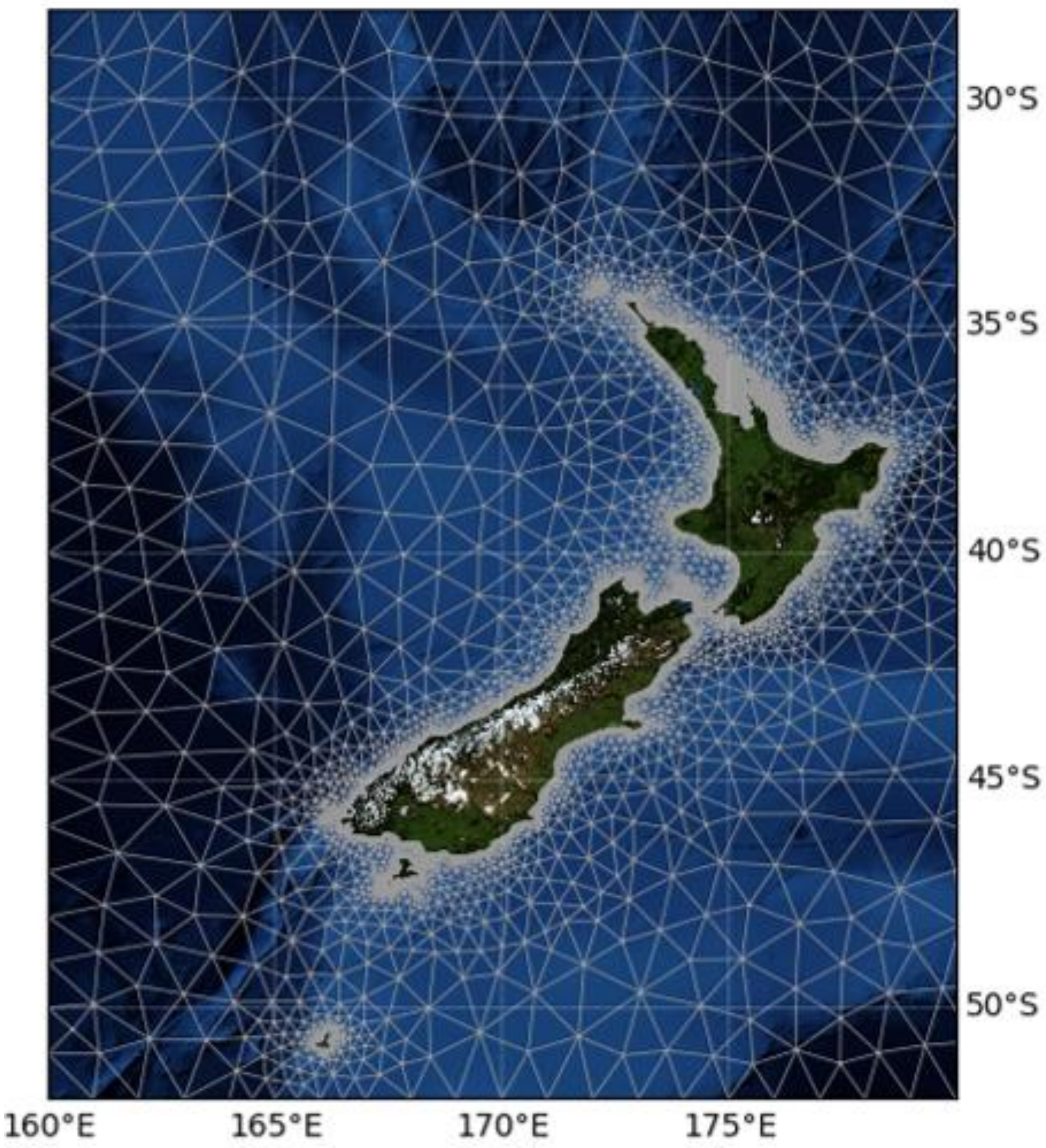


Figure 4-3 MIKE 21 SW flexible mesh grid used to simulate the propagation of waves around New Zealand.

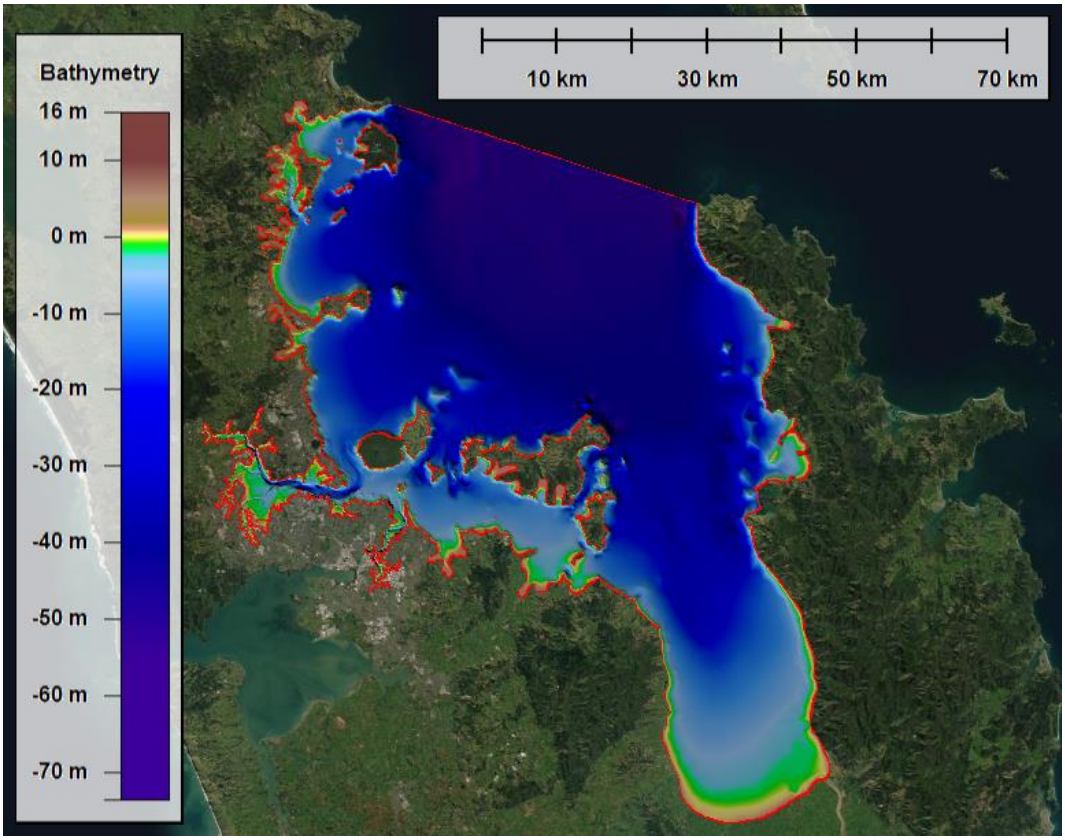


Figure 4-4 Hauraki domain and bathymetry defined in MIKE 21 SW to simulate the propagation of waves through the Hauraki Gulf.

4.4 Sediment Fate Model

The MIKE 21 Mud-Transport (DHI, 2020) was used to simulate the transport of clay, silt and sand particles within the receiving environment.

Bathymetry and hydrodynamic and wave forcings were all derived from coupled MIKE 21 HD and MIKE 21 SW outputs. Sediment fractions and settling velocities were setup in MIKE 21 MT based on the catchment model outputs.

The transport of sediment particles is driven by the hydrodynamics into the receiving water environment and the settling velocity of each particle. Settling velocities vary based on their size, shape and density. Flocculation effects between mud and sand greatly influence these parameters over time, making the settling velocity of each particle dynamically variant. Because it is impossible to predict the settling velocity of every particle over time, averaged settling velocities corresponding to a specific population of particles are generally applied in sediment transport models. It aims to capture the representative behaviour of a population, in this case, each sediment fraction.

An average settling velocity obtained from Ferguson and Church (2004) was defined in the model for each sediment fraction as shown in Table 4-1.

This simplistic approach which does not account for turbulent, or flocculation mechanisms driven by the mud/sand ratio or the mixing between fresh and salt waters is assumed here based on the very high level of complexity for accurately quantifying these processes in an estuary.

Table 4-1 Settling velocities for each sediment fraction included in the mud transport modelling.

Sediment fraction	Settling Velocity (mm/s)
Clay	0.1
Silt	0.5
Very Fine Sand	5.0

The deposition of suspended sediment is the transfer of sediment from the water column to the bed. Deposition takes place where the bed shear stress is smaller than the critical shear stress for deposition. A value of 0.15 N/m^2 was setup over the domain, except within the main subtidal channels and in the western corner of the estuary where a value of 0.0 N/m^3 was assumed to avoid the deposition of sediments immediately after their release due to a lack of resolution in the upper stream areas.

The critical bed shear stress for erosion that defines the threshold above which each fraction of sediment is resuspended, was setup to 0.175 N/m^2. In a mixed-bed composition environment characterised by high percentages of cohesive (mud) and non-cohesive (sand) sediments, the estimation of this threshold is normally determined during calibration. In absence of sediment transport measurements, a mid-range value was chosen to capture the resuspension of material within the estuary.

The model was setup using the Partheniades (1965) formulation for the erosion of soft mud with a constant density of 350 kg/m^3 (consistent with partly consolidated mud). An erosion coefficient of $6.5x10^{-5}$ $kg/m^2/s$ and the power of erosion was set to 4, was defined accordingly to the recommended values provided in DHI (2020) for soft bed mud.

MIKE 21 MT only simulates the suspended-load component of the sediment transport. The bed-load transport that mainly affect the coarsest particles is not included in the numerical modelling. This limitation is expected to greatly reduce the transport of sand throughout the estuary and limits SAR outputs within a sub-estuary and over time.

A limitation for the sediment fate models, is the FWMT inflows themselves. FWMT has been shown to perform well at predicting overall load and less favourably, concentration in 36 State of Environment sites over the 2013-2017 baseline period (Auckland Council, 2020). We suspect that concentrations during wet weather events are underpredicted for the Upper Waitemata Harbour, where sediment fate validation data was available, since the FWMT was shown toi generally underpredict TSS concentration for this area (Auckland Council, 2020). Output from FWMT was supplied at daily time step, which will smooth inflows during flashy wet weather events. Consequently, FWMT inputs are likely to deposit closer to source, especially sand, due to temporal aggregation. The FWMT can produce 15-minute outputs but daily outputs were deemed sufficient for the pilot purpose of this study. Note as a result the model is most likely over predicting deposition where there are significant inflows (i.e. Rangitopuni Stream and Henderson Creek).

A simple overview of the processes which the sediment fate model is representing is presented in Figure 4-5.

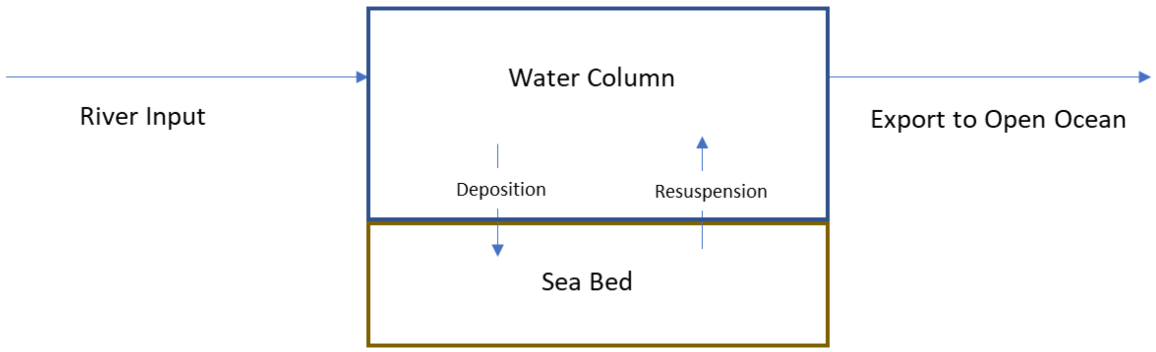


Figure 4-5 Simple overview of sediment fate model processes.

4.5 Nutrient Model

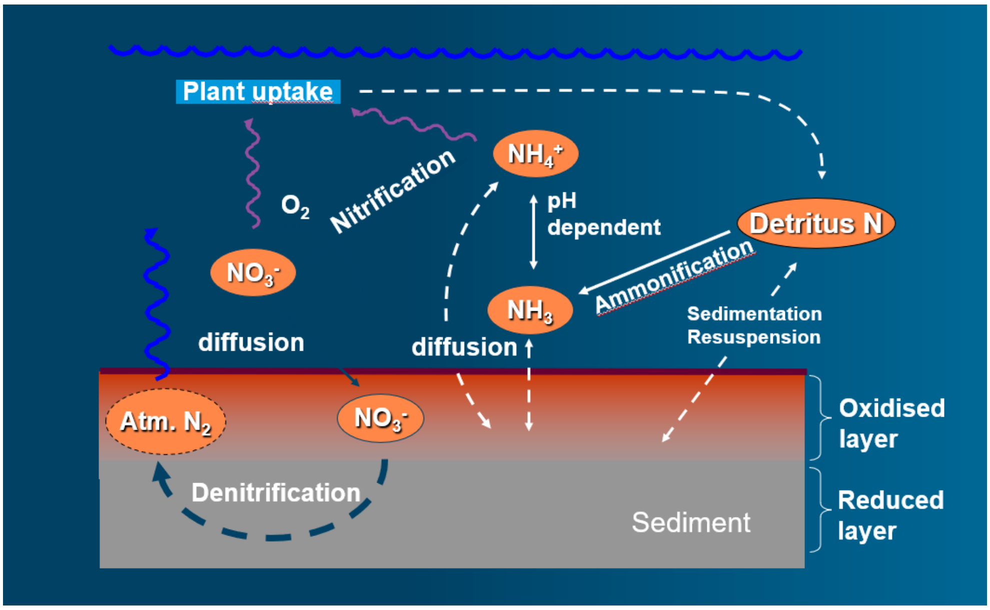
The behaviour of nutrients within the receiving environment has been represented using the advection-dispersion (AD) module (DHI, 2020). The AD module simulates the spread of dissolved and suspended substances as either a conservative tracer (i.e. no decay processes) or a decaying tracer, subject to the transport process derived from the hydrodynamic model.

For nitrogen, a decay tracer was used to represent cycling/transformation processes, while TP was simulated was simulated with a conservative tracer.

Through model validation (see Section 5), an appropriate decay rate for TN was determined, that simulates the overall estimated loss of TN due to such processes as ammonification, nitrification, denitrification, phytoplankton uptake, and loss to detritus.

The nutrient model does not account for the potential interaction of nutrients in the water column with sediments in the seabed and the potential for nutrients from the seabed to be a source of nutrients to the water column.

Figure 4-6 presents an overview of the processes which the TN model is representing with decay tracer, apart from sediment interaction and the processes that the TP model is not representing.



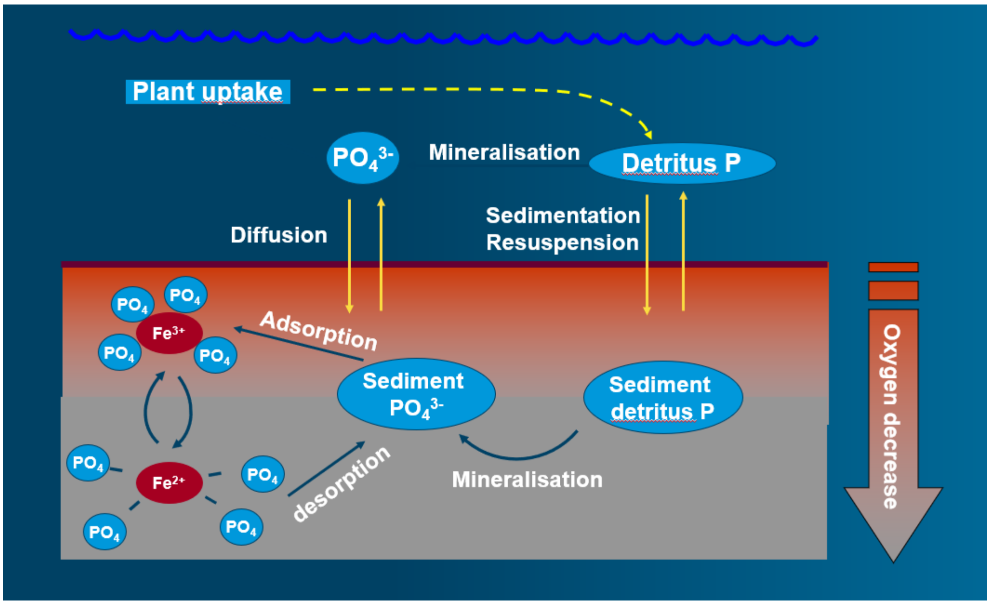


Figure 4-6 Processes which the TN model is representing with decay tracer, apart from sediment interaction (top) and the processes that the TP model is not representing with conservative tracer.

4.6 Heavy Metal Model

The metal sediment interactions are in dynamic equilibrium with the surrounding environment. Metals in the sediments can pose a threat to biota if released through dissolution, resuspension, transport, and erosion processes. The exposure, uptake, and impact of biota depends on the metal concentration in sediments and surrounding waters, the prevailing hydrodynamics, and physiology of the biota. This complex interaction of varying parameters influences the bioavailability of metals in coastal environments.

Heavy metal model outputs in this report refer to the accumulated sedimentary metals, which is indicative of but not identical to the bioavailable metal concentration in the water column.

The metal accumulation model calculates an equilibrium metal concentration within each sub-estuary in the MIKE21 model.

For each sub-estuary, the following methodology is applied.

It is assumed that there is a surface mixed layer on seabed that is uniformly mixed to a depth of λ (m) during each year by a combination of physical and bioturbation processes. Thus, at the end of each year, the sediment in the surface mixed layer consists of the sediment deposited from the catchment mixed uniformly with the existing bed sediments.

The mass of catchment derived sediment that accumulates on the seabed (S) over the course of a year is given by:

$$S_c = \rho\eta \text{ (kg/m}^2\text{)} \qquad (1)$$

where η is the sediment deposition rate (m/y) derived from the sediment transport model and ρ is the density (kg/m^3) of the bed sediments (assumed to be 1200 kg/m^3).

At the end of the year (t = 1) the sediment in the surface mixed layer consists of the catchment derived sediment deposited during the year mixed uniformly to a depth of $(\lambda - \eta)$ metres with pre-existing sediments. Hence, at the end of the year, the mass of sediment per unit area of seabed exhumed to a depth of $(\lambda - \eta)$, metres given by:

$$S_e = \rho(\lambda - \eta) \text{ (kg/m}^2\text{)} \qquad (2)$$

The total mass of sediment per unit area of seabed in the surface mixed layer at the end of the year (S_t) is given by the sum of sediment deposited (Sc) and sediment exhumed (Se):

$$S_t = \rho\eta + \rho(\lambda - \eta) \text{ (kg/m}^2\text{)} \qquad (3)$$

Assuming that the catchment derived sediment deposited during the course of the year carries metal at a concentration of C_c (kg metal / kg sediment – derived from the FWMT data), the mass of catchment derived metal that accumulates on the seabed per unit area of seabed over the year is:

$$M_c = \rho\eta C_c \text{ (kg)} \qquad (4)$$

At the beginning of the simulation period (time = 0) the metal concentration in the seabed surface mixed layer is C_0 (kg metal / kg sediment). The mass of metal per unit area of seabed that is exhumed from below during the year is:

$$M_e = \rho(\lambda - \eta)C_0 \text{ (kg)} \qquad (5)$$

Hence, the total mass of metal in the surface mixed layer at the end of the year is:

$$M_t = \rho[\eta C_c + (\lambda - \eta)C_0] \text{ (kg)} \qquad (6)$$

The metal concentration in the surface mixed layer at the end of the year, C_1, is given by the total mass of metal in the surface mixed layer (Mt) divided by the total mass of sediment in the surface mixed layer:

$$C_1 = \frac{\rho[\eta C_c + (\lambda - \eta)C_0]}{\rho\lambda} \text{ (kg metal/kg sediment)} \qquad (7)$$

Which reduces to:

$$C_1 = \frac{[\eta C_c + (\lambda - \eta)C_0]}{\lambda} \text{ (kg metal/kg sediment)} \qquad (8)$$

For the following year, the initial concentration (C0) becomes the predicted concentration at the end of year C_1, hence:

$$C_2 = \frac{[\eta C_C + (\lambda - \eta) C_1]}{\lambda} \text{ (kg metal/kg sediment)} \quad (9)$$

Sediment and metal load data is used to define the source concentration for each of the FWMT discharge nodes.

Outputs from the sediment transport model are used to determine the contribution that each source makes to the overall deposition seen in each model element.

For each model element C_c can then be derived by summing the percent contribution to the overall deposition of each sub-catchment by the predicted sub-catchment source concentration.

Data from the sediment transport model is used to define η for each model element and global values of λ are assigned as part of the calibration process (based on data in Auckland Regional Council (2008) and the spatial variability of the predicted sedimentation rates).

In the absence of historical load information, C_0 is initially set to zero and the model is run for 50 years to match current day observed metal concentrations in the surface mixed layer.

An overview of the surface sediment mixing the model is representing is presented in Figure 4-7.

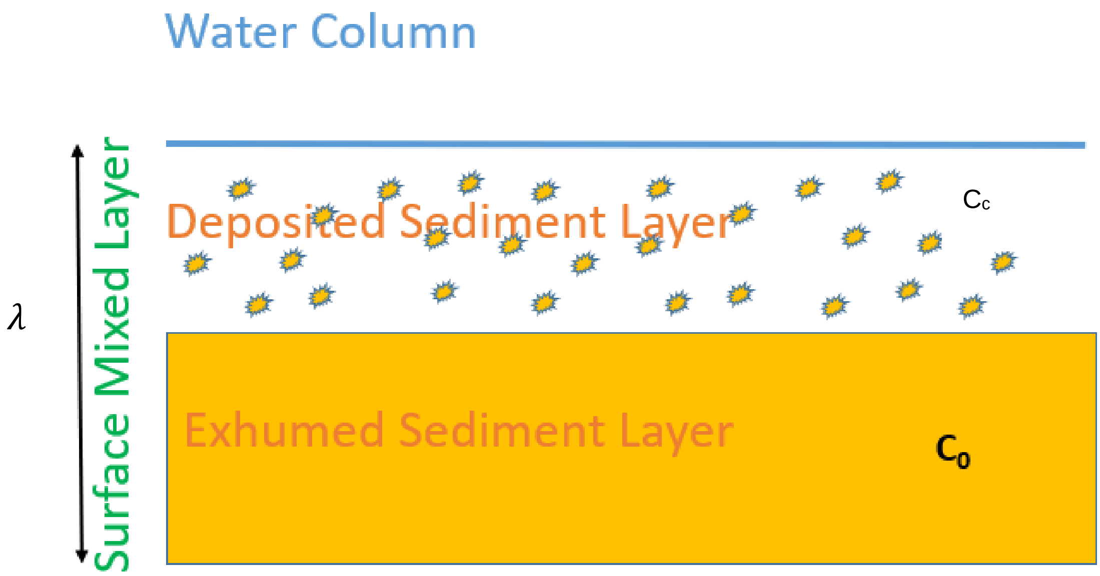


Figure 4-7 Overview of surface sediment mixing layer model representing

The source concentrations of metals for each FWMT discharge node are defined based on the ratio of the total metal to sediment load. The concentrations are presented in Appendix A.

4.7 Key Contaminant Assumptions

For sedimentary processes key assumptions affecting model complexity and effort include:

- Single settling velocities used for sand, silt and clay – more diverse responses likely due to variation of size, shape and density within each size class;
- Hydrodynamics simplified to exclude turbulent or flocculation mechanisms driven by the mud/sand ratio or the mixing between fresh and salt waters – estuarine mixing processes will vary with inflow rate and chemistry;
- Critical bed shear stress for deposition set to 0.15 N/m^2 domain wide except in main subtidal channels and western arm where no deposition permitted (critical shear set to 0 N/m^2) – varies with mud-composition and grain size of beds;
- Critical bed shear for stress erosion set to 0.175 N/m^2 domain wide – varies with mud-composition and grain size of beds;
- Bed-load transport not simulated – could inflate sand accumulation within Inner Waitematā domain (primarily affecting SAR and metal concentration outputs – less conservative);
- Marine sources not simulated – reduces inputs of sediment (and contaminants) with potential to deflate SAR but increase/decrease heavy metal concentrations (less conservative for SAR and less/more conservative for metal toxicity depending on sand content from marine sources – more problematic in Outer Waitematā domain).
- Legacy sources absent – no representation of reworked sediment and contaminants, assumes no available legacy reservoir.

For nutrient processes key assumptions affecting model complexity and effort include:

- For nitrogen, a decay tracer was used to represent cycling/transformation processes, while TP was simulated was simulated with a conservative tracer – simplification of processes affecting nutrient form and concentration (depending on the model domain, mesh size and algorithms solved for, decay rates could vary within and between sub-estuaries);
- The nutrient model does not account for the potential interaction of nutrients in the water column with sediments in the seabed and the potential for nutrients from the seabed to be a source of nutrients to the water column (less conservative);
- Direct inputs not simulated – reduces inputs from vessels and water facilities (wharves, jetties, marinas) (less conservative).

For heavy metal processes key assumptions affecting model complexity and effort include:

- Basis in sediment accumulation model on: source control estimates (and their reliance on limited observations); sediment deposition rate; uniform reworking (exhumed) depth; and assumed uniform mixing within sub-estuary
- Absence of biochemical regeneration – no geochemical or biological dissolution and precipitation processes represented (less conservative)
- Direct inputs not simulated – reduces inputs from vessels and water facilities (wharves, jetties, marinas) (less conservative).

5 Model Calibration or Validation

This section of the report provides an overview of the calibration of the 2D hydrodynamic model, wave model and the validation of the water quality models.

5.1 2D Hydrodynamic Model Calibration

This section of the report provides details of the calibration of DHI's hydrodynamic model of Waitematā Harbour against a selection of available hydrodynamic data. Note the mesh used for FWMT, has been modified slightly (with much higher resolution in the tidal creeks for example, but less resolution for some parts of the central Waitemata) to accommodate long run times. These changes are not expected to alter model hydrodynamic performance markedly from the Safeswim model.

The following data is presented to illustrate the 2D hydrodynamic model performance (via a visual comparison) for the inner and outer Waitematā Harbour model:

- As part of the 36th Americas Cup viaduct development, Auckland Council commissioned Cawthron to collect water level and current data at the viaduct bridge.
- As part of dredge channel deepening project, Port of Auckland, commissioned Cawthron to collect water level and current data in the southern bend of the Rangitoto Channel.
- As part of St Mary's Bay Water Quality Improvement Programme, Auckland Council, commissioned Discovery Marine Limited to collect current data throughout the water column in the vicinity of Point Erin, just to the west of the Harbour Bridge.

The locations of the water level and current data are presented in Figure 5-1.

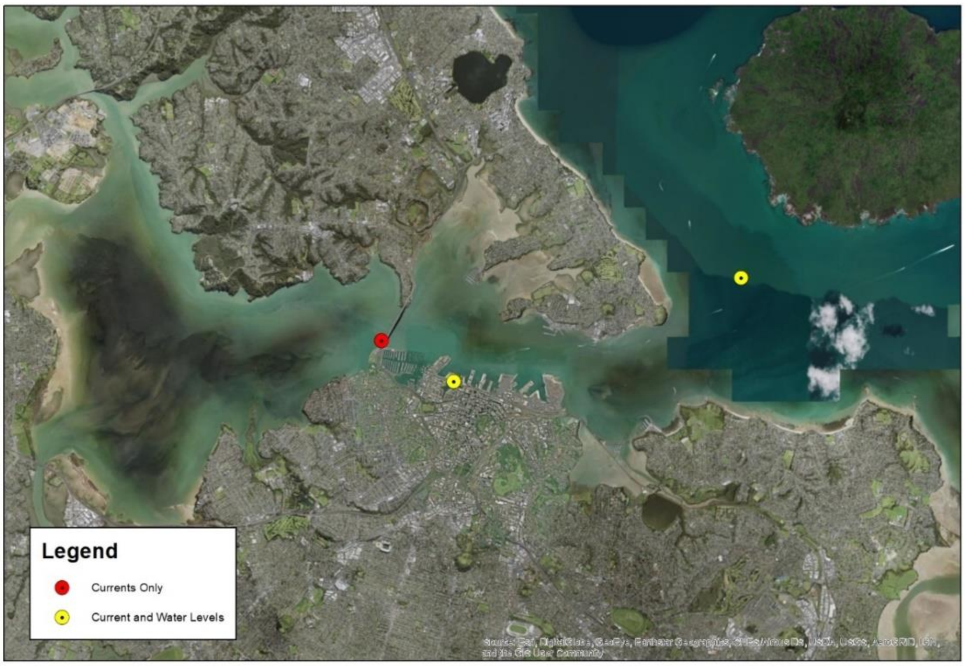
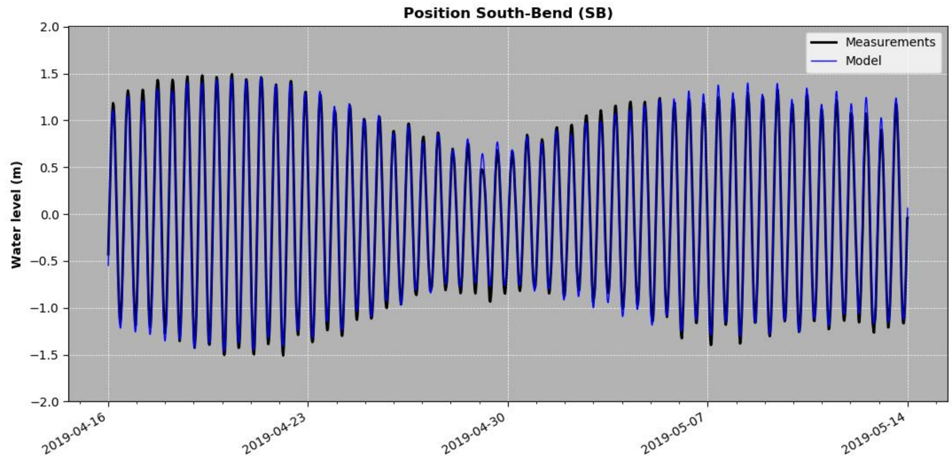


Figure 5-1 Locations of water level and current data.

The performance of the model with regards to depth averaged currents and water levels at the south bend of Rangitoto Channel is presented in Figure 5-2. The model was shown to perform very well with regards to predicting both water levels and currents.

The performance of the model with regards to depth averaged currents and water levels at the Viaduct Bridge is presented in Figure 5-3. Again the model was shown to perform very well with regards to predicting both water levels and currents.

The performance of the model with regards to currents near Point Erin is presented in Figure 5-4 Current speed has been compared for depth averaged currents. There is a reasonable agreement for current speeds throughout water column.



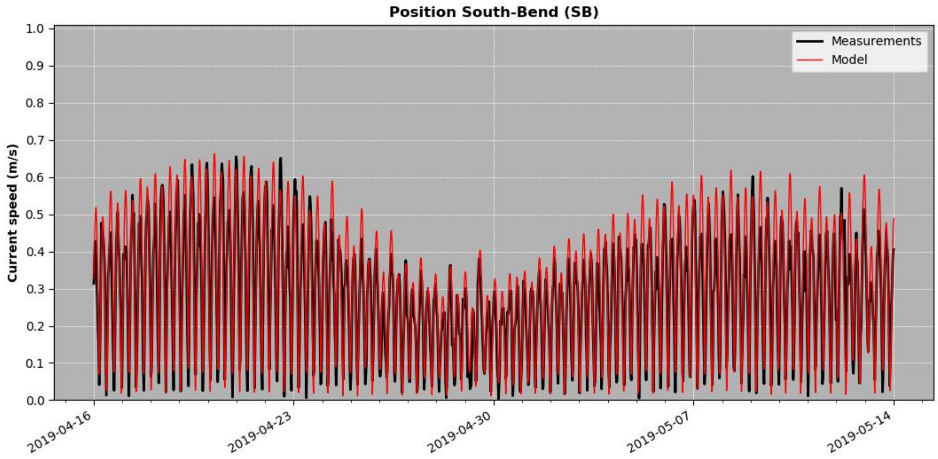


Figure 5-2 Comparison of observed and measured water level (top) and depth averaged current speed (bottom) for south bend of Rangitoto Channel.

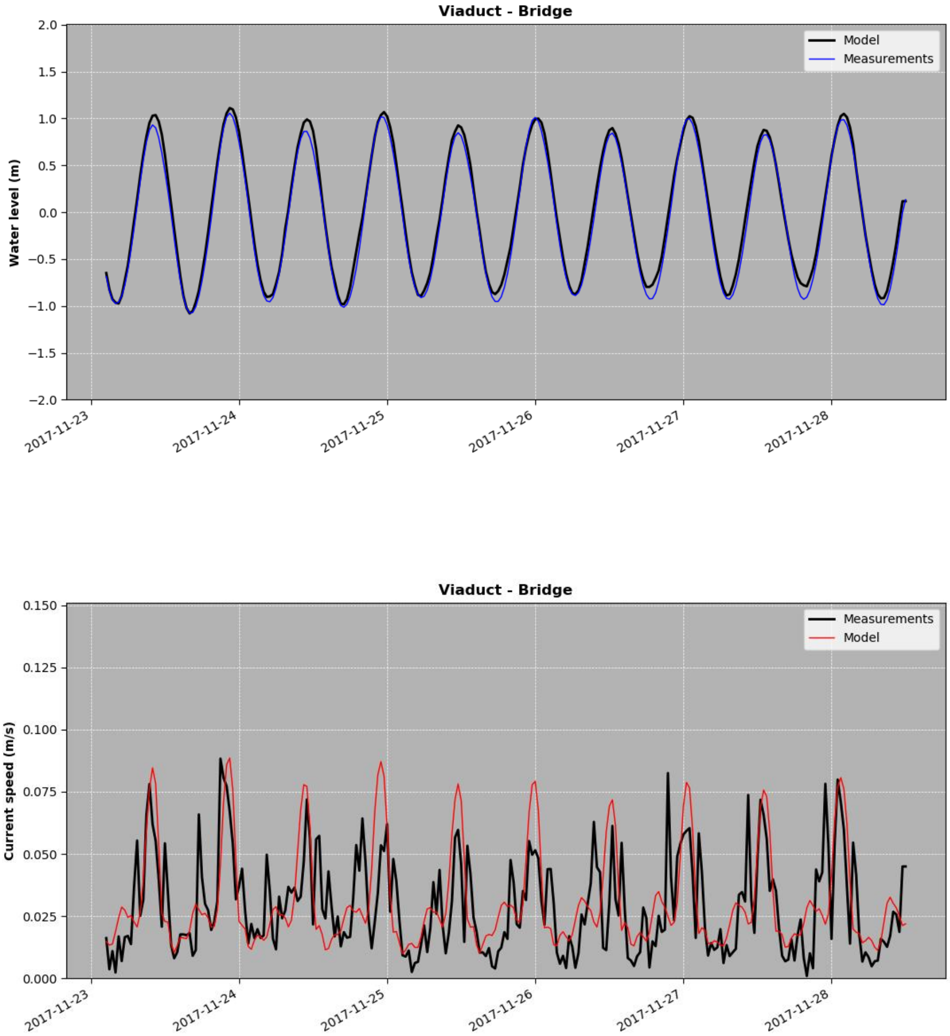


Figure 5-3 Comparison of observed and measured water level (top) and depth averaged current speed (bottom) for Viaduct Bridge.

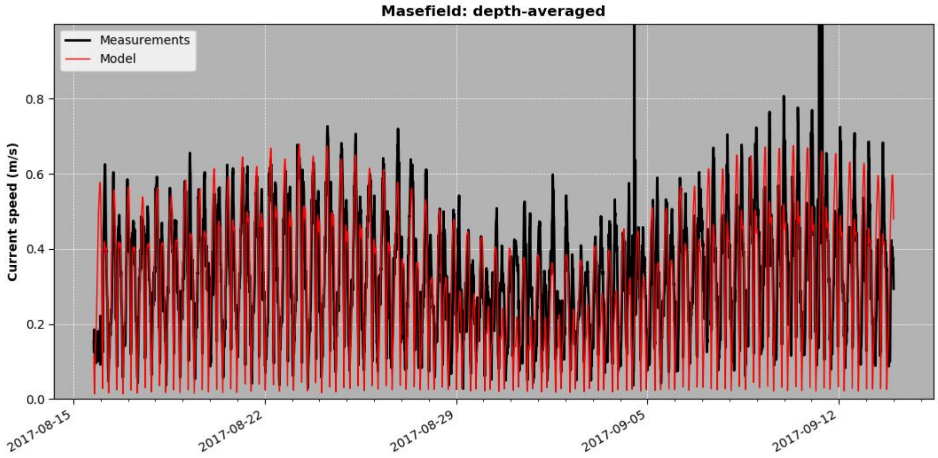


Figure 5-4 Comparison of observed (black) and predicted (red) current speed and direction in vicinity of Erin Point.

5.2 Wave Model Calibration

The wave model validation was done by comparing simulated significant wave heights (H_s) and peak wave periods (T_p) with measurements collected between February and October 2015 by a wave buoy (Auckland Council) deployed at the Hauraki Gulf entrance (Figure 5-5). The agreement between measured and hindcast wave conditions (see Figure 5-6) confirms the capability of the wave model to accurately predict the spectral wave conditions at the Hauraki Gulf entrance.

The absence of measurements within Hauraki Gulf itself, makes impossible the assessment of the model performance further in the Gulf. However, some limited qualitative validation has been undertaken for waves within the central Waitematā Harbour. NIWA previously deployed several DOBIE wave gauges at multiple locations (Figure 5-7) in Central Waitemata Harbour from May to the end of July 2006. The simulated 2018 wave predictions (continuous record) have been compared with the maximum significant wave heights calculated from DOBIE wave gauges.

The brief comparison between maximum measured and modelled significant wave heights indicate a relative good agreement (Table 5-1). In the absence of co-temporal wave measurements in the harbour, it was impossible to perform any quantitative validation.

The maximum significant wave height was used as a comparison, since in the central harbour, the main source for resuspension of sediment is waves. Larger waves will resuspend more sediment and at greater water depths, hence it was important to show the model was generally predicting wave of similar magnitude to what have been observed in the harbour.

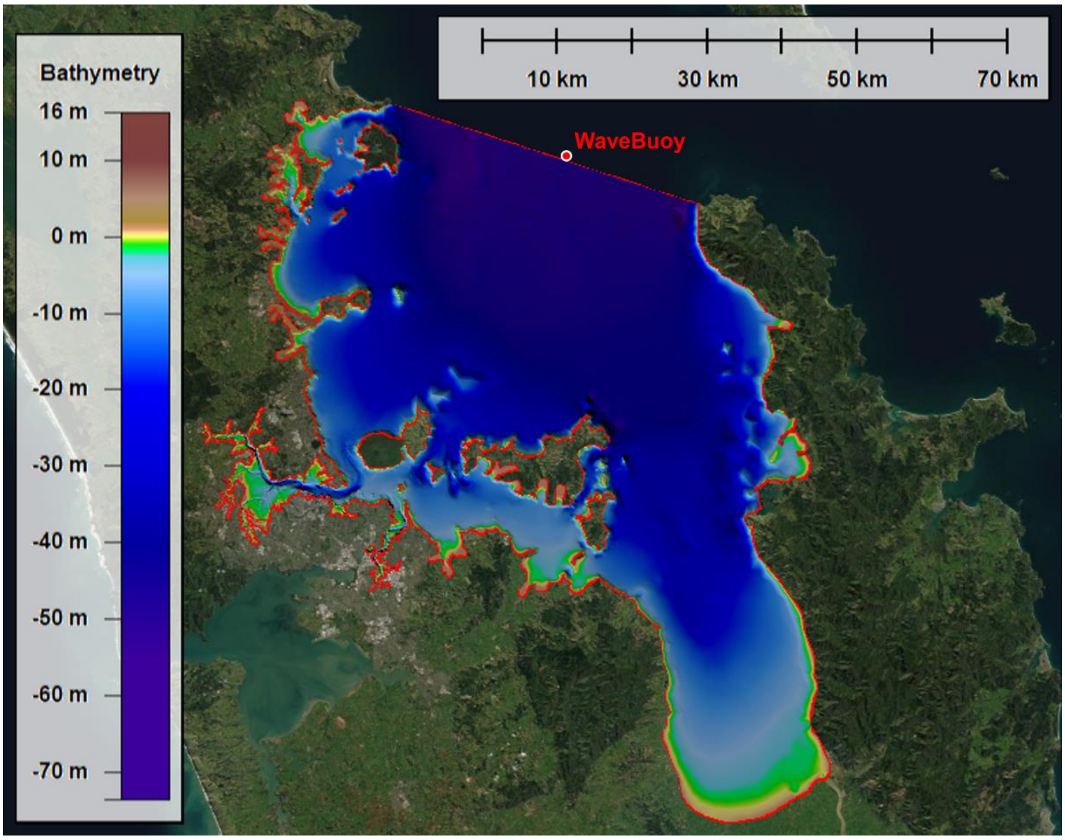


Figure 5-5 Location of the wave buoy on top of the bathymetry map within the Hauraki Gulf.

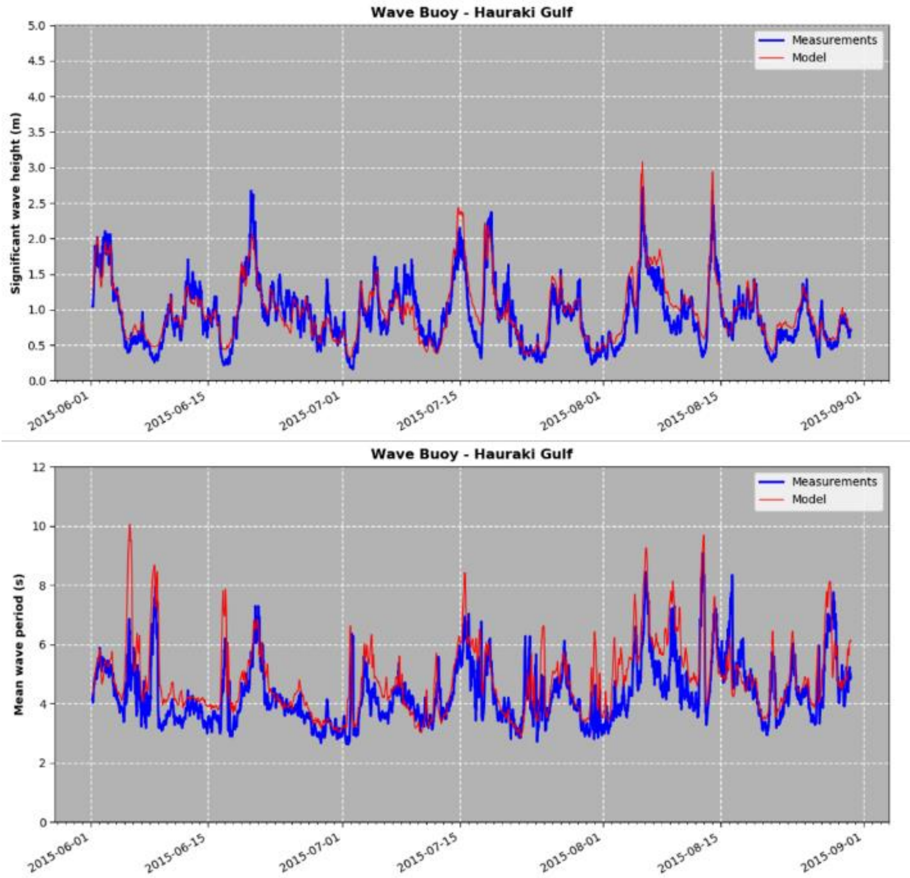


Figure 5-6 Comparison of the model significant wave height and peak wave period against wave buoy measurements at the entrance to the Hauraki Gulf.

Figure 5-7 Location of DOBIE instruments used to measure waves at sites 2, 4, 8 and 10 (source Auckland Council – Central Waitemata Harbour Study).

Table 5-1 Comparison between measured (May - July 2006) and model (2018) maximum significant wave heights.

Sites	Maximum Sign. Wave Height (m)	
	Measurements	Model
S2	0.7	0.4
S4	0.4	0.6
S8	0.7	0.6
S10	0.5	0.4

5.3 Water Quality Model Validation

This section provides an overview of the validation of the sediment fate and nutrient models. Model parameters have been tuned to achieve what is considered a reasonable validation.

5.3.1 Sediment Fate

There is very little sediment deposition data available for the Auckland region. NIWA (2008) carried out analysis of sedimentation within the central basin of the Waitematā Harbour, using the stratigraphic record in sediment cores. These are only representative of deposition rates for inner harbour locations, exposed to fetch limited wind waves . The result of the analysis suggested that the rate of sedimentation ranged between 2.2 and 6.8 mm/yr, except for one location of 0.7 mm/yr. The analysis was from locations with typically low mud content (less than 10%).

Figure 5-8 Calculated sedimentation rates (see NIWA, 2008). Locations approximate.

For 2015, approximately 8.3 x 10^6 kg of sand was discharged into the harbour from FWMT terminal nodes. Assuming that sand has a density of 2000 kg/m^3, the area of the central Waitematā Harbour is approximately 50 km^2 (NIWA, 2008) and that sand deposition would occur for only 25% of this area, equates to a deposition rate of 0.3 mm/yr. The latter sand-based sedimentation rate would likely be reduced further as sand can be expected to accumulate in upper Waitematā embayment's and other harbour arms. Consequently, the sand-based FWMT inputs appear to account for 4-44% of observed accumulation rates.

Based on this analysis, the FWMT might significantly underestimate influx of terrestrial sand (by approximately 20 times) delivered to the Waitematā, mud accounts for considerable input and deposition (latter analysis included only sand) and/or NIWA's observations include considerable ingress of marine sand (much of the domain has potentially beneficial effects of reduced terrestrial sediment dominance).

A recent bathymetry survey from Discovery Marine Limited (DML), in the vicinity of the Auckland Harbour bridge, suggests the presence of 3 to 4 m sand waves, on the eastern side of the bridge (unpublished data). It seems feasible that the sand waves would migrate through the bridge and represent a considerable sediment source to the central harbour domain.

For the outer Henderson Creek location where terrestrial fine sediment could be expected to settle, modelled sedimentation rate was about 5 mm/yr for the field observation while the model predicted a rate of about 7.3 mm/yr showing reasonable agreement.

Notably, Sedimentation rates of 20–30 mm/year over the last ~50 years are typical of Auckland's tidal creeks ((NIWA, 1993); (NIWA, 1999); (NIWA, 1997); (Swales et al, 2002b). The latter are well represented by the FWMT-DHI modelled outputs in tidal creeks:

- Whau Creek (2.7 to 10.3 mm);
- Henderson Creek (7.3 mm to 35.6 mm)
- Rangitopuni Stream (16.2 mm);
- Brighams Creek (32.5 mm);
- Paremoremo (6 mm);
- Lucas Creek (3.6 to 4.3 mm);
- Helleys (2.5 mm)

However, it is clear that the FWMT-DHI model cannot be expected to match observed deposition in the central part of the Waitematā Harbour, without either additional marine sources (primarily of sand) and/or very marked increases in sediment sources from land or additional marine sources (noting direct sediment sources from coastal activities are unlikely and that the FWMT has generally simulated sediment load estimates with satisfactory or better ability – Auckland Council, 2021).

A rough validation has been undertaken comparing the average mud content from observations with the mud content percentage predicted by sediment fate model (see Table 5-2). For the observations, the range of mud content percentages for each site is also presented to illustrate how dynamic some sites are over an annual modelled period.

None of the central Waitematā Harbour sites have been included in this assessment, since these areas are dominated by sand (potentially, marine sand) and for the reasons discussed above, the model does not replicate the transport of sand into the central harbour.

In our professional experience, there is a reasonable agreement between observations and predictions, especially if the potential range of mud content is considered. The model is overall predicting well where mud is likely to settle long term in lower energy environments.

Two sub-estuary locations are notable for lower FWMT-DHI model performance, Rangitopuni Creek and Herald Island north. For the Rangitopuni Creek location, it is suspected this is an error in bathymetry (i.e. the location is shallower in model than reality) resulting in less mud deposition.

Herald island north has very little sedimentation predicted in the model at this location (approximately 10 µm) and what is depositing is silt and clay. It is suspected that during large events in the Rangitopuni Stream, terrestrial sourced sand deposits in this area, during these events mud will also deposit here as well, however it more likely to be resuspended subsequently. This would explain the observed low mud content for this location.

However, the daily time step provided for FWMT inflows, most likely results in sand depositing closer to source compared with if a higher time step was available. A higher time step (i.e. 15 minutes) would better represent the higher flows that occur due to the flashy nature of the flood events, which would likely keep the sand in suspension for a longer duration allowing it to deposit further from the source than is currently modelled. This is a limitation of the sediment fate model, resulting from the FWMT inputs.

Table 5-2 Comparison of observed (2003 to 2017 – see Section 4.4) and predicted mud content percentage.

Location	Mud Content Percentage		
	Observations	Predictions	Difference
Upper Main Channel	89 (83 – 95)	92	3
Rangitopuni Creek	96 (91 – 99)	27	-69
Brigham Creek	89 (76 – 98)	83	-6
Central Main Channel	26 (18 - 32)	44	18
Lucas Creek	34 (14 – 71)	59	25
Herald Island North	13 (1 – 35)	82	69
Herald Island Waiarohia Inlet	16 (7 – 29)	45	29
Hellyers Creek	51 (31 – 89)	93	42
Hobsonsville Opposite	69 (50 – 88)	46	-23

5.3.2 Nutrients

An overview of the validation of the TN and TP model is presented in Table 5-3 and Table 5-4, with a range of T_{90} decay rates, which were simulated.

Auckland Council has historically collected water quality samples within Waitematā Harbour via boat at approximately 10 minutes to 2.5 hours after high tide (Auckland Council, 2019). Comparisons with model predictions have therefore been undertaken for one hour before high tide to 3 hours after high tide. Notably, earlier Safeswim monitoring demonstrated samples collected via helicopter poorly represented (biased) wet weather events (when contamination levels are typically elevated) as the helicopter could not be safely operated in wet or windy weather. For this reason, the medians of observations and predictions have been compared. Furthermore, in any given year only a limited number of samples are collected at each site (order of 10-12). Therefore, model predictions from the year-long simulation have been compared against all available data for each site (e.g., short but intensive modelling outputs compared to long but infrequent observations).

The best overall model performance was achieved with a T_{90} of 8 days for TN and no decay for TP and with an initial condition and boundary condition of 0.01 mg/l for both TN and TP.

Vant and Williams (1992) derived a T_{90} value of 20 days for the north-east sector of the Manukau Harbour. Caffery et al. (1993) derived a T_{90} value of 22 days for TN based on laboratory experiments using marine sediments. Earlier modelling in north-east sector of the Manukau (Black et al. 1995) derived T_{90} values of 8 and 25 days for late summer and early summer respectively. For the work carried out for the Porirua Whaitua project (DHI, 2019) a seasonally varying T_{90} decay rate of between 9 and 26 days was used to match observed data and modelled seasonal water column estimates across a range of sites within Porirua harbour. A T_{90} of 8 days is on the high side, especially if applied across the whole year, however using a lower T_{90} resulted in a significant overprediction of TN within the inner harbour arms.

To the best of our knowledge, there is little literature available with a New Zealand context, for decay of TP in ocean receiving environment. However, DHI have previously obtained a good fit within Porirua Harbour using a T_{90} of 45 days (DHI, 2019).

Table 5-3 Comparison of median observed (2003 to 2017 – see Section 4.4) and predicted TN concentrations with T90 decay of 8 days and 25 days.

Location	Observations (mg/l)	Predictions (mg/l)	
		T90 – 8 days	T90 – 25 days
Chelsea	0.057	0.014	0.031
Whau Creek	0.079	0.063	0.115
Henderson Creek	0.094	0.096	0.149
Hobsonville	0.059	0.045	0.085
Paremoremo	0.156	0.168	0.248
Rangitopuni	0.349	0.421	0.489
Brighams Creek	0.315	0.369	0.440

Table 5-4 Comparison of median observed and predicted TP concentrations with no decay or T90 of 45 days.

Location	Observations (mg/l)	Predictions (mg/l)	
		No decay	T90 – 45 days
Chelsea	0.026	0.016	0.005
Whau Creek	0.030	0.033	0.019
Henderson Creek	0.031	0.035	0.022
Hobsonville	0.028	0.026	0.014
Paremoremo	0.036	0.038	0.026
Rangitopuni	0.044	0.040	0.032
Brighams Creek	0.042	0.031	0.023

5.3.3 Heavy Metals

Results for metal deposition in Inner and Outer Waitemata Harbour are presented in Appendix A.

The metal accumulation was calibrated against the available sediment metals monitoring data from 2003-2017 (Section 3.2.3) for both Zinc and Copper. This involved setting the surface mixed layer depth to 4 cm as was assumed in the South-East Manukau Study (ARC, 2008) and adjusting the particulate loss term which defines the degree of mixing between the incoming and legacy sediments and the effective net loss to dissolved form of metals that takes place. This loss term is the combination of the source particulate/dissolved partitioning and the subsequent desorption of metals to the water column from particulates in both the sediments and the water column.

For Zinc and Copper, to achieve a reasonable level of calibration the particulate loss term in the metal accumulation model was set to 75%. These values were based on studies carried out in Auckland and across New Zealand (Ellwood et. al. 2008, Kelly 2006, Mills et. al. 2006, Zitoun 2019).

Results are discussed in the context of the (ERC) guideline criteria set out in Auckland Regional Council (2004) and summarized in Table 5-5 for Zinc and Copper.

Table 5-5 Environmental Response Criteria (ERC) for Zinc and Copper in sediments (mg/kg) from Auckland Regional Council (2004).

Metals	Green	Amber	Red
Zinc	< 124	124-150	> 150
Copper	< 19	19-34	> 34

The comparison plots of the metal accumulation against field concentrations of Zinc and Copper are shown in Figure 5-9 and Figure 5-10. For Zinc, in three out of ten sites, the observed and modelled metal concentration in sediments fall in the same category (Green). For Copper, in one out of ten sites, the observed and modelled metal concentration in sediment falls in the same category (Amber). The possible reasons for lower modelled coastal metal accumulation rates than observed, could include:

1. The modelled catchment (FWMT) loads of metals are lower than actual; and
2. The modelled catchment (FWMT) loads of sediments are higher than actual (unlikely – see above); and
3. Direct metal sources from marinas and industrial discharges to coast, are considerable;
4. Legacy metal sources from earlier terrestrial discharges (remobilised by disturbance and/or REDOX) are considerable; and
5. Sub-estuary configuration is unable to represent the variety of accumulation rates with existing mesh sizing.

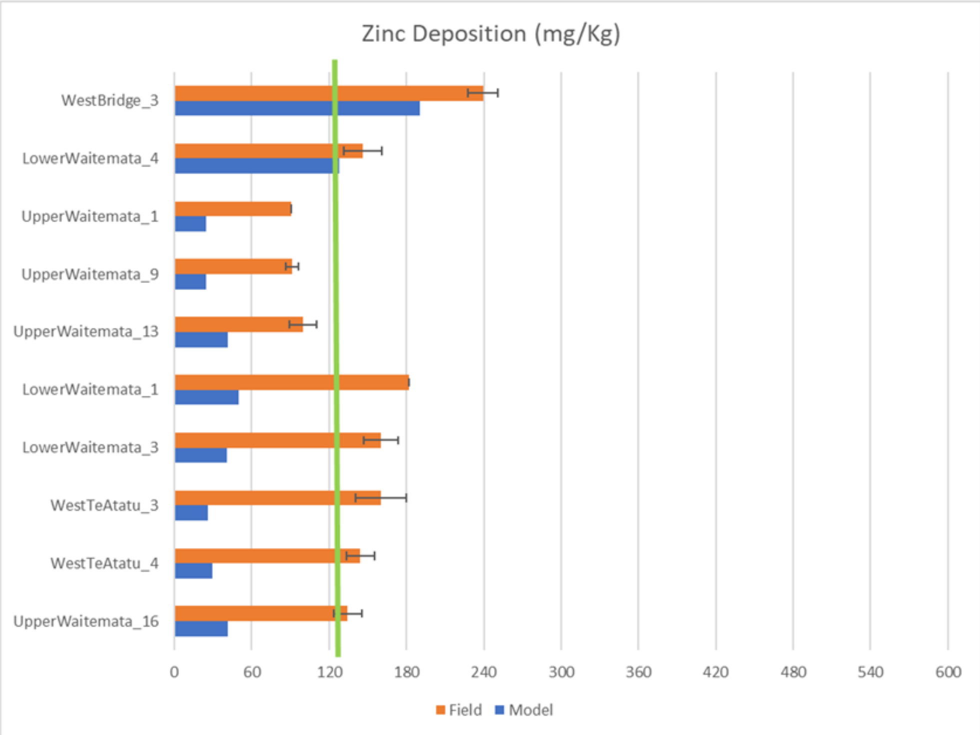


Figure 5-9 Comparison of the predicted surface sediment Zinc concentrations (mg/kg) against field data.

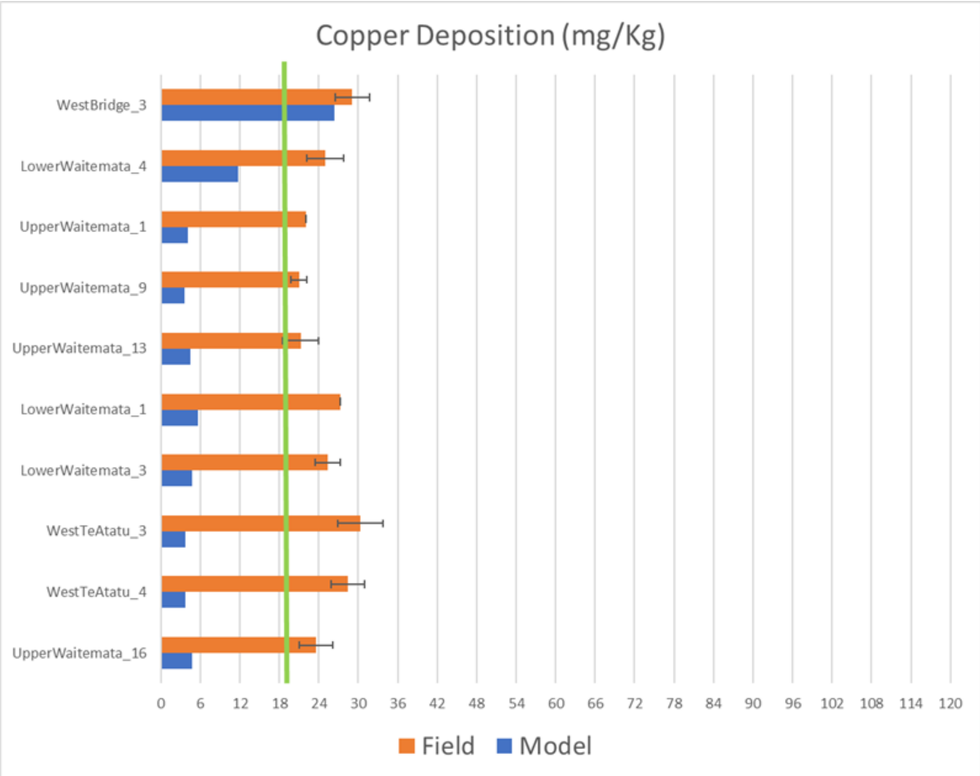


Figure 5-10 Comparison of the predicted surface sediment Copper concentrations (mg/kg) against field data.

6 CREST Portal Set Up and Navigation

This section provides an overview of the simulations and the data processing required to set up the CREST portal. A brief overview of the system is provided to support navigation and use of the portal.

6.1 CREST Portal Set Up

DHI have undertaken the year-long simulations for the identified typical year for TSS, TN and TP. This provided predictions of baseline receiving environment levels for the whole model domain for loads of contaminants TN, TP, TSS, Cu and Zn.

The model domain was divided into sub-estuary polygons. This included the beaches and the main channels of the harbour. The sub-estuary polygons are presented in Figure 6-1, with 49 defined for the inner Waitematā and 37 defined for the outer Waitematā.

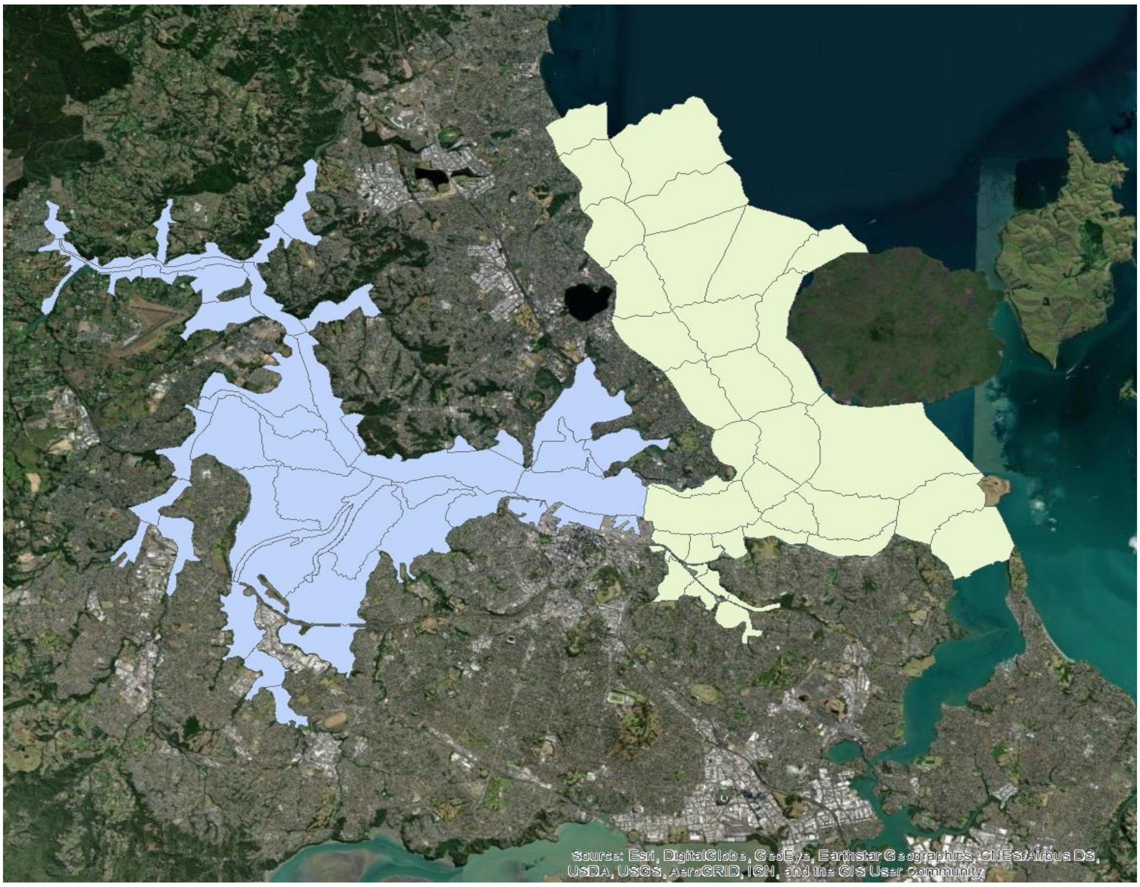


Figure 6-1 Sub-estuary polygons. Inner Waitematā (blue) and Outer Waitematā (green).

The baseline results have been processed and presented in the following way:

- Sedimentation – mean of the final sedimentation (mm) for the area of the model domain contained within the polygon. Deposition below 10 µm is ignored from this assessment, since in practical terms it is below the diameter of a clay particle, and it can skew the model predictions if included. It should be noted that using this approach, terrestrial sourced deposition may only be occurring over a small percentage of the polygon area.

- Nutrients – mean of the mean annual nutrient (TN and TP) concentration for the area of model domain contained within the polygon.
- Heavy Metals – mean of the metal (Cu and Zn) accumulation over a 50-year time frame for the area of the model domain contained within the polygon.

For both sediments and nutrients, a connectivity matrix has been developed between FMWT inflows and each sub-estuary within the model domain. This requires multiple simulations to identify the contribution of each contaminant to each sub-estuary. With this approach the impact on the receiving environment of reducing catchment loads can be estimated, without having to undertake additional simulations.

6.2 CREST Portal Navigation

Auckland Council have been provided access to an intuitive web based CREST system (http://web.nz.dhigroup.com/WaitematāCrest/). This allows the council to undertake their own investigations into the impact of load reductions on the receiving environment. For all the defined receiving environment sub-estuaries, Council can scale FWMT loads from 0 to 100% and assess the impacts of these load reductions on the receiving environment. The portal does not require detailed instructions to navigate, however a brief overview if provided below.

Once logged in the user can access either the inner or outer Waitematā Harbour CREST (see Figure 6-2).

Selecting one of these options then presents two tabs. One tab which illustrates the connectivity between FWMT inflows and defined sub-estuaries for sediment and nutrients from the year long simulation (see Figure 6-3). This information helps the user make informed decisions around which FWMT contaminant inflows to reduce to have a significant positive impact in selected sub-estuaries.

The second tab provides an overview of the baseline results. The user can toggle between the different contaminants whether the agreed thresholds are exceeded within each sub-estuary polygon is displayed. An example of this is presented in Figure 6-4. Green indicates less than 2 mm/yr, yellow 2 – 5 mm/yr and red greater than 5 mm/yr. Note clicking on a sub-estuary displays the rate to the right.

The user can run a scenario manager to reduce each of the contaminants loads separately by a percentage between 0-99%. This can be done for all FWMT inflows or user selected FWMT inflows. The three main pages of the scenario manager is presented in Figure 6-5. Each scenario is saved, so that user can access the scenario when required.

Once the scenario has run, a spatial view of whether guidelines for criteria is met is presented, one the user selects the scenario (select scenario menu in top right hand of menu), with the user able to toggle between the different contaminants (see Figure 6-6).

The user can then click on any sub-estuary polygon where a plot of baseline and scenario results will be presented. In this way the user is able to assess whether predicted results are close to achieving the guideline, for both the baseline or contaminant reduction scenario (see (see Figure 6-6).

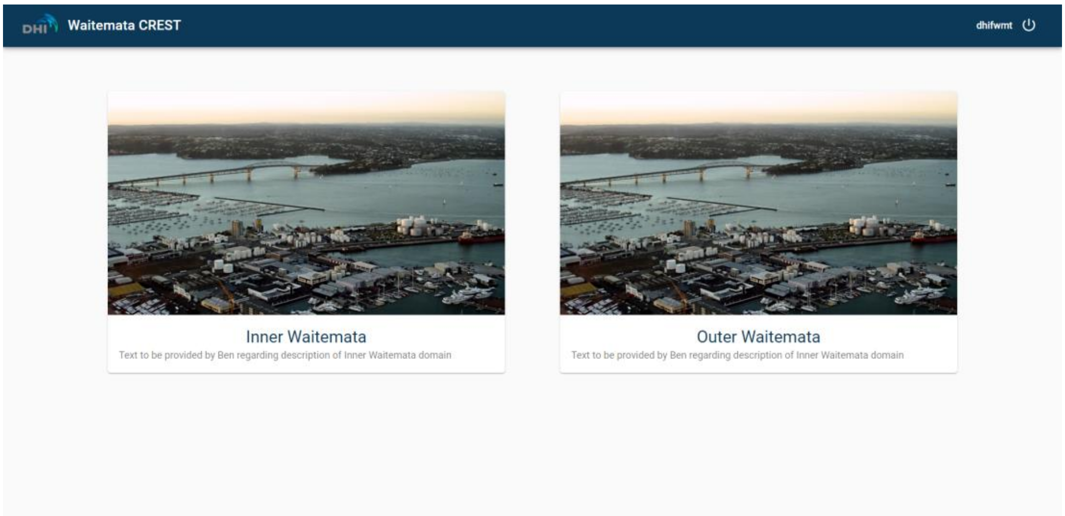


Figure 6-2 Homepage for Waitematā Harbour CREST.

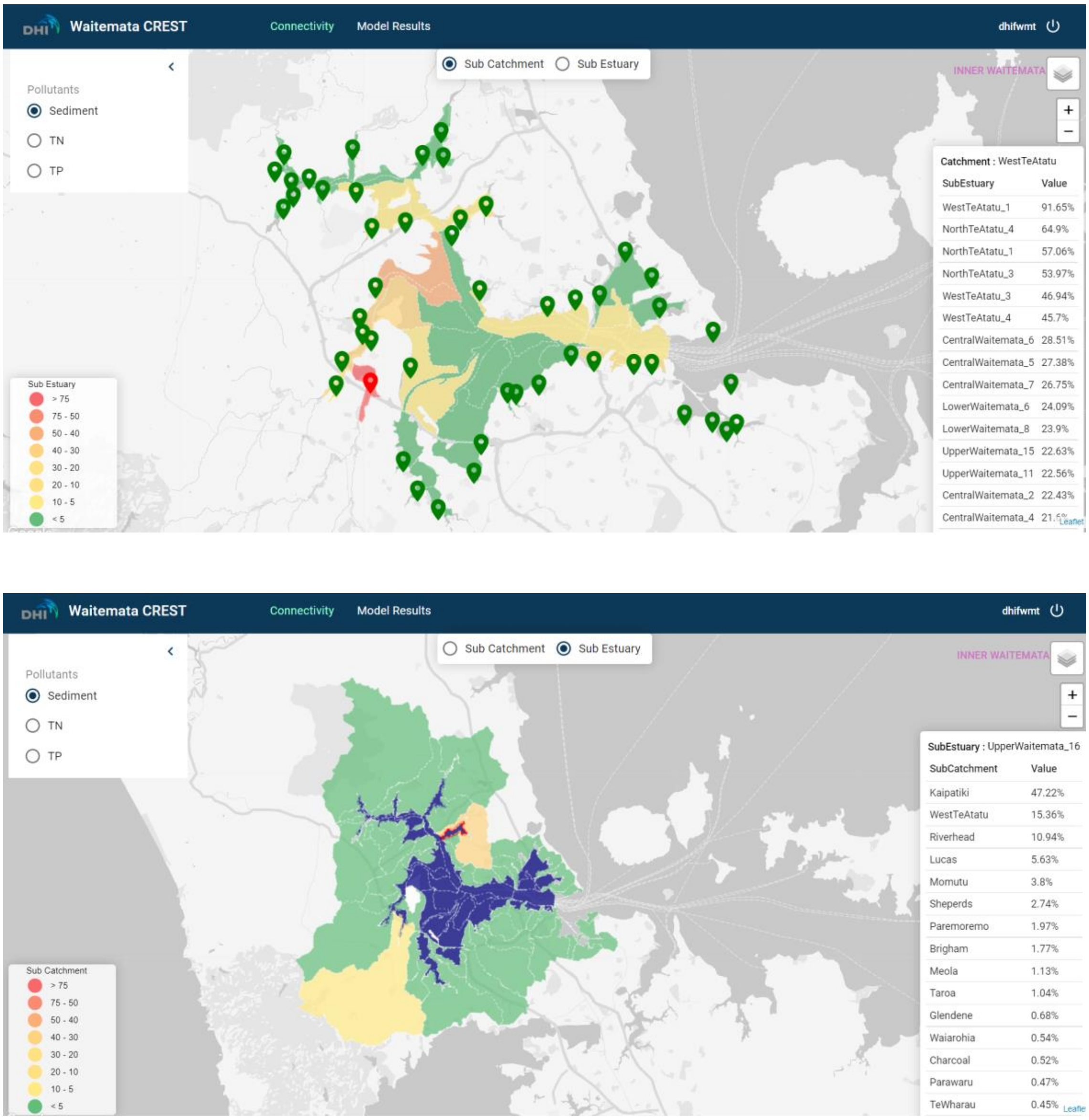


Figure 6-3 Connectivity tab for sediments.

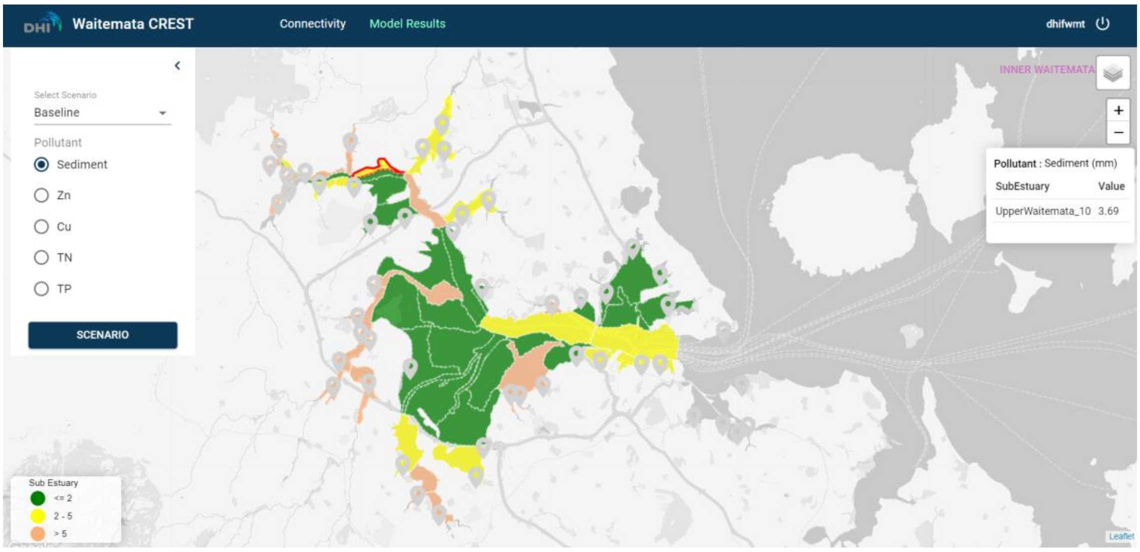


Figure 6-4 Example of baseline sedimentation tab for sedimentation and whether threshold rate is exceeded. Green indicates less than 2 mm/yr, yellow 2 – 5 mm/yr and red greater than 5 mm/yr. Note clicking on a sub-estuary displays the rate to the right.

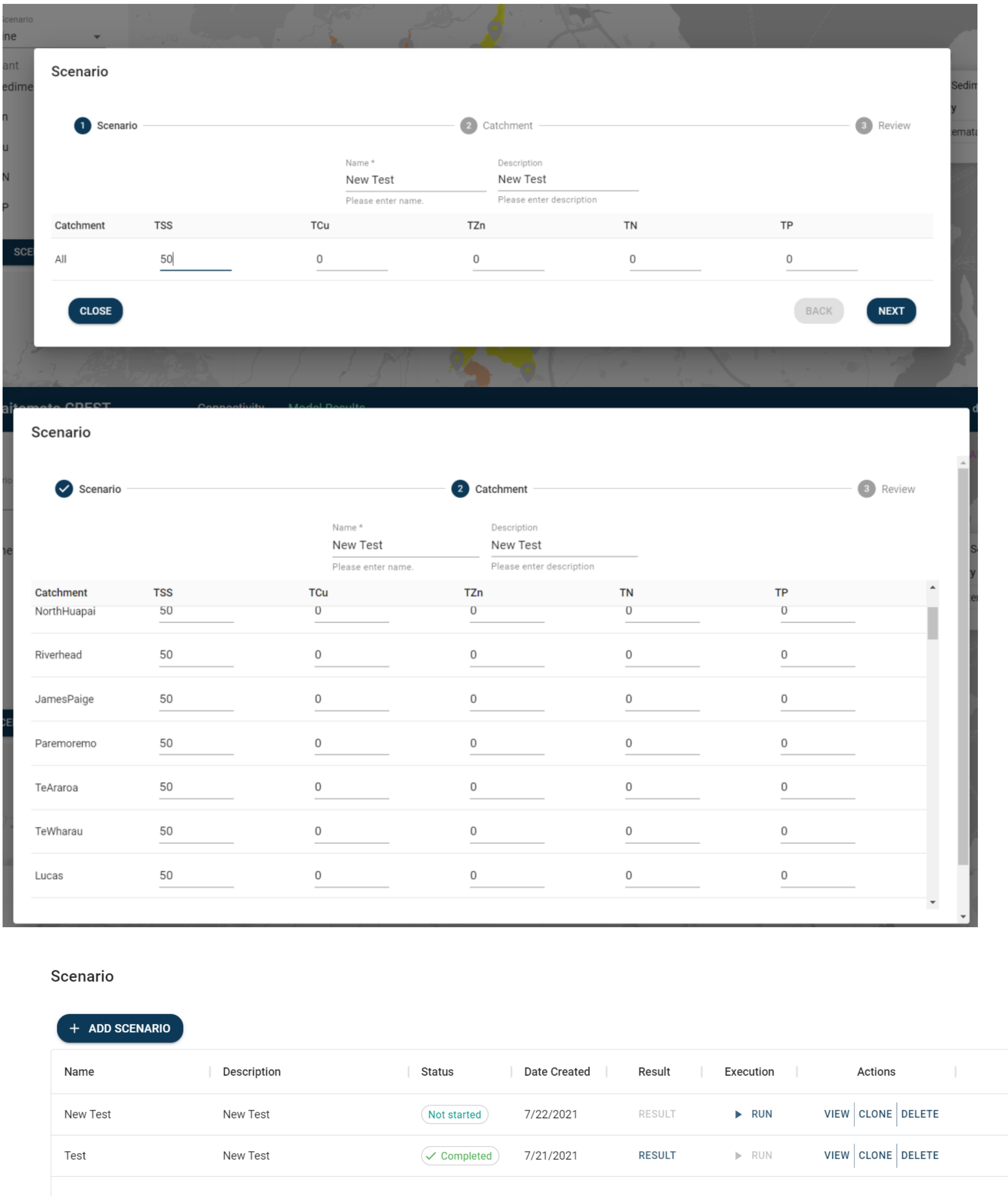


Figure 6-5 Scenario manager- global catchment reduction (top), individual catchment reduction (middle) and scenario execution and view details page.

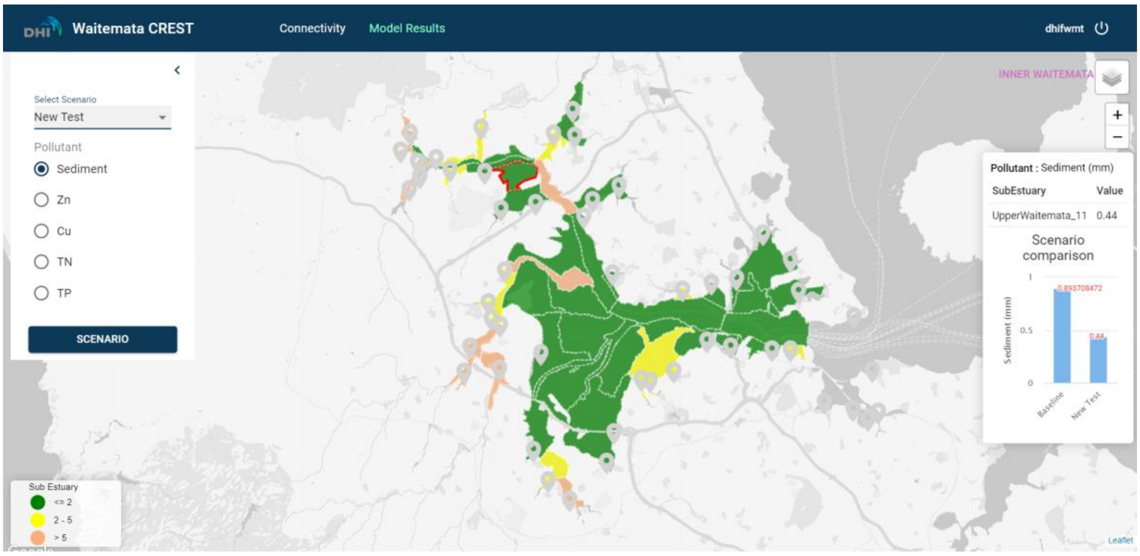


Figure 6-6 Sub-estuary polygon comparison of baseline and contaminant reduction scenario with guideline value indicated.

7 Recommendations

To obtain a better understanding of the current rates of deposition within Auckland Estuaries and Harbour, we recommend Auckland Council initiate a programme of sediment plate data. Greater Wellington Regional Council and Waikato Regional Council are collecting this type of data and it is proving very insightful (DHI, 2019). It is also incredibly useful for validating sediment fate models (DHI, 2019), which shows the accuracy that can be obtained.

Targeted wet weather sampling of nutrient, would further illustrate robustness of approach for modelling fate of nutrients.

Sensitivity tests should be undertaken to determine the impacts of using a daily time step for FWMT outputs compared with a smaller time step of 1 hour. It is suspected the daily time step maybe causing underprediction of the spread of terrestrial sourced sand in the tidal creeks and intertidal zones.

If there are more recent and appropriate thresholds for contaminants, either newly proposed or that project team were not aware of. then these should be incorporated into CREST and supporting document moving forward. However there is a need for better contaminant guidance of coastal state with which to ensure the effects of terrestrial and freshwater resource use are managed for coastal outcome (e.g., akin to the National Objective Framework for assessing acute and chronic state).

Moving forward the focus can shift to areas less exposed to significant wave energy, such as tidal creeks; estuaries and harbours as opposed to the open coast. The open coast is shown to be well flushed and beaches unlikely to exceed contaminant thresholds

If there are any significant updates and improvements to the FWMT, consideration should be given to rerunning the year-long simulation to assess any changes to the contaminant model calibration performance and the predicted current state within the sub-estuaries.

Investigate the potential for additional sources of heavy metals to the receiving environment, whether local point sources (not included in the model) or higher loads from catchments than what is predicted by FWMT

Run sediment fate model for longer periods than one year (i.e. 5 years), to investigate impacts that potential remobilisation of deposited sediment, has on long term sedimentation rates within sub-estuaries.

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Appendix A – Overview of FWMT Sources for TSS, TN, TP, Cu and Zn

Table A-1 Overview of FWMT sources for TSS.

Sub-catchment	Mean flow (m3/s)	Sand Mass (Kg)	Silt Mass (Kg)	Clay Mass (Kg)	Total Mass (Kg)	Percentage Mud (%)
West Te Atatu	1.380	3129497	1938498	5219420	10287416	69.6
Momutu	0.610	998737	800339	1926721	3725798	73.2
Riverhead	1.100	787295	871419	1893039	3551754	77.8
Otara	0.513	502180	679741	1203148	2385070	78.9
Taroa	0.443	426320	521929	1118621	2066871	79.4
Pakuranga	0.449	310693	225146	583853	1119693	72.3
Lucas	0.360	284220	227672	574931	1086824	73.8
Meola	0.362	260208	212082	488166	960456	72.9
Brigham	0.291	300907	145897	497417	944222	68.1
Castor	0.256	153566	145477	509126	808170	81.0
Glendene	0.120	122403	150239	447808	720451	83.0
Kaipatiki	0.164	151084	174209	372249	697544	78.3
Wairau	0.094	131181	172363	358811	662356	80.2
Paremoremo	0.130	139254	121968	384322	645545	78.4
Orakei	0.184	116437	62979	245185	424602	72.6
Oakley	0.242	100197	107331	216234	423764	76.4
Motions	0.264	114725	81291	198189	394207	70.9
Westhobson	0.160	103614	67081	215720	386416	73.2
Parawaru	0.061	72068	88729	178820	339618	78.8
Hillcrest	0.092	70973	73677	189063	333714	78.7
Manutewhau	0.070	73823	66153	165704	305682	75.8
Sulphur	0.050	52115	43925	158272	254313	79.5
Coxs	0.088	50174	53603	138418	242195	79.3
Omaru	0.096	52008	48935	112671	213614	75.7
Tewharau	0.070	49690	40768	122608	213067	76.7
Waiarohia	0.075	62066	24914	122627	209607	70.4
Curlew	0.131	57769	35311	114189	207270	72.1
Soldiers	0.025	28640	38853	130766	198260	85.6
Waipareira	0.063	52078	24344	110788	187211	72.2
Charcoal	0.036	29664	35133	121008	185805	84.0
Viaduct	0.074	60566	29591	90352	180510	66.4
Port Auckland	0.078	57663	28345	87366	173374	66.7

Sub-catchment	Mean flow (m3/s)	Sand Mass (Kg)	Silt Mass (Kg)	Clay Mass (Kg)	Total Mass (Kg)	Percentage Mud (%)
Eastdale	0.057	41006	26896	92932	160835	74.5
Chelsea	0.037	26310	37027	87643	150981	82.6
Ngataringa	0.048	28742	24060	87025	139828	79.4
Southeastern	0.069	43438	17338	76696	137473	68.4
Pourewa	0.045	28721	23165	78465	130352	78.0
Westhaven	0.043	39033	20538	63375	122948	68.3
East Te Atatu	0.042	24652	18690	70438	113780	78.3
Halfmoon	0.045	25041	17919	66012	108972	77.0
Panmure	0.058	32998	14565	59027	106591	69.0
Takapuna	0.031	22849	18816	64836	106502	78.5
Teararoa	0.019	24139	16029	65100	105269	77.1
Glendowie	0.057	23804	16138	56359	96302	75.3
Shoal	0.027	18062	17036	60498	95597	81.1
Teokoriki	0.031	20916	14961	58471	94349	77.8
Rarawaru	0.048	26842	15810	46669	89322	69.9
Torpedo	0.020	16098	16063	56594	88756	81.9
Redbluff	0.029	18120	17924	51737	87782	79.4
Taiorahi	0.038	22153	17209	45180	84543	73.8
Merewhira	0.013	19653	12215	50993	82862	76.3
East Massey	0.016	12915	15266	52347	80529	84.0
Little Shoal	0.021	17011	18608	43032	78653	78.4
James Paige	0.014	19601	10081	45140	74823	73.8
Mission	0.030	18651	12011	41355	72018	74.1
Okahu	0.022	17407	14523	39167	71097	75.5
East Hobson	0.029	16826	12830	39061	68719	75.5
Sheperds	0.019	12678	10983	37617	61279	79.3
Mt. Wellington	0.041	21156	7018	32707	60882	65.2
Orukuwai	0.021	11116	10737	37929	59782	81.4
St. Heliers	0.029	15768	8238	32546	56553	72.1
Riverina	0.028	15126	6340	26882	48348	68.7
Thorne	0.052	8495	9710	27509	45715	81.4
Tamaki	0.024	11321	6205	26882	44409	74.5
Wakaaranga	0.021	11324	6533	25275	43133	73.7
Kohimarama	0.033	12480	6274	22073	40829	69.4
South Huapai	0.013	11921	4230	22233	38385	68.9
North Huapai	0.015	14090	3920	20072	38084	63.0
Kotukutuku	0.018	7199	5321	20561	33082	78.2
Riverlea	0.012	8624	2018	13208	23851	63.8
North Pakuranga	0.012	6254	3053	12119	21426	70.8

Sub-catchment	Mean flow (m3/s)	Sand Mass (Kg)	Silt Mass (Kg)	Clay Mass (Kg)	Total Mass (Kg)	Percentage Mud (%)
Erin	0.004	3379	3063	9265	15708	78.5
Home	0.004	3379	3063	9265	15708	78.5

Table A-2 Overview of FWMT sources for TN, TP, Zn and Cu.

Sub-catchment	Mean flow (m3/s)	TN (kg)	TP (kg)	TZn (kg)	TCu (kg)
West Te Atatu	1.380	85212	16904	459	138
Momutu	0.610	22240	6045	178	53
Riverhead	1.100	73259	7821	158	56
Otara	0.513	13104	1829	281	47
Taroa	0.443	12758	1590	229	48
Pakuranga	0.449	12127	654	276	31
Lucas	0.360	8196	558	184	26
Meola	0.362	65543	13115	465	133
Brigham	0.291	13861	780	36	11
Castor	0.256	5161	280	177	21
Glendene	0.120	2429	111	62	11
Kaipatiki	0.164	2809	200	70	14
Wairau	0.094	1523	91	47	9
Paremoremo	0.130	5802	944	21	7
Orakei	0.184	11237	1836	109	19
Oakley	0.242	10505	1346	131	23
Motions	0.264	10184	1609	115	23
West Hobson	0.160	21568	3992	131	28
Parawaru	0.061	1043	65	23	6
Hillcrest	0.092	1942	109	48	8
Manutewhau	0.070	1354	65	25	5
Sulphur	0.050	1584	121	31	5
Coxs	0.088	15624	3442	117	34
Omaru	0.096	13791	2206	89	17
Tewharau	0.070	1015	58	18	3
Waiarohia	0.075	3041	102	8	2
Curlew	0.131	3700	176	70	9
Soldiers	0.025	404	33	8	2
Waipareira	0.063	1025	40	14	2
Charcoal	0.036	681	31	11	2
Viaduct	0.074	15299	2670	80	12
Port Auckland	0.078	9952	1508	60	11

Sub-catchment	Mean flow (m3/s)	TN (kg)	TP (kg)	TZn (kg)	TCu (kg)
Eastdale	0.057	4687	653	68	9
Chelsea	0.037	1875	230	19	4
Ngataringa	0.048	1319	50	25	3
Southeastern	0.069	1848	71	65	6
Pourewa	0.045	1326	127	21	3
Westhaven	0.043	5078	1003	45	9
East Te Atatu	0.042	871	33	17	2
Halfmoon	0.045	1147	32	19	2
Panmure	0.058	1562	41	32	4
Takapuna	0.031	1847	258	21	3
Teararoa	0.019	733	169	4	1
Glendowie	0.057	1403	132	23	3
Shoal	0.027	661	21	11	1
Teokoriki	0.031	472	33	7	1
Rarawaru	0.048	2653	88	9	1
Torpedo	0.020	669	16	13	1
Redbluff	0.029	835	74	12	2
Taiorahi	0.038	848	78	18	2
Merewhira	0.013	624	164	2	0
East Massey	0.016	330	15	5	1
Little Shoal	0.021	435	23	12	1
James Paige	0.014	675	200	1	0
Mission	0.030	2701	465	18	3
Okahu	0.022	2693	498	15	4
East Hobson	0.029	3844	680	22	4
Sheperds	0.019	1004	128	10	1
Mt. Wellington	0.041	1284	33	26	2
Orukuwai	0.021	436	15	7	1
St. Heliers	0.029	999	63	14	2
Riverina	0.028	996	43	17	2
Thorne	0.052	1114	210	13	2
Tamaki	0.024	1051	132	12	2
Wakaaranga	0.021	708	38	9	1
Kohimarama	0.033	643	64	15	2
South Huapai	0.013	2157	40	1	0
North Huapai	0.015	1377	14	1	0
Kotukutuku	0.018	948	32	2	0
Riverlea	0.012	1779	49	1	0
North Pakuranga	0.012	461	31	5	0

Sub-catchment	Mean flow (m3/s)	TN (kg)	TP (kg)	TZn (kg)	TCu (kg)
Erin	0.004	596	140	5	1
Home	0.004	596	140	5	1

Table A-3 Source concentrations of Zinc and Cooper based on predicted sediment and metal loads from the FWMT.

Sites	Zinc (mg/Kg)	Copper (mg/Kg)
Brigham	72.4	22.1
Castor	347.7	41.2
Charcoal	90.9	16.5
Chelsea	216.8	45.6
Coxs	845.3	245.6
Curlew	613.0	78.8
Eastdale	731.7	96.8
East Hobson	563.2	102.4
East Massey	95.5	19.1
East Te Atatu	241.3	28.4
Erin	539.7	107.9
Glendene	138.5	24.6
Glendowie	408.1	53.2
Halfmoon	287.8	30.3
Hillcrest	253.9	42.3
Home	539.7	107.9
James Paige	22.2	0.0
Kaipatiki	188.0	37.6
Kohimarama	679.6	90.6
Kotukutuku	97.3	0.0
Little Shoal	278.9	23.2
Lucas	320.0	45.2
Manutewhau	150.9	30.2
Meola	952.5	272.4

Sites	Zinc (mg/Kg)	Copper (mg/Kg)
Mission	435.3	72.5
Momutu	92.4	27.5
Motions	580.3	116.1
Mt. Wellington	794.9	61.1
Ngataringa	287.3	34.5
North Huapai	49.8	0.0
North Pakuranga	412.6	0.0
Oakley	605.8	106.4
Okahu	383.0	102.1
Omaru	789.9	150.9
Orakei	444.6	77.5
Orukuwai	184.6	26.4
Otara	233.6	39.1
Pakuranga	472.7	53.1
Panmure	542.1	67.8
Parawaru	128.6	33.6
Paremoremo	52.8	16.1
Port Auckland	686.8	125.9
Pourewa	267.6	38.2
Rarawaru	192.8	21.4
Red Bluff	231.9	38.7
Riverhead	83.5	29.6
Riverina	632.4	74.4
Riverlea	75.7	0.0
Sheperds	265.8	26.6
Shoal	181.8	16.5
Soldiers	61.2	15.3
Southeastern	847.5	78.2
South Huapai	45.0	0.0

Sites	Zinc (mg/Kg)	Copper (mg/Kg)
St. Heliers	430.2	61.5
Sulphur	195.9	31.6
Taiorahi	398.4	44.3
Takapuna	323.9	46.3
Tamaki	446.4	74.4
Taroa	204.7	42.9
Teararoa	61.4	15.4
Teokoriki	119.7	17.1
Tewharau	146.8	24.5
Thorne	472.6	72.7
Torpedo	229.7	17.7
Viaduct	885.4	132.8
Waiarohia	65.2	16.3
Waipareira	126.4	18.1
Wairau	131.0	25.1
Wakaaranga	356.1	39.6
Westhaven	710.1	142.0
West Hobson	607.3	129.8
West Te Atatu	87.9	26.4

Appendix B – Predicted Zinc and Copper Deposition in Inner and Outer Waitemata Harbour

Table B-1 Zinc and Copper deposition in Inner Waitemata Harbour

Sub Estuary	Zinc (mg/Kg)	Copper (mg/Kg)
CentralWaitemata_7	71.43	8.19
CentralWaitemata_5	74.41	8.82
CentralWaitemata_6	68.39	7.80
WestBridge_2	0.00	0.00
WestBridge_4	25.90	3.46
CentralWaitemata_3	57.90	5.33
CentralWaitemata_2	40.56	4.81
LowerWaitemata_4	127.78	11.69
NorthTeAtatu_5	1.57	0.19
LowerWaitemata_7	0.91	0.11
WestBridge_3	190.65	26.33
NorthTeAtatu_3	20.22	2.72
LowerWaitemata_9	1.41	0.17
CentralWaitemata_1	41.16	3.92
CentralWaitemata_4	51.41	6.35
UpperWaitemata_4	24.37	3.69
UpperWaitemata_5	23.04	3.14
UpperWaitemata_3	22.21	3.83
UpperWaitemata_7	33.07	4.07
UpperWaitemata_9	24.60	3.56
UpperWaitemata_8	32.18	3.70
UpperWaitemata_13	41.50	4.46
UpperWaitemata_16	41.28	4.69
UpperWaitemata_11	24.14	3.08
WestTeAtatu_1	22.58	3.42
WestTeAtatu_2	23.24	3.55
WestTeAtatu_3	26.10	3.76
NorthTeAtatu_4	28.91	4.09
WestTeAtatu_4	29.31	3.74
NorthTeAtatu_6	24.35	3.40
UpperWaitemata_10	27.31	3.73
UpperWaitemata_12	35.39	4.20
LowerWaitemata_1	49.99	5.69
LowerWaitemata_3	40.85	4.79
LowerWaitemata_10	1.36	0.17
NorthTeAtatu_1	23.10	3.14
UpperWaitemata_1	24.88	4.09
LowerWaitemata_8	18.81	2.08

Sub Estuary	Zinc (mg/Kg)	Copper (mg/Kg)
UpperWaitemata_6	1.05	0.12
UpperWaitemata_14	40.81	4.83
NorthTeAtatu_2	24.98	3.03
LowerWaitemata_2	42.49	4.79
LowerWaitemata_5	4.30	0.54
LowerWaitemata_6	20.35	2.52
UpperWaitemata_2	26.18	3.93
WestBridge_5	44.58	4.86
WestBridge_6	48.63	5.98
UpperWaitemata_15	28.58	3.68
WestBridge_1	48.56	5.85

Table A-4 Zinc and Copper deposition in Outer Waitemata Harbour

Sub Estuary	Zinc (mg/Kg)	Copper (mg/Kg)
Hobson_7	63.09	13.27
Hobson_8	22.47	4.68
Hobson_2	38.17	7.18
Hobson_4	118.21	21.97
Hobson_3	3.90	0.79
Devonport_1	4.47	0.90
Hobson_9	1.07	0.23
Hobson_11	1.63	0.35
Hobson_10	28.20	5.95
Hobson_1	74.31	13.26
Hobson_5	133.23	28.41
Kohimarama_1	1.68	0.31
OuterChannel_2	0.00	0.00
Devonport_2	0.00	0.00
Rangitoto_3	0.00	0.00
Northshore_7	0.00	0.00
Takapuna_1	0.00	0.00
Northshore_3	0.00	0.00
Northshore_5	0.00	0.00
Northshore_1	0.00	0.00
Takapuna_2	0.00	0.00
Kohimarama_2	0.77	0.16
OuterChannel_5	0.00	0.00
Tamaki_2	0.85	0.16
OuterChannel_4	0.00	0.00
Tamaki_1	0.87	0.16
Rangitoto_2	0.00	0.00
OuterChannel_3	0.00	0.00

Sub Estuary	Zinc (mg/Kg)	Copper (mg/Kg)
Hobson_6	61.03	12.21
Northshore_4	0.00	0.00
Northshore_2	0.00	0.00
OuterChannel_6	0.00	0.00
OuterChannel_1	0.00	0.00
Mission_2	0.72	0.15
Mission_1	0.74	0.15
Northshore_6	0.00	0.00
Rangitoto_1	1.34	0.28