Okura Wēiti Marine Receiving Environment Modelling Technical Summary

Auckland Council

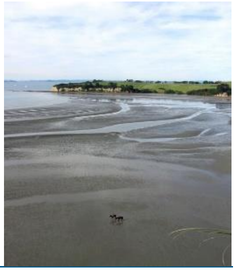
Report 44801163/04

December 2019

Okura Wēiti Marine Receiving Environment Modelling Technical Summary

Prepared for Auckland Council

Represented by Tom Porter



Karepiro Bay looking towards Dacre Point, Auckland Hiking Group

Project manager	John Oldman

Project number	44801474
Approval date	12th Dec 2019
Revision	Final
Classification	Open

DHI Water & Environment Ltd• B:HIVE, Smales Farm• 0622 Auckland• New Zealand•
Telephone: +64 9 912 9638 • Telefax: +64 9 912 9639 • jwo@dhigroup.com• www.dhigroup.com

CONTENTS

1 Introduction

There is potential for significant development within the catchments which surround the Wēiti and Okura estuaries (Figure 1) and, to date, there has been limited work to assess the potential for the combined effects of such developments on the marine receiving environment.

To address this, Auckland Council commissioned DHI to carry out a study that linked outputs from the Freshwater Management Tool (FWMT) work being undertaken by Morphum to fully coupled hydrodynamic, wave, sediment transport and heavy metal models.

The following technical reports provide details of the FWMT development and land use scenarios, overview of field data collected for the study, calibration of the marine receiving environment models and the scenario report.

- Morphum Environmental 2019. Long Bay/Okura Freshwater Management Tool Study.
- DHI, 2018. Okura Wēiti Sediment Transport Modelling - Data report 44801163/01 prepared for Auckland Council.
- DHI, 2019a. Okura Wēiti Sediment Transport Modelling - Calibration report 44801163/02 prepared for Auckland Council.
- DHI, 2019b. Okura Wēiti Sediment Transport Modelling – Scenario report 44801163/03 prepared for Auckland Council.

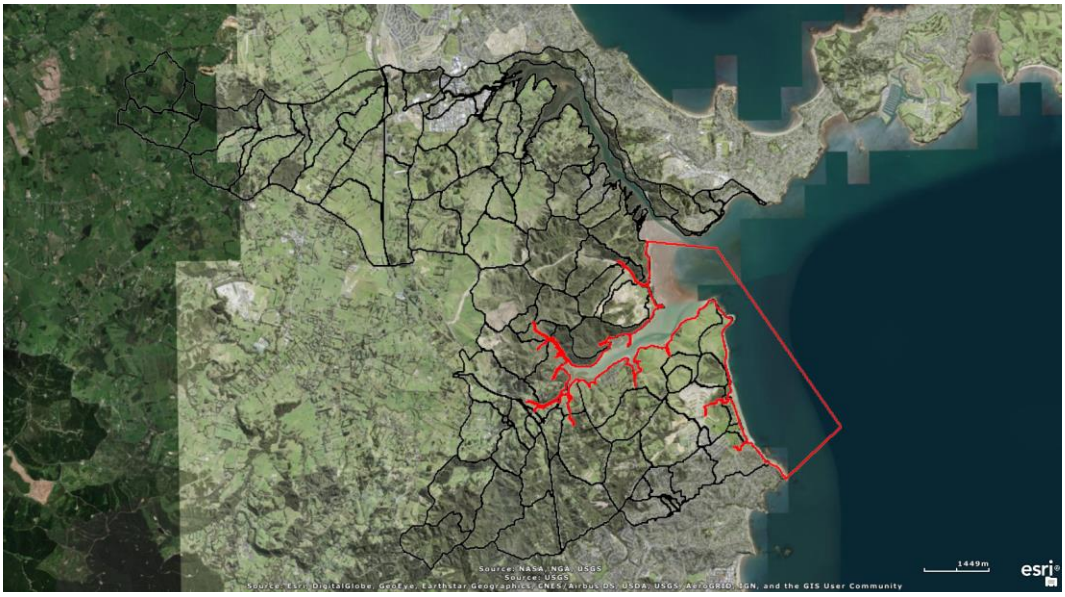


Figure 1. Catchments surrounding the Okura estuary and Wēiti River and the boundaries of the Long Bay-Okura Marne Reserve.

The suite of marine receiving environment models has been used to quantify the impact that potential development scenarios within the Okura and Wēiti catchments may have within the marine receiving environment.

An analysis of the predicted catchment inputs between 2001 and 2018 has been used to define a representative period for modelling the fate of catchment derived sediments and heavy metals in the marine receiving environment. During this representative period (January-July 2018) just over 3,100 tonnes of sediment are generated within the catchments with a maximum daily load of 650 tonnes and a number of days when the daily load exceeds 100 tonnes.

In total, fifteen potential land use scenarios have been considered. For each of these scenario, details of the model outputs are provided in DHI (2019b) which gives an overview of the changes due to the land use scenarios with regard to sediment deposition, suspended sediment concentrations and heavy metal accumulation.

This report provides as summary of the three technical reports produced for the study including an overview of the future land use scenarios considered and the catchment inputs associated with those scenarios (Section 2), an outline of the calibration of the marine receiving models (Section 3). The key results from the modelling are presented firstly for the Baseline scenario (Section 4) and the future land use scenarios (Section 5).

2 Catchment Inputs and Scenarios Considered

An overview of the scenarios considered in terms of assumed development, the mean annual loads (sediment, Zinc and Copper) under the scenario are shown in Table 1. The development areas referenced in Table 1 are shown in Figure 2 and the subcatchment outlets used within the marine receiving environment model are shown in Figure 3.

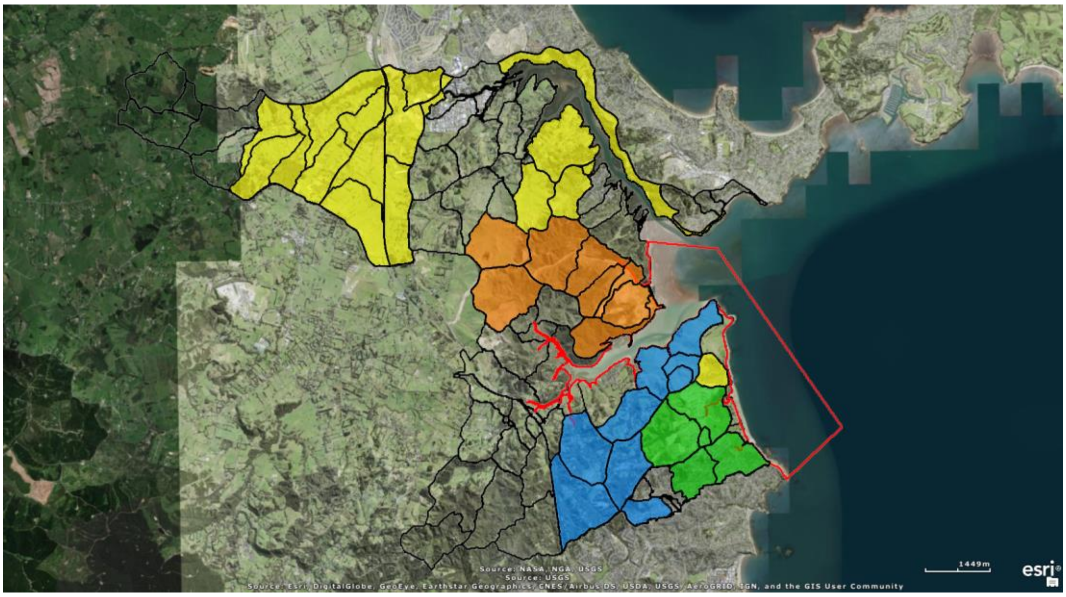


Figure 2. Development areas considered. Long Bay (green), Wēiti (orange), Future (yellow) and OHL (blue).

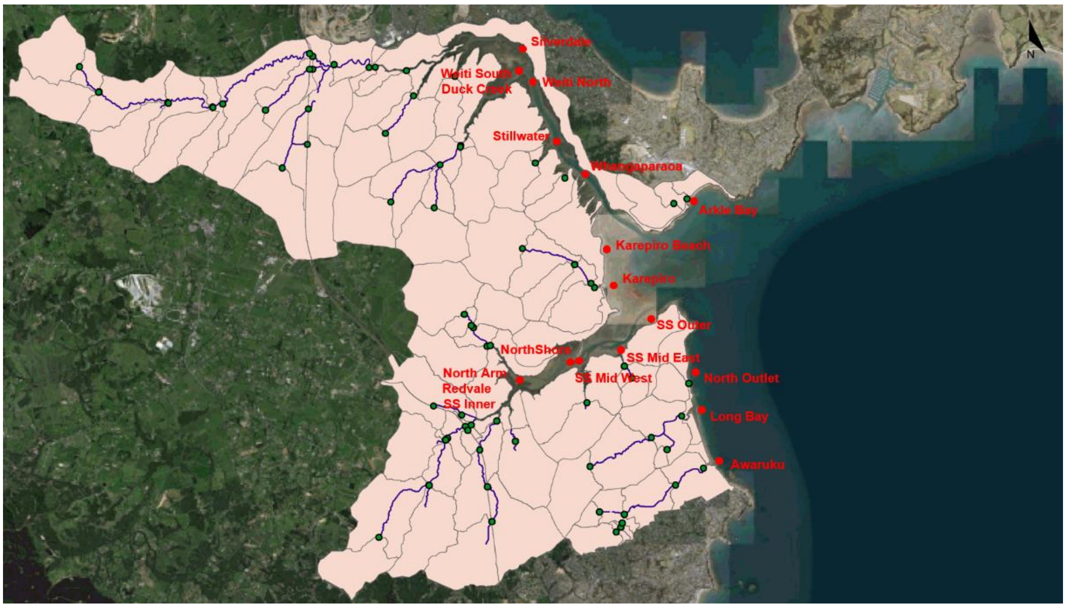


Figure 3. Okura estuary and Wēiti river subcatchments defined in the FWMT and the marine receiving environment model subcatchment outlets.

The subcatchment predictions of sediment, Zinc and Copper load and runoff for the baseline scenario (Scenario 0) from the FWMT are shown in Table 2. The table also shows the proportion of the total runoff and load for each of the subcatchments and highlights the relative contributions that each of the subcatchments makes to the overall catchment load. The table also shows which subcatchments contain the development areas.

Data in Table 2 shows that the Silverdale and Redvale subcatchments contribute the highest portion of sediment loads to the system but the Redvale subcatchment delivers around half the metal load and has around half the runoff of the Silverdale subcatchment.

The next largest contribution to loads are from the Wēiti South, North Arm and Long Bay subcatchments. All other subcatchments contribute less than 2% of the overall sediment and metal loads to the marine receiving environment except the Awaruku, Stillwater and Arkle Bay subcatchments which deliver a higher metal loads relative to their sediment loads.

The key scenarios which highlight the differences that the potential land use development scenario may have on the marine receiving environment are as follows:

Scenario 0 – Quantifies the current state of the system. This scenario is used as baseline for quantifying the dynamics of catchment derived sediments in the context of the dynamics of the existing bed sediments. This is discussed in detail in Section 4.

Scenario 1 – Quantifies the potential impacts of recent development within the Awaruku/Long Bay area,

Scenario 3 – Quantifies the potential impacts of full Wēiti development (1200 homes),

Scenario 6 – Quantifies the potential impacts of development in the future growth area,

Scenario 10 – Quantifies the potential impacts of full development in the OHL area.

Scenarios 7 – Quantify the effects of a general increases in Zinc and Copper loads

Scenarios 8 – Quantify the effects of a general decrease in Zinc and Copper loads

Scenarios 11-14 – Quantify the effects of inert roofing material within the Wēiti and Future development areas.

Table 1. Summary of scenarios considered, mean annual loads and differences in mean annual loads relative to the comparative scenario.

Scenario 1	Scenario 0 + Current land use plus recent development at Long Bay	Scenario 0	2274	337	87
Scenario 2	Scenario 1 + 550 home development Wēiti Bay growth areas	Scenario 1	2297	351	88
Scenario 3	Scenario 2 + 1200 home development Wēiti Bay growth areas	Scenario 2	2300	352	88
Scenario 4	Scenario 1 plus development in future growth areas	Scenario 1	2095	511	88
Scenario 5	Scenario 2 plus development in future growth areas	Scenario 2	2100	526	89
Scenario 6	Scenario 3 plus development in future growth area	Scenario 3	2103	526	89
Scenario 7	Scenario 6 with less Cu/Zn build-up wash-off	Scenario 6	2105	261	45
Scenario 8	Scenario 6 with more Cu/Zn build-up wash-off	Scenario 6	2106	1048	178
Scenario 9	Scenario 5 plus 1400 home development at OHL site	Scenario 5	2134	538	90
Scenario 10	Scenario 6 plus 1400 home development at OHL site	Scenario 6	2137	539	91
Scenario 11	Scenario 6 with inert roofing materials applied to Wēiti Bay	Scenario 6	2103	520	89
Scenario 12	Scenario 8 with inert roofing materials applied to Wēiti Bay	Scenario 8	2106	521	89
Scenario 13	Scenario 6 with inert roofing materials applied to future growth	Scenario 6	2103	383	89
Scenario 14	Scenario 8 with inert roofing materials applied to future growth	Scenario 8	2106	383	89

Table 2. Summary of catchment loads and runoff for each of the catchment outlets for Scenario 0 along with the subcatchments within the development areas. Numbers in brackets of percentage of total load/runoff for each individual subcatchment.

	Awaruku	Long Bay	SS Outer	SS Mid East	SS Mid West	SS Inner	Redvale	North Arm	North Shore	Karepiro	Karepiro Beach	Stillwater	Wēiti South	Silverdale	Arkle Bay	Whangaparaoa	Wēiti North	North Outlet	Duck Creek
Sediment (tonnes/yr)	53.1 (2.3)	129.3 (5.7)	16.9 (0.7)	35.8 (1.6)	26.7 (1.2)	27.1 (1.2)	589.9 (26.0)	186.1 (8.2)	10.1 (0.4)	26.1 (1.2)	29.9 (1.3)	28.2 (1.2)	205.7 (9.1)	801.7 (35.4)	23.7 (1.0)	12.9 (0.6)	12.9 (0.6)	17.7 (0.8)	32.9 (1.5)
Zn (kg/yr)	54 (16.3)	13.4 (4.1)	1.3 (0.4)	4.5 (1.4)	3.5 (1.1)	6.9 (2.1)	49.5 (15)	14.9 (4.5)	0.4 (0.1)	1.1 (0.3)	2.2 (0.7)	11.4 (3.5)	16.6 (5.0)	115.1 (34.8)	15.2 (4.6)	6.6 (2.0)	6.6 (2.0)	1.1 (0.3)	6.1 (1.8)
Cu (kg/yr)	7.9 (9.1)	3.9 (4.5)	0.6 (0.7)	1.3 (1.5)	1.0 (1.2)	1.4 (1.6)	15 (17.3)	5.4 (6.2)	0.2 (0.2)	0.6 (0.7)	0.9 (1.0)	1.8 (2.1)	6.1 (7.0)	33.8 (38.9)	2.2 (2.5)	1.2 (1.4)	1.2 (1.4)	0.6 (0.7)	1.7 (2.0)
Runoff (m^3 x 10^3/year)	1810 (4.7)	2042 (5.3)	369 (1.0)	477 (1.2)	428 (1.1)	463 (1.2)	6622 (17.2)	3327 (8.7)	379 (1.0)	930 (2.4)	1508 (3.9)	853 (2.2)	2970 (7.7)	13451 (35.0)	677 (1.8)	463 (1.2)	463 (1.2)	466 (1.2)	723 (1.9)
Development area within subcatchment	Long Bay	Long Bay, Future, OHL	OHL	OHL	OHL	OHL	OHL	Wēiti, Future	Wēiti, OHL	Wēiti, OHL	Wēiti, OHL	Future	Wēiti, Future	Future	-	Future	Future	Future, OHL	Future

3 Model calibration

Details of the calibration of the models are provided in DHI (2019a). The following provides an overview of the calibration process.

Extensive field data was collected at various sites within Karepiro Bay from March-July 2018. Total rainfall over the period of the instrument deployment was 513 mm with 65 days of rain, several events of more than 30 mm per day and a maximum daily rainfall of 56 mm recorded on the 4th of June (estimated to be around a 1 year return period event). Maximum recorded wind speed during the deployment period was 26.8 m/s on the 10th of April (the highest on record at the Whangaparoao weather station) but because of the wind direction (easterly) this event did not result in the highest waves during the deployment period. Largest waves (>1 m) occurred during north-easterly wind events associated with longer period swells combined with the generation of local wind waves.

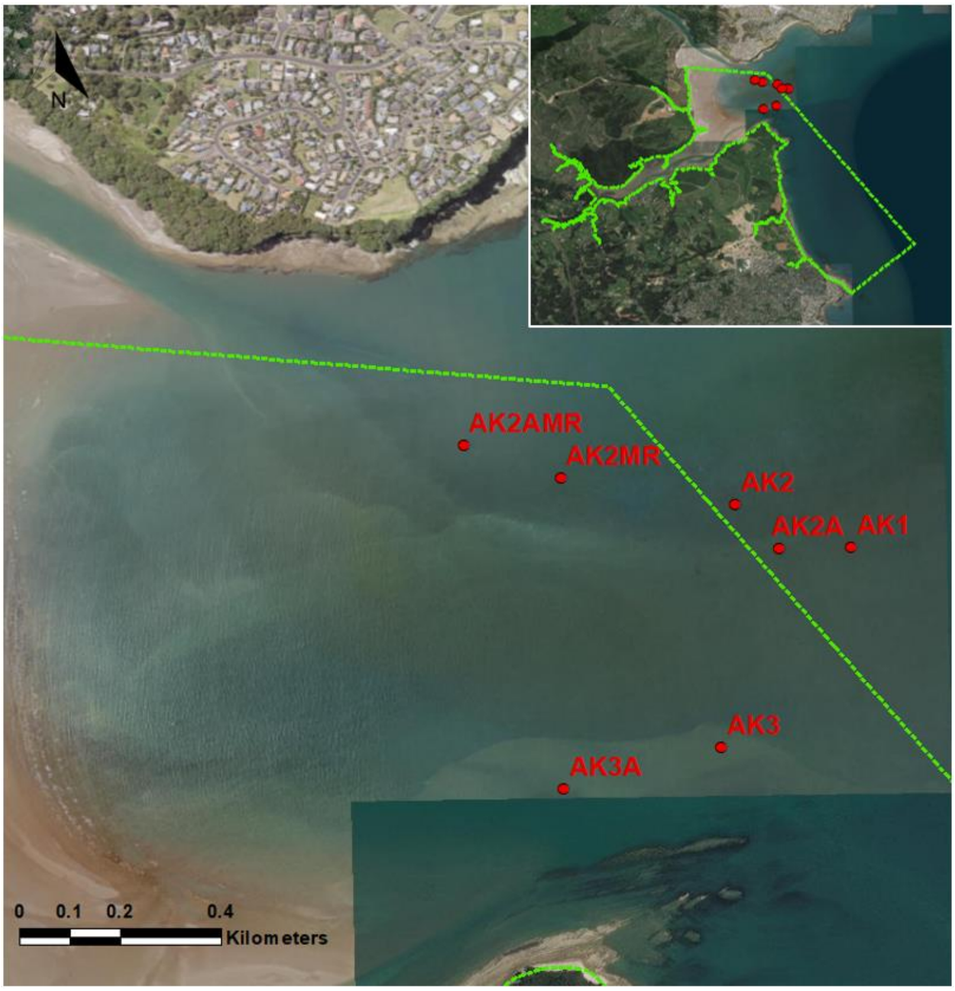


Figure 4. Locations of the monitoring stations within Karepiro Bay. The dashed green polygon delimits the Long Bay – Okura Marine Reserve.

Both the wave and hydrodynamic components of the marine receiving environment model are well calibrated as shown in Figure 5 (for wave height) and Figure 6 (for currents). As such the models provide good quantification of the relative influences of tidally driven sediment transport (which dominants sediment transport processes within the Wēiti river and Okura estuary) and wave induced sediment transport (which is the key driver of sediment transport within Karepiro Bay).

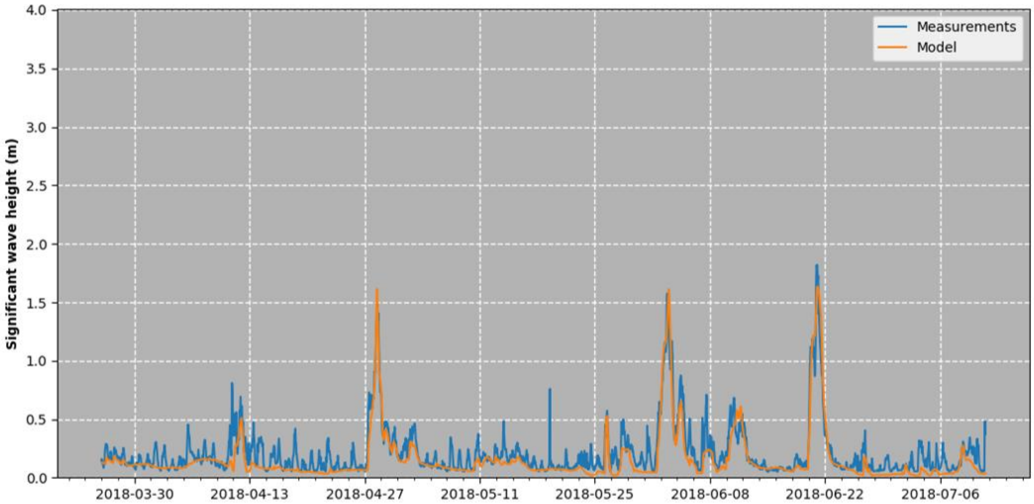


Figure 5. Measured and model significant wave heights at the entrance to Karepiro Bay (site AK1, Figure 4).

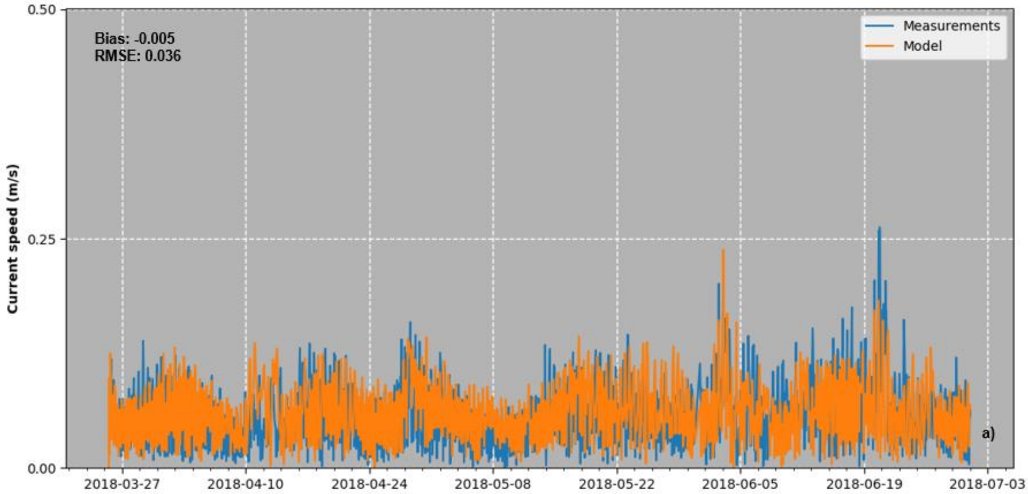


Figure 6. Measured and model mid-depth current timeseries at the entrance to Karepiro Bay (site AK1, Figure 4).

Limited information on the variability of offshore sediment meant that the calibration of the observed bed level changes was problematic. However, the calibrated sediment transport model still provides the basis for investigating the behaviour of catchment derived sediments in the context of existing bed sediment behaviour under a broad range of wind, tide and wave conditions.

The calibration of the metal accumulation model is based on the available monitoring data at five sites - Long Bay and Awaruku (1998-2013), upper Wēiti (1998-2016) plus one-off sampling within the Okura estuary in 2010.

Monitoring data at the Long Bay and Awaruku sites show very little trend in metal accumulation over time and this is reflected in the metal accumulation model results which show very low current day metal concentrations in areas where the sediment transport model predicts low deposition rates from catchment derived sediments.

The metal accumulation model predicts the highest current day metal concentrations in the upper Wēiti (consistent with the monitoring data) which is due to a combination of the highest predicted deposition rates and the highest metal loads from catchments surrounding the upper Wēiti.

4 Scenario 0 - with existing seabed sediments

This is the baseline scenario used for the calibration of the marine receiving environment models. The mean annual sediment load delivered to the marine receiving environment is 2267 tonnes/yr and the mean annual Zinc and Copper loads are 330 kg/yr and 87 kg/yr respectively.

The focus of the study is to quantify the fate of catchment derived sediments and how they influence observed deposition, suspended sediment concentrations and future metal accumulation in surface sediments. However, to calibrate the sediment transport model existing seabed sediments have to be included in the model as they play a significant role in terms of contributing to suspended sediment concentrations (particularly during wave events as detailed in DHI, 2019a).

Figures 7 and 8 illustrate the dynamic nature of the sediment transport in the marine receiving environment. These plots show the net change in bed level predicted by the sediment transport with the inclusion of both the catchment derived sediments and the existing seabed sediments.

Prior to the large wave event on the 28th of April (Figure 5) it can be seen that there are areas of net deposition (shown in brown) within both the Okura estuary and Wēiti River (Figure 7). Within Karepiro Bay there are patches of both net erosion (shown in green) and net deposition. Shoreline sediments (i.e. those along the Long Bay and Whangaparoao shoreline) have moved offshore under the combined effects of waves and currents so we see bands of net erosion close to the shoreline and areas of deposition just offshore.

Following the large wave event of the 28th of April (Figure 5) it can be seen that there is significant increases in deposition within the Okura estuary and Wēiti River and net erosion across all of Karepiro Bay – this gives an indication of the sources and sinks of offshore sediment during such a wave event. In addition, sediments have been moved offshore of the area of Long Bay (Figure 8).

These figures show the spatial complexity of the sediment dynamics of the system which is further illustrated by considering the time-series of the daily change in bed level at the key sites shown in Figure 9. The sediment dynamics at these sites can be summarised as follows;

Upper Okura
Net deposition. Periods of both deposition (68% of days) and erosion (32% of days) driven by tidal currents.

Mid Okura
Net deposition. No net daily erosion so a series of depostional events relating to resuspension of existing sediments and delivery of catchment derived sediments.

Upper Wēiti
Net deposition. No net daily erosion so a series of depostional events of predominantly catchment derived but some contribution from existing sediments.

Mid Wēiti
Net deposition. Periods of both deposition (34% of days) of both catchment derived and existing sediments and erosion (66% of days) driven by tidal currents.

Karepiro
Net erosion: About equal number of days of net erosion or deposition but erosion rate outstrips deposition rate.

Wēiti Delta and Arkle Bay
Net deposition. Periods of both deposition (90% of days) and erosion (10% of days) dominated by wave events.

Outer Karepiro and Long Bay
Net erosion. Periods of both deposition (80% of days) and erosion (20% of days) dominated by wave events.

The maximum suspended sediment concentration and time when the threshold of 80 mg/L is exceeded are as follows -

Upper Okura
309.25 hours above 80 mg/L and maximum of 666 mg/L

Mid Okura
516.50 hours above 80 mg/L and maximum of 1885 mg/L

Upper Wēiti
704.00 hours above 80 mg/L and maximum of 1593 mg/L

Mid Wēiti
725.0 hours above 80 mg/L and maximum of 2988 mg/L

Karepiro
931.75 hours above 80 mg/L and maximum of 9271 mg/L

Wēiti Delta
889.25 hours above 80 mg/L and maximum of 4050 mg/L

Outer Karepiro
606.5 hours above 80 mg/L and maximum of 3582 mg/L

Arkle Bay
406.75 hours above 80 mg/L and maximum of 2459 mg/L

Long Bay
746.25 hours above 80 mg/L and maximum of 1157 mg/L

One of the key outcomes of the modelling is the development of the connectivity matrix which defines how individual catchment outlets are connected to the marine receiving environment at a subestuary level. Table 3 shows the connectivity matrices for the individual catchment outlets and each of the subestuaries. This table shows the proportion of sediment deposited in each subestuary for each of the catchment outlets and gives an indication of how individual subcatchments influence the overall deposition of catchment derived sediments.

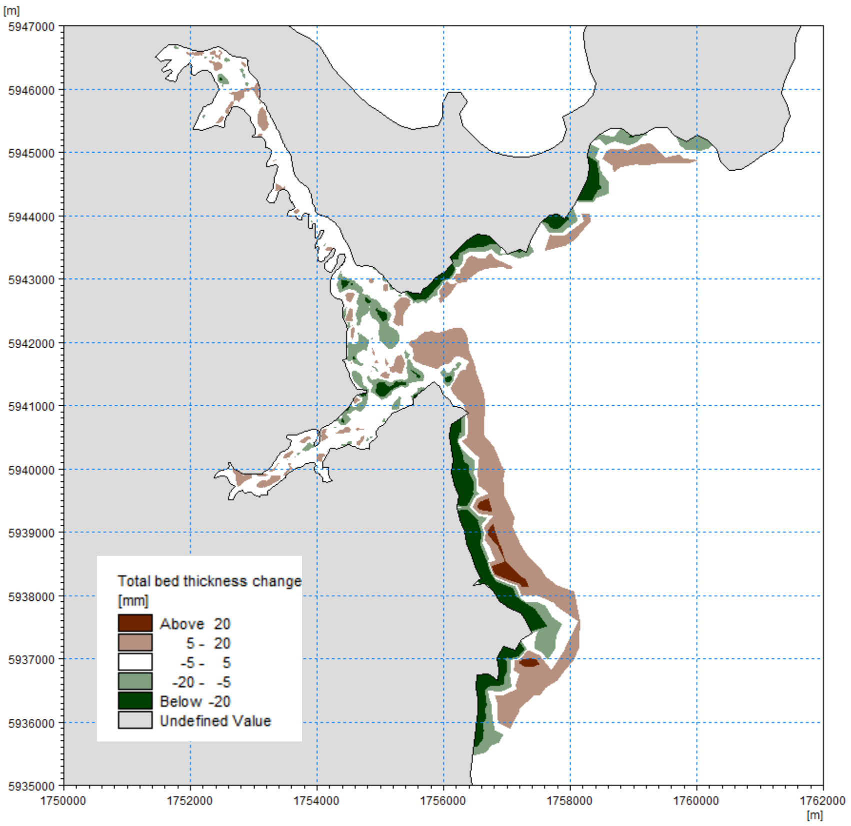


Figure 7. Total bed level change since January 1st 2018 just prior to the April 28th wave event (Figure 5).

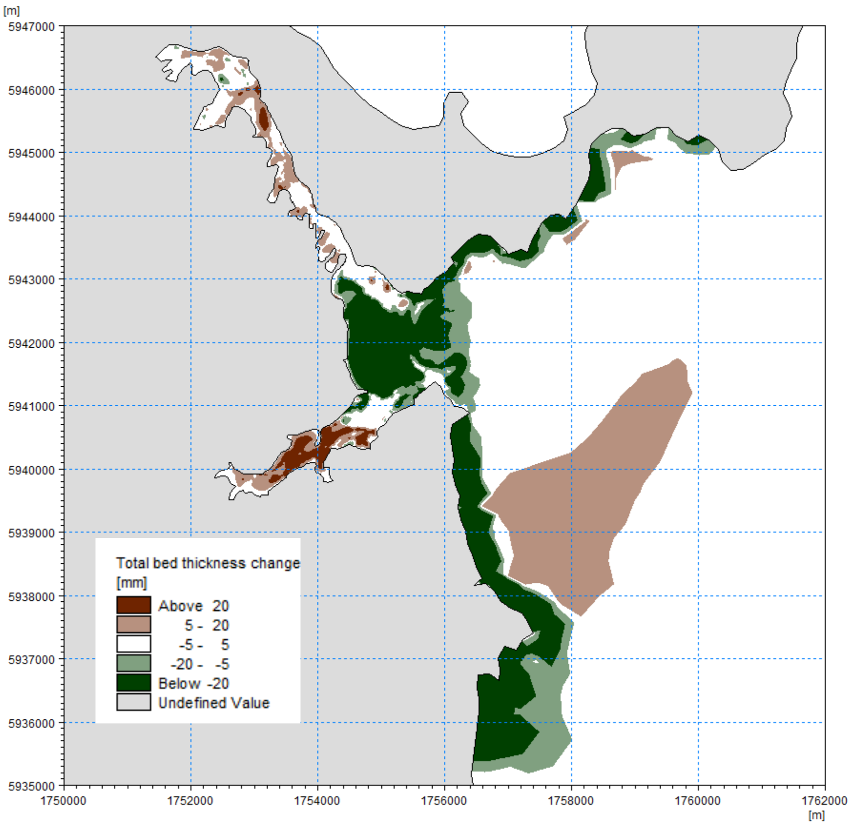


Figure 8. Total bed level change since January 1st 2018 just after the April 28th wave event (Figure 5).

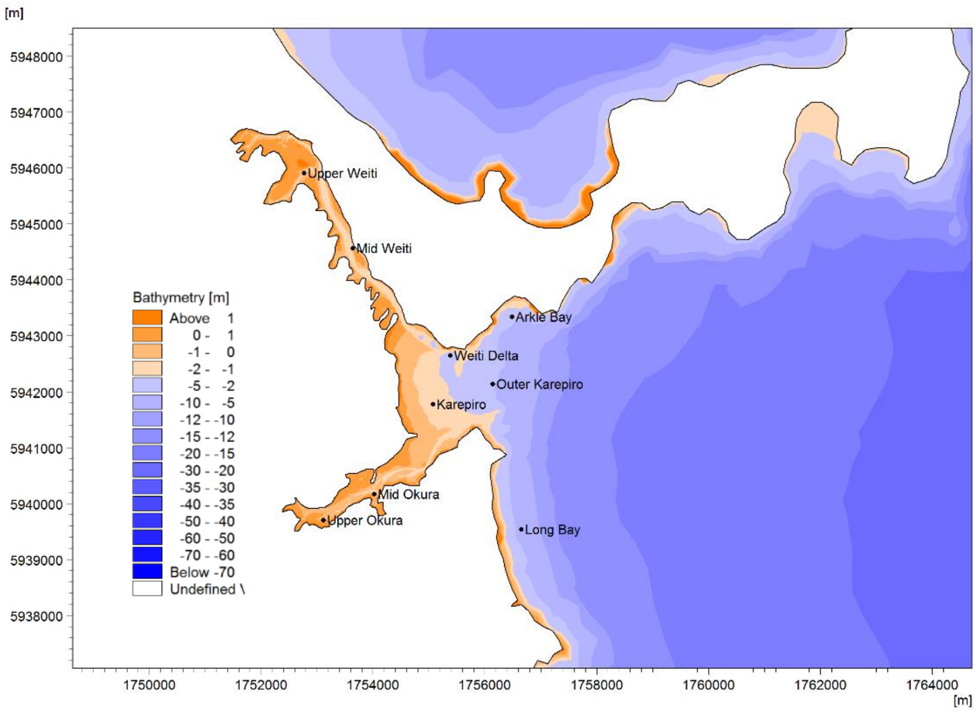


Figure 9. Location of key sites.

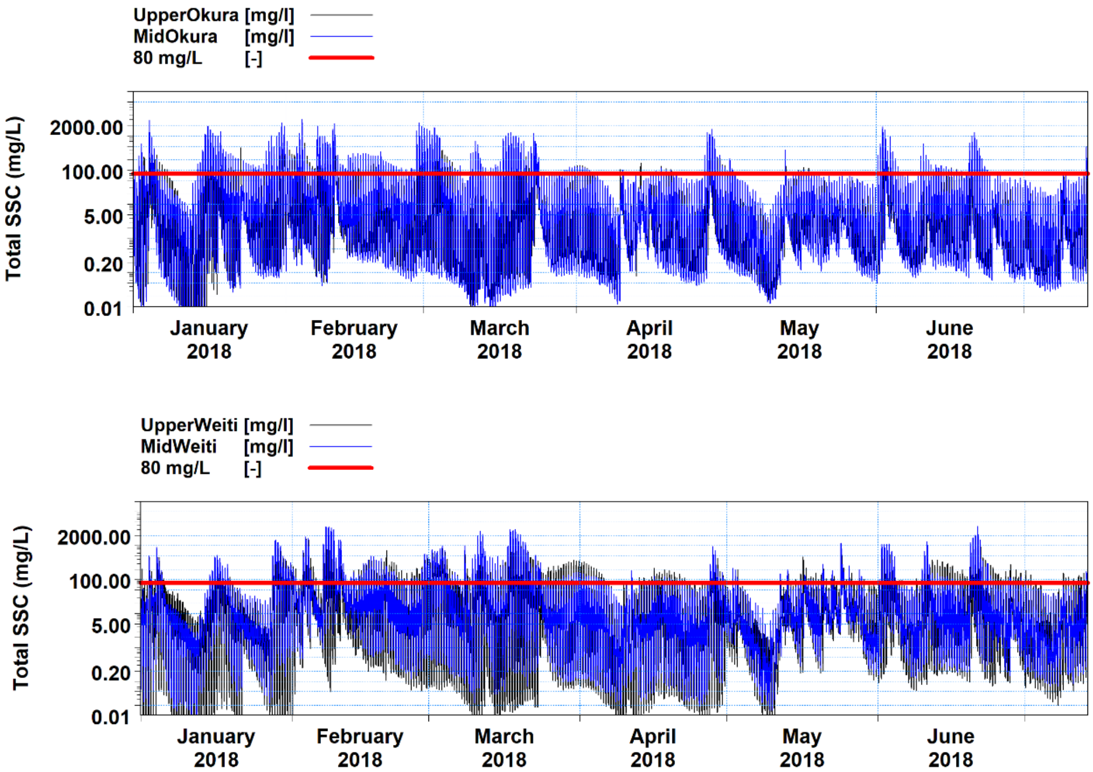


Figure 10. Total suspended sediment concentration at the Okura estuary and Wēiti river sites under Scenario 0 with existing seabed sediments.

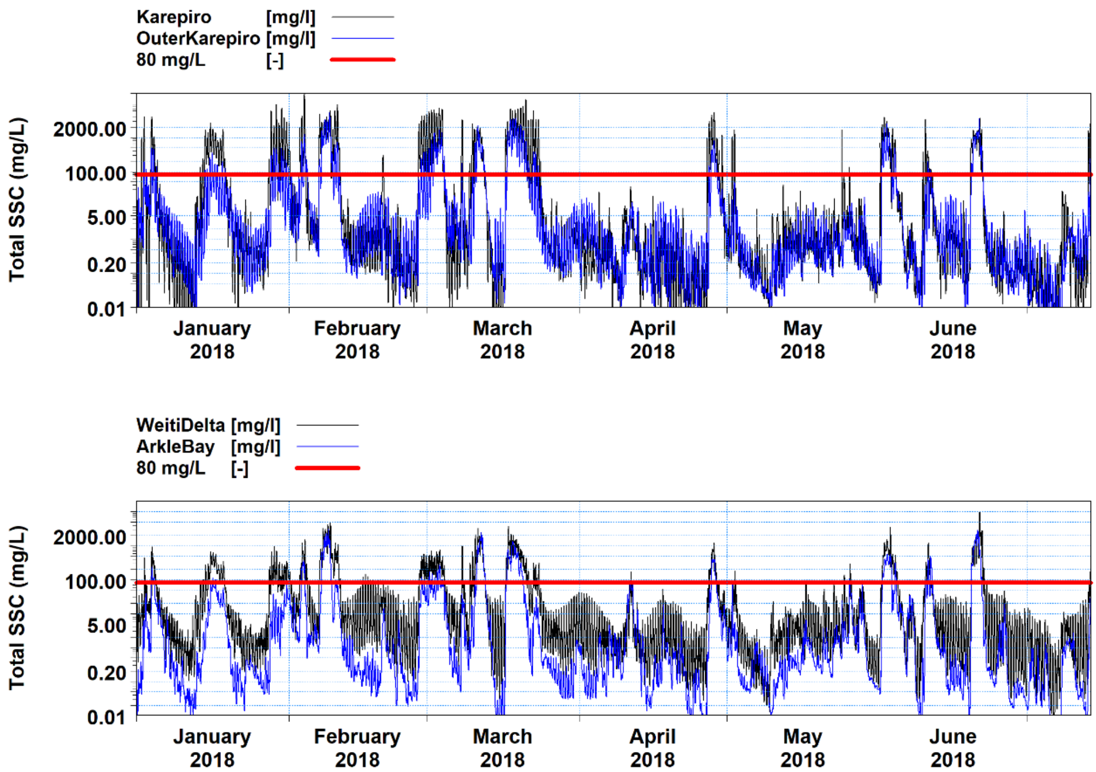


Figure 11. Total suspended sediment concentration at the Karepiro Bay sites under Scenario 0 with existing seabed sediments.

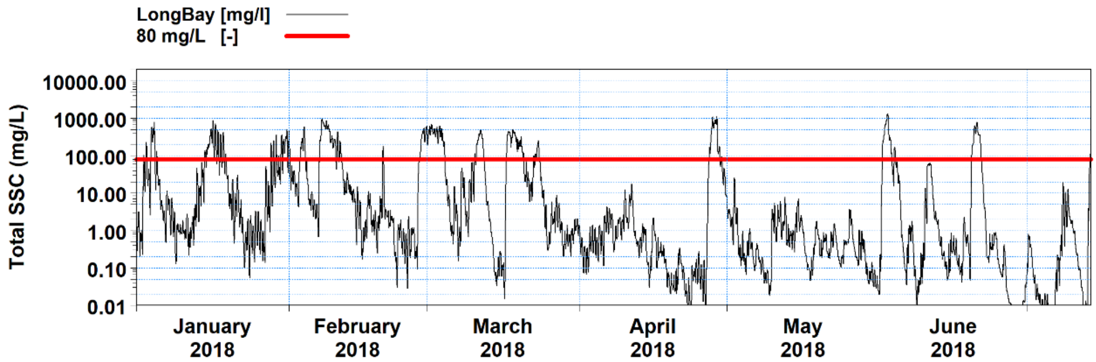


Figure 12. Total suspended sediment concentration at the Long Bay site under Scenario 0 with existing seabed sediments.

Figure 13. Extent of the subestuaries within the Okura/Wēiti marine receiving environment.

Table 3. Percentage of each catchment sediment load deposited within each of the subestuaries shown in Figure 13. Row is the percentage of each individual catchment load deposited within the given subestuary. Colour coding indicates degree of connectivity - red being highly connected, intermediate connectivity in yellow, and low connectivity in green.

Catchment Outlet	Subestuary												
	Okura (Upper)	Okura (Mid)	Okura (Outer)	Karepiro (S)	Karepiro (N)	Wēiti (Upper)	Wēiti (Mid)	Wēiti (Outer)	Marine Reserve	Karepiro Bay	Whangaparaoa	Outer Karepiro Bay	Outer Gulf
Awaruku	0.77	0.26	0.00	0.02	0.01	0.87	0.22	0.14	3.15	0.66	3.27	4.24	86.37
Long Bay	2.32	1.00	0.07	0.04	0.02	2.23	0.62	0.40	2.35	0.57	2.90	3.21	84.28
SS Outer	34.78	15.47	0.27	0.19	0.43	12.81	3.53	2.35	0.63	0.47	1.67	1.34	26.06
SS Mid East	39.50	19.04	0.39	0.16	0.54	14.82	4.15	2.70	0.49	0.46	1.44	0.92	15.39
SS Mid-West	46.98	21.60	0.33	0.14	0.38	13.45	3.58	2.23	0.34	0.36	1.05	0.58	8.97
SS Inner	71.92	14.76	0.12	0.10	0.14	5.39	1.40	0.93	0.16	0.13	0.52	0.25	4.18
Redvale	75.71	12.10	0.09	0.08	0.10	4.96	1.27	0.82	0.14	0.11	0.46	0.23	3.90
North Arm	76.49	12.25	0.08	0.07	0.09	4.32	1.10	0.71	0.13	0.10	0.41	0.23	4.02
NorthShore	39.67	24.69	0.46	0.18	0.53	16.23	4.33	2.70	0.39	0.46	1.16	0.52	8.68
Karepiro	31.58	15.02	0.07	0.13	0.14	13.53	3.39	2.05	0.68	0.22	1.20	0.88	31.12
Karepiro Beach	20.37	9.98	0.15	0.19	1.35	33.06	7.18	5.07	0.32	0.50	3.10	0.90	17.84
Stillwater	4.92	1.98	0.01	0.02	0.06	48.17	16.67	5.57	0.42	0.16	1.05	0.56	20.41
Wēiti South	2.34	0.97	0.00	0.02	0.05	76.45	7.40	2.56	0.17	0.10	0.62	0.30	9.03
Silverdale	2.32	0.97	0.00	0.02	0.06	77.21	7.40	2.10	0.15	0.10	0.62	0.30	8.75
Arkle Bay	4.35	1.90	0.02	0.02	0.08	13.54	3.53	2.50	0.64	0.50	3.52	2.09	67.30
Whangaparaoa	4.85	1.98	0.02	0.06	0.23	53.37	11.11	5.80	0.31	0.32	1.85	0.79	19.31
Wēiti North	2.96	1.20	0.01	0.04	0.12	73.05	8.29	3.24	0.18	0.16	0.95	0.45	9.35
North Outlet	3.97	1.80	0.11	0.04	0.02	4.70	1.33	0.86	1.88	0.60	2.94	2.78	78.96
Duck Creek	2.26	0.92	0.00	0.03	0.09	80.20	6.39	2.22	0.13	0.12	0.74	0.32	6.58

6 Scenario 0 - without existing seabed

In this section of the report results from a model simulation for Scenario 0 without the existing seabed sediments are summarised. Using this approach, a like-for-like comparison of model result can be carried out which highlights the differences resulting from the scenarios being considered.

The time when suspended sediment concentrations exceed 80 mg/L and the maximum suspended sediment concentration at the key sites shown in Figure 9 are as follows;

Upper Okura
18 hours above 80 mg/L and maximum of 428 mg/L

Mid Okura
17 hours above 80 mg/L and maximum of 378 mg/L

Upper Wēiti
44 hours above 80 mg/L and maximum of 603 mg/L

Mid Wēiti
34.25 hours above 80 mg/L and maximum of 955 mg/L

Karepiro
10.25 hours above 80 mg/L and maximum of 1444 mg/L

Wēiti Delta
7.25 hours above 80 mg/L and maximum of 122 mg/L

Outer Karepiro
0 hours above 80 mg/L and maximum of 16 mg/L

Arkle Bay
0 hours above 80 mg/L and maximum of 33 mg/L

Long Bay
0 hours above 80 mg/L and maximum of 8 mg/L

The time series of predicted suspended sediment concentrations at the key sites are shown in Figure 14 and Figure 15. Compared to the results with existing bed sediments (Section 4) it can be seen that concentrations are much lower when just the catchment derived sediments are considered and the time above the 80 mg/L threshold is much shorter. This is due to 1) the resuspension of existing seabed sediments in deeper parts of the system during wave events and 2) the transport of resuspended seabed sediment into the Okura estuary and Wēiti River adding to the elevated suspended sediment concentrations due to catchment derived sediments.

Data in Table 4 shows the mass of sediment deposited within each subestuary at the end of the model simulation time along with the portion of the total deposition of 2632 tonnes (i.e. just over the annual sediment load) in each subestuary. Figure 17 shows the spatial distribution of the deposition and indicates that the predominant sinks for catchment derived sediments are the Upper Okura estuary and Wēiti river. In addition, there are strong gradients of deposition along axis of the Okura estuary and Wēiti river and the embayment's along the edge of the Wēiti River are deposition sinks. Model results show that there is very little long-term deposition on Karepiro beach and outer Okura estuary due to resuspension of sediments by waves, and that less than 5% of the catchment derived sediments deposits in wider Karepiro Bay.

Future metal concentrations reflect the net effects of the connectivity of the system (i.e. how connected individual catchments are to different areas of the marine receiving environment), the ratio of metal to sediment load from the catchment outlets (which defines the catchment source concentration) and the predicted level of deposition that occurs within the different subestuaries. Hence, data in Table 5 shows the highest future metal concentrations occurring in areas of highest deposition that are strongly linked to catchment sources which have a high metal to sediment load ratio. Elsewhere, future metal concentrations do not increase much over current day levels due to low deposition rates.

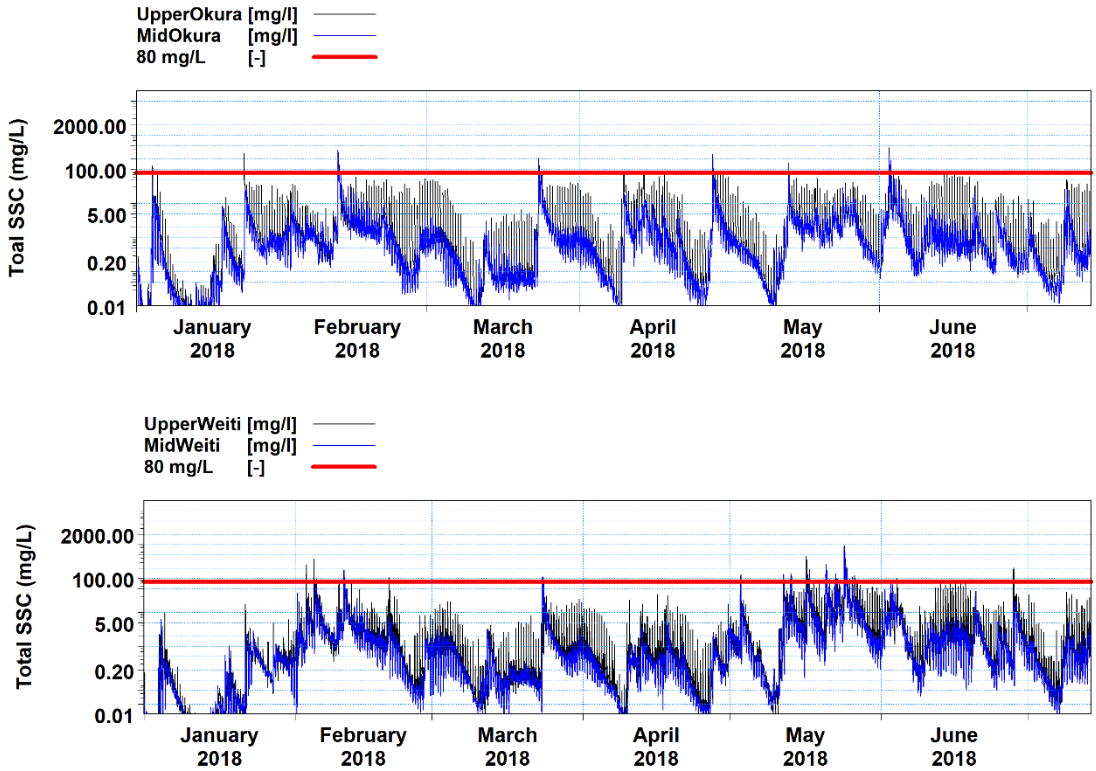


Figure 14. Total suspended sediment concentration at the Okura estuary and Wēiti river sites under Scenario 0 with just catchment sediments being delivered to the marine receiving environment.

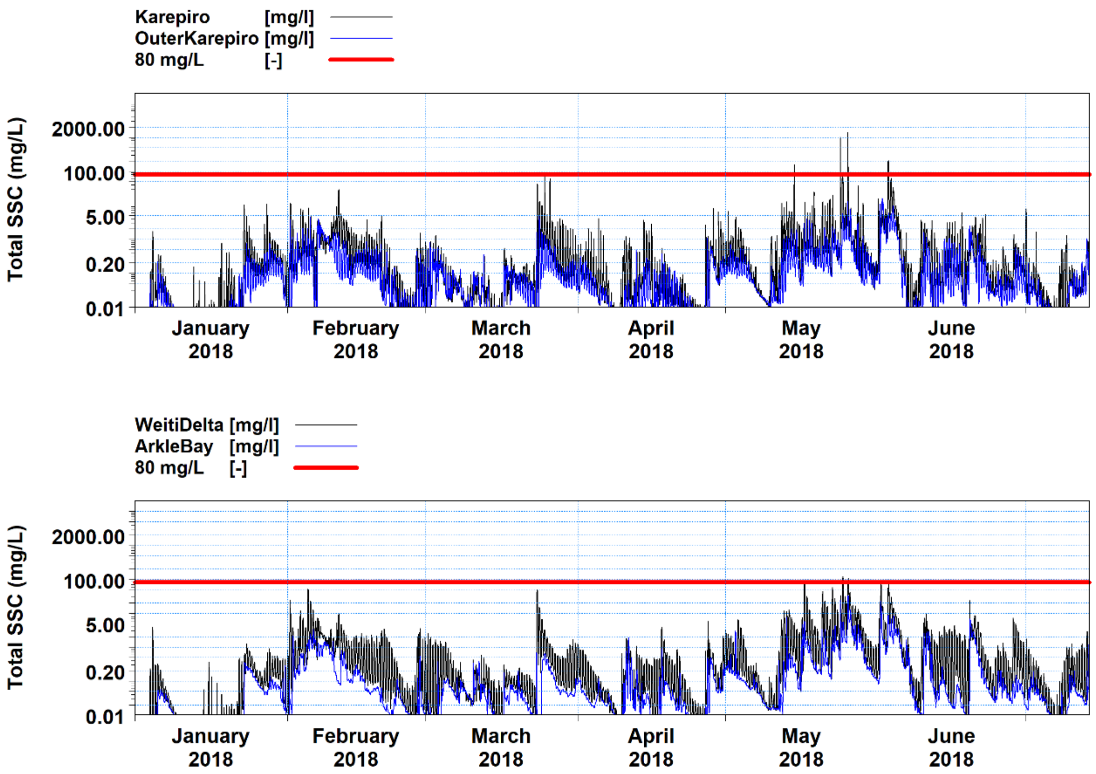


Figure 15. Total suspended sediment concentration at the Karepiro Bay sites under Scenario 0 with just catchment sediments being delivered to the marine receiving environment.

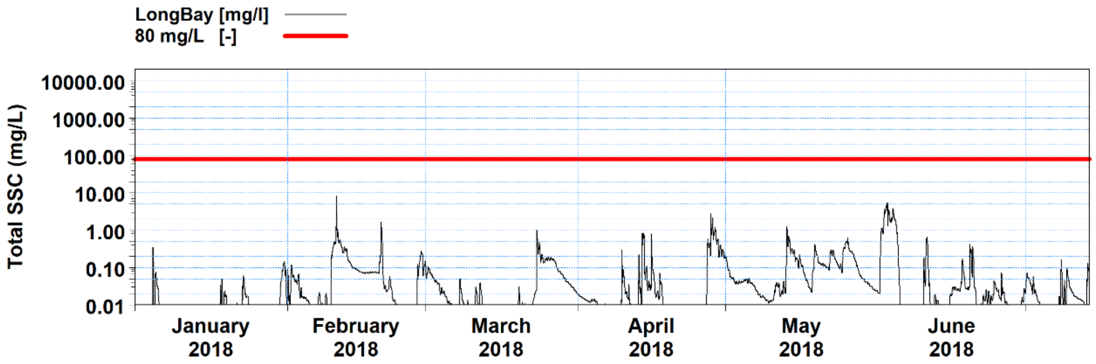


Figure 16. Total suspended sediment concentration at the Long Bay site under Scenario 0 with just catchment sediments being delivered to the marine receiving environment.

Table 4. Total mass deposited (tonnes) at the end of the model simulation within each of the subestuaries (Figure 13) for Scenario 0.

Subestuary	Mass Deposited Scenario 0 (tonnes)	Percentage of total deposition
Upper Okura	382.2	21.4%
Mid Okura	58.5	3.3%
Outer Okura	0.2	0.0%
Karepiro (S)	0.5	0.0%
Karepiro (N)	3.8	0.2%
Upper Wēiti	1110.9	62.2%
Mid Wēiti	122.4	6.9%
Outer Wēiti	27.2	1.5%
Marine Reserve	36.6	2.1%
Outer Karepiro	3.9	0.2%
Whangaparaoa	39.0	2.2%

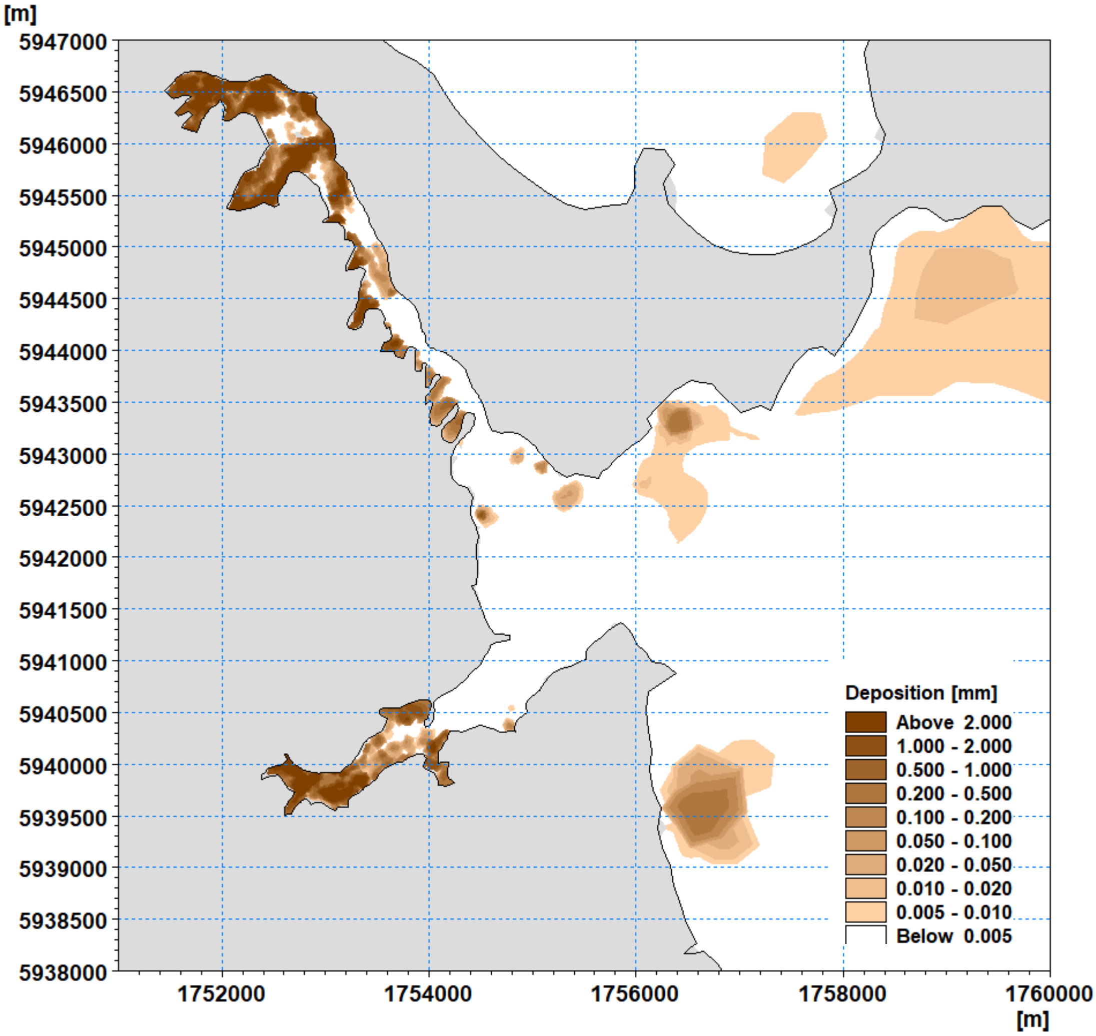


Figure 17. Predicted deposition (mm) at the end of the model simulation under Scenario 0 with just catchment sediments being delivered to the marine receiving environment.

Table 5. Future subestuary metal concentration (mg/kg) under Scenario 0 along with the area where PEL thresholds of 271 mg/kg for Zinc and 108 mg/kg for Copper are exceeded and the maximum predicted concentrations.

	Future Zinc (mg/kg)	Future Copper (mg/kg)
Upper Okura subestuary concentration	80.5	23.9
Mid Okura subestuary concentration	47.9	12.6
Lower Okura subestuary concentration	26.0	5.0
Karepiro (S) subestuary concentration	26.0	5.0
Karepiro (N) subestuary concentration	26.7	5.2
Upper Wēiti subestuary concentration	91.3	24.9
Mid Wēiti subestuary concentration	60.2	14.4
Lower Wēiti subestuary concentration	58.3	13.7
Marine Reserve subestuary concentration	26.5	5.0
Outer Karepiro subestuary concentration	26.6	5.0
Whangaparaoa subestuary concentration	29.6	5.8
Total area (ha) where PEL is exceeded		
	0.0	0.0
Maximum Concentration (mg/kg)		
	186.3	48.2

7 Long Bay Development (Scenario 1)

Compared to Scenario 0, this scenario delivers an additional 7.0 tonnes of sediment and an additional 6.2 and 0.1 tonnes of Zinc and Copper respectively to the marine receiving environment from the Awaruku and Long Bay subcatchments (Figure 3). Annual runoff increases by around 10% for these two subcatchments.

Sediments from these catchments tend to be dispersed relatively widely (Table 3) so, even though there are increases in the mass deposited within a number of subestuaries, the increases in deposition rates are very small (< 0.5 mm) compared to Scenario 0.

Because of the small change in deposition rates there are only minor (<0.1 mg/kg) increases in future Zinc concentrations at a subestuary level within the Upper and Mid Okura and the Marine Reserve subestuaries compared to Scenario 0 (Table A2).

Because of the small change in sediment load under this scenario there are no significant changes in suspended sediment concentrations compared to scenario 0.

8 Wēiti Development (Scenario 3)

Compared to Scenario 1, this scenario delivers an additional 25.9 tonnes of sediment and an additional 15.3 and 1.6 kg of Zinc and Copper respectively to the marine receiving environment from the subcatchments within the Wēiti development area (Figure 2) with increased metal loads from the Karepiro and Karepiro Beach subcatchments. Annual runoff increases by around 5% for all the Wēiti development subcatchments (Figure 2) except the Wēiti South subcatchment where runoff is predicted to decrease by 7%.

Because of the relative strong connection between the Karepiro subcatchment outlets and the upper sections of the Wēiti river (Table 3) and the decreased runoff from the Wēiti South subcatchment under this scenario, there is a shift in the deposition pattern within the Wēiti subestuary with more being deposited in the Upper Wēiti subestuary (see Table A3) – particularly around the Duck Creek inter-tidal areas near the Wēiti South catchment outlet. The maximum increase in deposition is greater than 4 mm.

Because of the predicted increase runoff from the North Arm subcatchment (Figure 3) there is a shift in the deposition pattern within the Okura estuary with less deposition in the upper section and more towards the middle section of the estuary (see Table A3) with changes of the order of 1 mm occurring.

Compared to Scenario 1, future metal concentrations increase at a subestuary level by up to 11.5 mg/kg for Zinc and 1.0 mg/kg for Copper but do not exceed PEL thresholds (See Tables A1 and A2).

Compared to Scenario 1, the average suspended sediment concentrations at the Upper Okura site (Figure 9) decreases by around 0.5%. Increases in the average suspended sediment concentration of around 5% occur at the Upper Wēiti site and at other key sites the average suspended sediment concentrations decrease by around 0.6%.

9 Future Growth Development (Scenario 6)

This Scenario delivers 196.4 tonnes/yr less sediment than Scenario 3 and an additional 174.6 and 0.7 kg/yr of Zinc and Copper respectively. Increased sediment loads occur across all the future growth subcatchments except the Silverdale and Long Bay subcatchments where decreases of 201 tonnes/yr and 8 tonnes/yr occur respectively. Compared to Scenario 3, significant increases in runoff occur for the Long Bay subcatchment (+23%) the Silverdale subcatchment (+14%) and decreased runoff from the Weiti South subcatchment (-22%).

The largest increased in Zinc load (165 tonnes/yr) occurs within the Silverdale subcatchment although small increases in Zinc and Copper.

Because of the significant decrease in sediment load from the Silverdale subcatchment there is much less deposition across most of the Upper and Mid Wēiti subestuaries (Table A3).

The relative decrease in sediment load and increase in metal loads from the Silverdale catchment lead to future metal concentrations ranging from 91 to 198 mg/kg for Zinc and 15 to 29 mg/kg for Copper in the Wēiti subestuaries (See Tables A1 and A2). The Zinc PEL threshold (of 271 mg/kg) is exceeded in 48.3 hectares of the Upper Wēiti river.

Compared to Scenario 3, the average suspended sediment concentrations at Okura key sites (Figure 9) decreases by around 2%, decreases of around 15% occur at the Wēiti key sites and at the offshore sites the average suspended sediment concentrations decrease by around 10%.

Compared to Scenario 3, the maximum suspended sediment concentration decreases by between 20 and 150 mg/L at the Upper, Mid and Weiti Delta key sites but does not significantly change at other sites. The time above 80 mg/L reduces by around 6-10 hours at the Upper and Mid Wēiti site but does not significantly change at other sites.

10 OHL Development (Scenario 10)

This scenario delivers an additional 33.5 tonnes of sediment compared to Scenario 6 and an additional 12.1 and 1.5 kg of Zinc and Copper respectively. Compared to Scenario 6, increases in runoff occur for the SS Outer and SS Mid East (12%) and decreases for the Long Bay subcatchment (-16%).

Increased sediment loads occur for the Redvale, SS Mid West and Karepiro subcatchments with increased metal loads for the SS Outer and SS Mid East.

The relative decrease in sediment load and increase in metal loads from the Silverdale catchment lead to future metal concentrations ranging from 91 to 198 mg/kg for Zinc and 15 to 29 mg/kg for Copper in the Wēiti subestuaries (See Tables A1 and A2). The Zinc PEL threshold (of 271 mg/kg) is exceeded in 48.3 hectares of the Upper Wēiti river.

Because of the significant decrease in sediment load from the Silverdale subcatchment there is less deposition across most of the Wēiti subestuaries and the overall reduction in sediment load from the Okura subcatchments leads to reduced levels of deposition in the upper parts of the Okura estuary (Table A3).

Compared to Scenario 6, there are small decreases and increases in future Copper concentrations occur in the Upper and Mid Okura subestuaries respectively (Table A1) and small increase in future Zinc concentrations in the Okura estuary (<1.7 mg/kg), while in the Wēiti River the Karepiro (N) subestuary future Zinc concentrations increase by less than 0.3 mg/kg (Table A2) .

Compared to Scenario 6, the average suspended sediment concentrations at Okura key sites (Figure 9) increase by around 1%. There are no changes in the average suspended sediment concentrations at the Wēiti key sites and, at the offshore sites, the average suspended sediment concentrations increase by around 0.5%.

11 Decrease Metal Load (Scenario 7)

This scenario applies a global reduction in Zinc and Copper and the sediment loads associated with Scenario 6.

Because of the significant decrease in metal loads there are widespread decreases in future metal concentrations across all the subestuaries (See Tables A1 and A2) compared to Scenario 6. PEL thresholds are not exceeded anywhere.

At a subestuary level, future metal concentrations are all below the Scenario 0 levels (Table A1, A2) except Zinc levels in the Upper Wēiti subestuary.

12 Increased Metal Load (Scenario 8)

This scenario applies a global increase in Zinc and Copper and the sediment loads associated with Scenario 6.

Because of the significant increase in metal loads there are widespread increases in future metal concentrations across all the subestuaries compared to Scenario 6 (See Tables A1 and A2).

The PEL threshold for Zinc is exceeded in 67.7 hectares, mostly in the Upper Wēiti River where maximum Zinc concentrations of 931 mg/kg are predicted, but also in an area just landward of the spit opposite Okura township.

The PEL for Copper is exceeded in 21.2 hectares in the upper Wēiti river where maximum future concentrations of 119 mg/kg are predicted.

13 Reduced Metal Load Scenarios (11, 12, 13 and 14).

For Scenarios 11 and 13, sediment loads are the same as Scenario 6, while for Scenarios 12 and 14, sediment loads are the same as Scenario 8 (Table 1).

Overall Copper loads for these scenarios are the same as Scenario 6 (Table 1) so future Copper concentrations are the same as Scenario 6 (Table A1).

For Scenarios 11 and 12, Zinc loads are reduced to around those for Scenario 6, while for Scenarios 13 and 14, Zinc loads are just above those of Scenario 3 (Table 1).

For Scenario 11 and 12 future metal concentrations range from 88 to 195 mg/kg for Zinc in the Wēiti subestuaries and 26 to 94 mg/kg in the Okura subestuaries (Table A2). The Zinc PEL threshold (of 271 mg/kg) is exceeded in just over 47 hectares of the Upper Wēiti river.

For Scenario 13 and 14 future metal concentrations range from 70 to 130 mg/kg for Zinc in the Wēiti subestuaries and 26 to 89 mg/kg in the Okura subestuaries (Table A2). The Zinc PEL threshold (of 271 mg/kg) is exceeded in just over 1 hectare of the Upper Wēiti river.

.

Table A1. Future subestuary Copper metal concentrations (mg/kg). Highlighted columns indicate the scenarios discussed in the text and numbers in brackets indicate the change (if any) from the comparative scenario.

	Scenario 0	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Scenario 9	Scenario 10	Scenario 11	Scenario 12	Scenario 13	Scenario 14
Upper Okura	23.9	23.9	24.9	24.9 (1.0)	23.9	25	25 (0.2)	13.1	48.2	24.9	24.9 (-0.2)	24.8	24.8	24.8	24.8
Mid Okura	12.6	12.6	13.4	13.4 (0.8)	12.7	13.6	13.6 (0.1)	8.5	23.2	13.7	13.7 (0.1)	13.4	13.4	13.4	13.4
Lower Okura	5.0	5.0	5.0	5.0	5.0	5.0	5.0	4.8	5.4	5.1	5.1	5.0	5.0	5.0	5.0
Karepiro (S)	5.0	5.0	5.1	5.1 (0.1)	5.0	5.1	5.1	4.9	5.5	5.1	5.1	5.1	5.1	5.1	5.1
Karepiro (N)	5.2	5.2	5.4	5.4 (0.1)	5.2	5.4	5.4	5.0	6.1	5.4	5.4	5.4	5.4	5.4	5.4
Upper Wēiti	24.9	24.9	25.6	25.5 (0.6)	28.4	29.1	29.1 (3.6)	16.1	54.8	29.2	29.1	29.1	29.0	29.1	29.0
Mid Wēiti	14.4	14.4	14.8	14.8 (0.4)	15.6	16	16 (1.2)	9.9	28.1	16.1	16.0	16.0	16.0	16.0	16.0
Lower Wēiti	13.7	13.7	14.3	14.3 (0.6)	14.4	15.1	15 (0.8)	9.5	25.9	15.1	15.1	15.0	15.0	15.0	15.0
Marine Reserve	5.0	5.0	5.0	5.0	5.0	5.0	5.0	4.9	5.3	5.0	5.	5.0	5.0	5.0	5.0
Outer Karepiro	5.0	5.0	5.0	5.0	5.0	5.0	5.0	4.8	5.3	5.0	5.0	5.0	5.0	5.0	5.0
Whangaparaoa	5.8	5.8	6.0	6 (0.2)	5.9	6.0	6.0	5.4	7.2	6.0	6.0	6.0	6.0	6.0	6.0

Table A2. Future subestuary Zinc metal concentrations (mg/kg). Highlighted columns indicate the scenarios discussed in the text and numbers in brackets indicate the change from the comparative scenario.

	Scenario 0	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Scenario 9	Scenario 10	Scenario 11	Scenario 12	Scenario 13	Scenario 14
Upper Okura	80.5	80.5 (0.1)	92.0	92 (11.5)	87.4	99.4	99.3 (7.3)	51.5	188.2	100.6	100.5 (1.1)	94.1	94.0	89.0	88.9
Mid Okura	47.9	48 (0.1)	57.2	57.2 (9.2)	53.5	62.9	62.9 (5.7)	39.5	104.0	64.7	64.6 (1.7)	58.7	58.6	54.8	54.7
Lower Okura	26.0	26.0	26.4	26.4 (0.4)	26.2	26.6	26.6 (0.2)	25.7	28.3	26.9	26.9 (0.2)	26.4	26.4	26.3	26.3
Karepiro (S)	26.0	26.0	26.8	26.8 (0.9)	26.4	27.3	27.3 (0.5)	26	29.5	27.3	27.3	26.9	26.9	26.6	26.6
Karepiro (N)	26.7	26.7	28.1	28.1 (1.4)	27.5	28.9	28.9 (0.8)	26.8	32.8	29.1	29.1 (0.2)	28.4	28.4	27.8	27.8
Upper Wēiti	91.3	91.3	98.6	98.5 (7.2)	190.9	198.5	198.1 (99.6)	105.4	379	198.9	198.2 (0.1)	195.3	194.7	129.6	129.3
Mid Wēiti	60.2	60.3	65.3	65.2 (4.9)	96.3	101.4	101.2 (36)	59.7	181.2	101.8	101.4 (0.3)	99.2	98.8	75.2	75.0
Lower Wēiti	58.3	58.4	65.1	64.9 (6.5)	84.6	91.4	91.1 (26.1)	55	159.5	91.8	91.2 (0.2)	88.4	87.9	70.6	70.3
Marine Reserve	26.5	26.6 (0.1)	26.7	26.7 (0.1)	27.0	27.1	27.1 (0.4)	26.1	29.0	27.1	27.1	27.1	27.1	26.7	26.7
Outer Karepiro	26.6	26.6	26.8	26.8 (0.2)	27.1	27.2	27.2 (0.5)	26.2	29.2	27.3	27.3	27.2	27.2	26.8	26.8
Whangaparaoa	29.6	29.6	31.1	31.1 (1.5)	31.7	33.3	33.3 (2.2)	29.2	41	33.3	33.3	32.7	32.7	31.1	31.1

Table A3. Predicted mass deposited (tonnes) in each subestuary at the end of the representative period (01/01/2018-14/07/2018) under the different scenarios . Highlighted columns indicate the scenarios discussed in the text and numbers in brackets indicate the change (if any) from the comparative scenario.

	Scenario 0	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Scenario 9	Scenario 10	Scenario 11	Scenario 12	Scenario 13	Scenario 14
Upper Okura	382.2	382.2	374.0	374.3 (-7.9)	371.3	372.4	372.9 (-1.4)	373.2	373.3	380.6	380.8 (8)	372.9	373.3	372.9	373.3
Mid Okura	58.5	58.4 (-0.1)	61.6	61.7 (3.3)	60.1	60.8	60.6 (-1.1)	60.8	60.9	61.6	61.6 (1)	60.6	60.9	60.6	60.9
Lower Okura	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Karepiro (S)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Karepiro (N)	3.8	3.9	3.9	3.9	4.0	4.2	3.5 (-0.4)	3.6	4.2	3.6	4.0 (0.5)	3.5	4.2	3.5	4.2
Upper Wēiti	1110.9	1110.3 (-0.7)	1132.4	1130.9 (20.6)	911.2	909.6	911.0 (-219.9)	911.0	910.7	910.9	911.5 (0.5)	911.0	910.7	911.0	910.7
Mid Wēiti	122.4	122.9 (0.4)	121.1	122.2 (-0.7)	97.0	99.1	98.3 (-23.9)	98.0	98.5	98.4	98.2 (-0.2)	98.3	98.5	98.3	98.5
Lower Wēiti	27.2	27.0 (-0.2)	26.7	26.7 (-0.3)	23.6	23.7	23.8 (-2.9)	23.8	23.8	23.7	23.9 (0.1)	23.8	23.8	23.8	23.8
Marine Reserve	36.6	38.2 (1.5)	38.2	38.2	32.5	32.5	32.6 (-5.6)	32.6	32.6	32.4	32.4 (-0.1)	32.6	32.6	32.6	32.6
Outer Karepiro	3.9	3.9	3.9	3.9	3.6	3.7	3.7 (-0.2)	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7
Whangaparaoa	39.0	39.2 (0.2)	39.3	39.3 (0.2)	37.2	37.2	37.3 (-2)	37.4	37.3	37.3	37.4 (0.1)	37.3	37.3	37.3	37.3