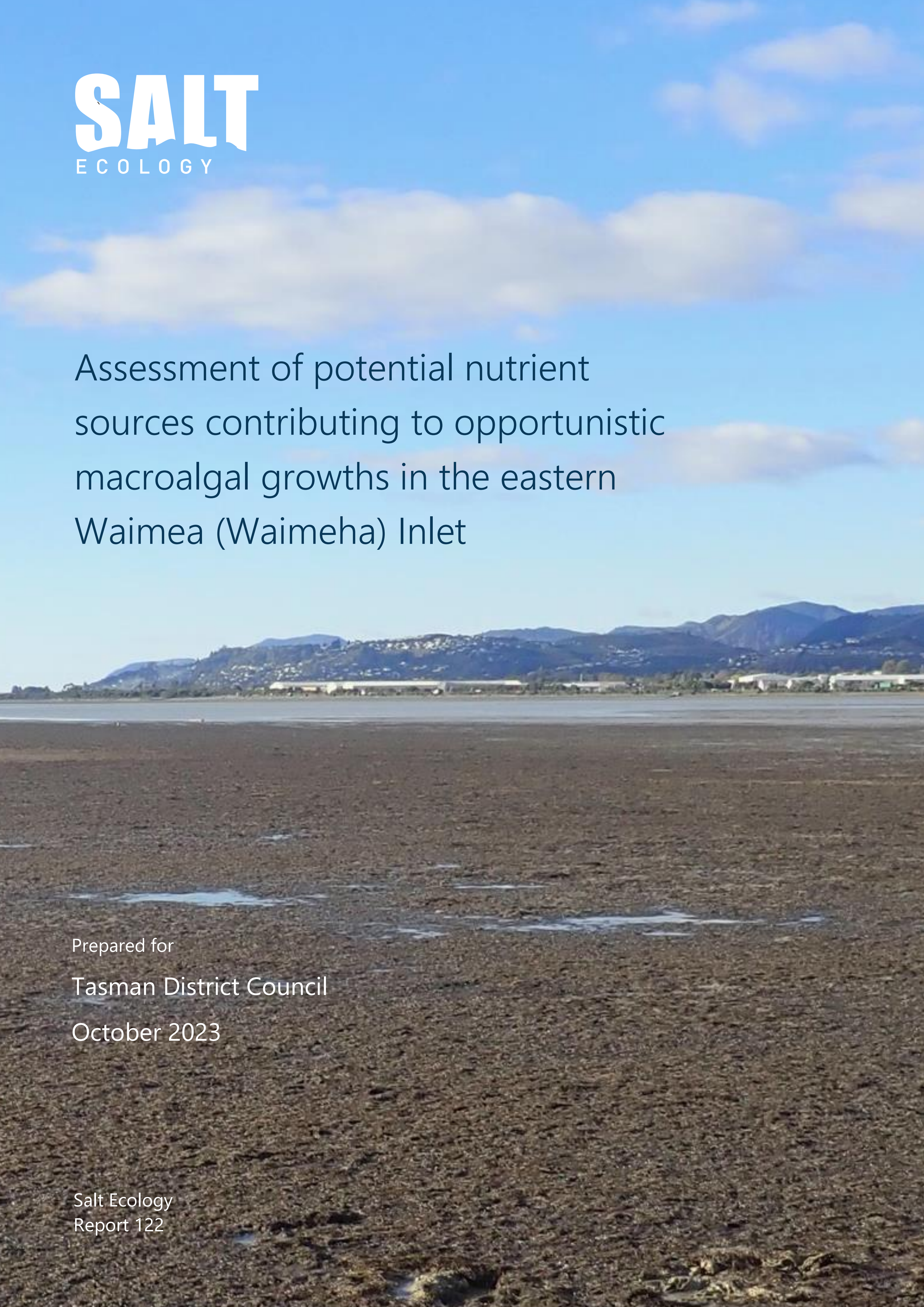

SALT ECOLOGY

Assessment of potential nutrient sources contributing to opportunistic macroalgal growths in the eastern Waimea (Waimeha) Inlet

Prepared for

Tasman District Council

October 2023

Salt Ecology
Report 122

Cover photo: Site 11 located in a dense bed of opportunistic macroalgae (*Agarophyton* spp.) on intertidal flats near Richmond.

RECOMMENDED CITATION

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Assessment of potential nutrient sources contributing to opportunistic macroalgal growths in the eastern Waimea (Waimeha) Inlet

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October 2023

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GLOSSARY

ANZG	Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2018)
aRPD	Apparent redox potential discontinuity
As	Arsenic
Cd	Cadmium
CLUES	Catchment Land Use for Environmental Sustainability - NIWA model.
Cr	Chromium
Cu	Copper
DGV	Default Guideline Value
DRP	Dissolved Reactive Phosphorus
Hg	Mercury
LoD	Limit of detection
NCC	Nelson City Council
NH_4	Ammonium Nitrogen
Ni	Nickel
NO_3	Nitrate Nitrogen
NRSBU	Nelson Regional Sewerage Business Unit
Pb	Lead
SOE	State of Environment (monitoring)
SVOC	Semi Volatile Organic Compounds
TDC	Tasman District Council
TN	Total nitrogen
TOC	Total organic carbon
TOM	Total organic matter
TP	Total phosphorus
WWTP	Wastewater Treatment Plant
Zn	Zinc

ACKNOWLEDGEMENTS

Many thanks to Trevor James (TDC) for his support in undertaking this work, and peer review of the report. We are also grateful to the NRSBU and NCC for allowing use of existing monitoring data.

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BACKGROUND

To assess the relative importance of nutrient sources, particularly nitrogen, in relation to the recent establishment of dense, sediment-entrained nuisance macroalgal beds in the eastern Waimea Inlet, Tasman District Council (TDC) commissioned Salt Ecology to review available data and collect and analyse sediment samples from 13 sites in the southeast part of Waimea Inlet. The primary focus was persistent macroalgal beds adjacent to the MDF plant/Bark Processor's sites, near Neimann Creek, and in the estuary near the confluence of Jimmy Lee and Reservoir Creeks.

KEY FINDINGS

The largest estimated sources of Total Nitrogen (TN) and Total Phosphorus (TP) to Waimea Inlet are the Waimea River (~255 t/y of TN, 58% of total load; and ~48t/y of TP, 59% of total load) and the Bell Island Wastewater Treatment Plant (WWTP) (~93t/y of TN, 21% of total load; and T~27t/y of TP, 33% of total load). However, as much or most of these loads are expelled into Tasman Bay by the ebbing tide, they are likely to have a negligible influence on the areas where macroalgal beds have developed.

The smaller streams entering the southeastern part of Waimea Inlet are therefore the most likely sources of nutrients to the macroalgal beds, contributing an estimated 54t/y of TN (12% of total load); and 3.7t/y of TP (5% of total load) to the estuary. Of this, ~27t/y (49%) of the predicted TN load is attributed to two sources - Borck and Seal Creeks. Water quality monitoring data confirms Borck Creek it is a major source of nitrogen. Therefore, Borck and Seal Creeks appear to be major contributors to the general development of macroalgal growth in the estuary.

However, individual beds, such as those around the mouth of Neimann and Jimmy Lee Creeks are expected to be influenced by more local sources, but for which no water quality monitoring data were available. Patterns of water movement will determine how nutrient-rich water and sediment discharged by creeks is dispersed or concentrated, but these are poorly understood in these shallow coastal areas limiting the ability to pinpoint contributing sources.

Sediment sampling conducted as part of the current study found TN and Total Organic Carbon (TOC) concentrations were relatively high at many of the sites sampled (Penny Farthing Stream in particular), and high relative to other shallow, intertidal-dominated estuaries in New Zealand. However, there was no clear relationship between sediment nutrient concentrations and water quality data from Borck and Neimann Creeks.

Concentrations of trace metals and semi-volatile organic contaminants in the sediments were well below guideline values at which adverse effects on aquatic organisms might occur, with the exception of naturally elevated concentrations of chromium and nickel (apparent throughout Waimea Inlet because of catchment geology).

Based on the nutrient loads present in the estuary, expansion in the spatial extent and density of some of the macroalgal beds observed between the 2014 and 2020 is likely to continue.

RECOMMENDATIONS

1. Investigate potential sources of nutrients to Borck and Seal Creeks, the source of high organic matter and nutrients measured in Penny Farthing Stream (culverted under the MDF plant), and the discharge from the sump and pipe draining the southeast corner of the Bark Processers yard. Source tracking of nitrogen compounds may identify the relative contributions of different catchment sources, such as wastewater, livestock and fertilisers.
2. Derive more accurate estimates of the nutrient loads from individual stream catchments than are currently available. Estimates based on nutrient concentrations should incorporate a range of rainfall events and be modelled and validated with existing flow and water-quality data.
3. Incorporate information on inputs of nutrients from nearby streams in the eastern side of the estuary (including sewage overflows), and which are managed by NCC, into estimates of mass loads to the estuary.
4. Identify patterns of distribution of stream-derived sediments and nutrients once they enter the estuary ideally by modelling water movements around the southeastern estuary over the tidal cycle.
5. Measure sediment accumulation rates in the areas where macroalgal beds are growing, and nutrient concentration in the sediments over time, to identify sinks of sediments and associated nutrients.
6. Map macroalgal percent cover and measure biomass and entrainment to characterise changes at time scales shorter than the current estuarine broad-scale surveys (for example, annually as opposed to 5-10 yearly).

1. INTRODUCTION

The development, spatial extent and surface cover of beds of opportunistic macroalgae, such as sea lettuce (*Ulva* spp.) and the red alga *Agarophyton* (*Gracilaria*) spp. are early indicators of problems of nutrient driven eutrophication. The 2009 vulnerability assessment for Waimea Inlet (Stevens & Robertson 2010) noted that nuisance macroalgal growth was periodically present at a relatively low spatial coverage and was concentrated near main channels in the lower estuary and in parts of the upper reaches of sheltered arms and embayments. Macroalgal cover was >50% over 56ha (2.2%) of the estuary. Cover in 2009 had extended relative to 2001 and continued monitoring was recommended.

Gillespie and Berthelsen (2017) assessed the capacity of Waimea Inlet to assimilate additional nutrients, as part of the application to renew the discharge consent for the Bell Island wastewater treatment plant (WWTP). They compared nutrient concentrations in water samples from reference locations in the inlet and areal loading estimates (modelled estimates of nutrient loads from the catchment) with New Zealand and overseas guidelines and standards for concentrations and loadings of nitrogen and phosphorus in coastal waters. This comparison suggested that there is limited capacity for assimilation of additional nutrients into the food web or by microbial conversion of nutrient forms of nitrogen and carbon into non-nutrient forms such as nitrogen gas and carbon dioxide. Nutrients can also be sequestered by burial in the bed of the estuary below the depth of microbial activity. Although there was no evidence of a general expression of adverse effects from existing concentrations and loads, the assessment indicated moderate to high vulnerability for such effects.

Broad-scale monitoring of Waimea Inlet (Clark et al. 2008, Stevens & Robertson 2014, Stevens et al. 2020) has shown growth of new and existing beds of macroalgae (mainly *Agarophyton* but also *Ulva*) at several locations around Waimea Inlet (Fig. 1).

The areas where macroalgal cover exceeded 30% cover were highly localised and were near obvious inputs of nutrients to the estuary (such as the Bells Island wastewater outfall, around the mouths of rivers and streams, and near seepages around the bark processing plant). In many instances macroalgae had become entrained, defined as growing in stable beds or with roots deep (e.g., >30mm) within the sediments, and indicating that persistent macroalgal growths have established.

Dense and entrained macroalgal beds were present adjacent to the MDF plant/Bark Processor's sites, near Hoddy Peninsula, and south of Rough Island. Additional areas of nuisance growth were located between Bell and Best Islands, Neimann Creek, in the upper extent of the Hoddy arms, and parts of the southeast estuary near Richmond where many streams have consistently high nutrient concentrations (James & McCallum 2015).

The key features of these areas were:

• MDF plant/Bark Processor's sites in the eastern arm had the densest cover (up to 100%) and the greatest biomass (12kg/m^2) of entrained macroalgae, consisting primarily of *Agarophyton* spp.

• Around Hoddy Peninsula, entrained *Agarophyton* spp. was found in numerous small patches of dense (70 to <90%) cover, predominantly east of the peninsula.

• South of Rough Island, one of the conspicuous features was extensive mats of *Ulva* containing smaller areas of *Agarophyton* spp. entrained in the sediment.

Where macroalgal mats had become entrained, or had an extensive cover or high biomass, they had a smothering effect, leading to the development of black anoxic sediment. Adjacent to the MDF plant sediment conditions appear to have been degraded to a point where remaining macroalgae could no longer survive. Extensive microbial mats were observed in these areas with underlying sediments having a high organic content and strong hydrogen sulphide odours (see photo below).

Previous area of dense macroalgal cover with underlying sediments having a high organic content and strong hydrogen sulphide odours. Microbial mats now extensive on the surface (photo 2020).

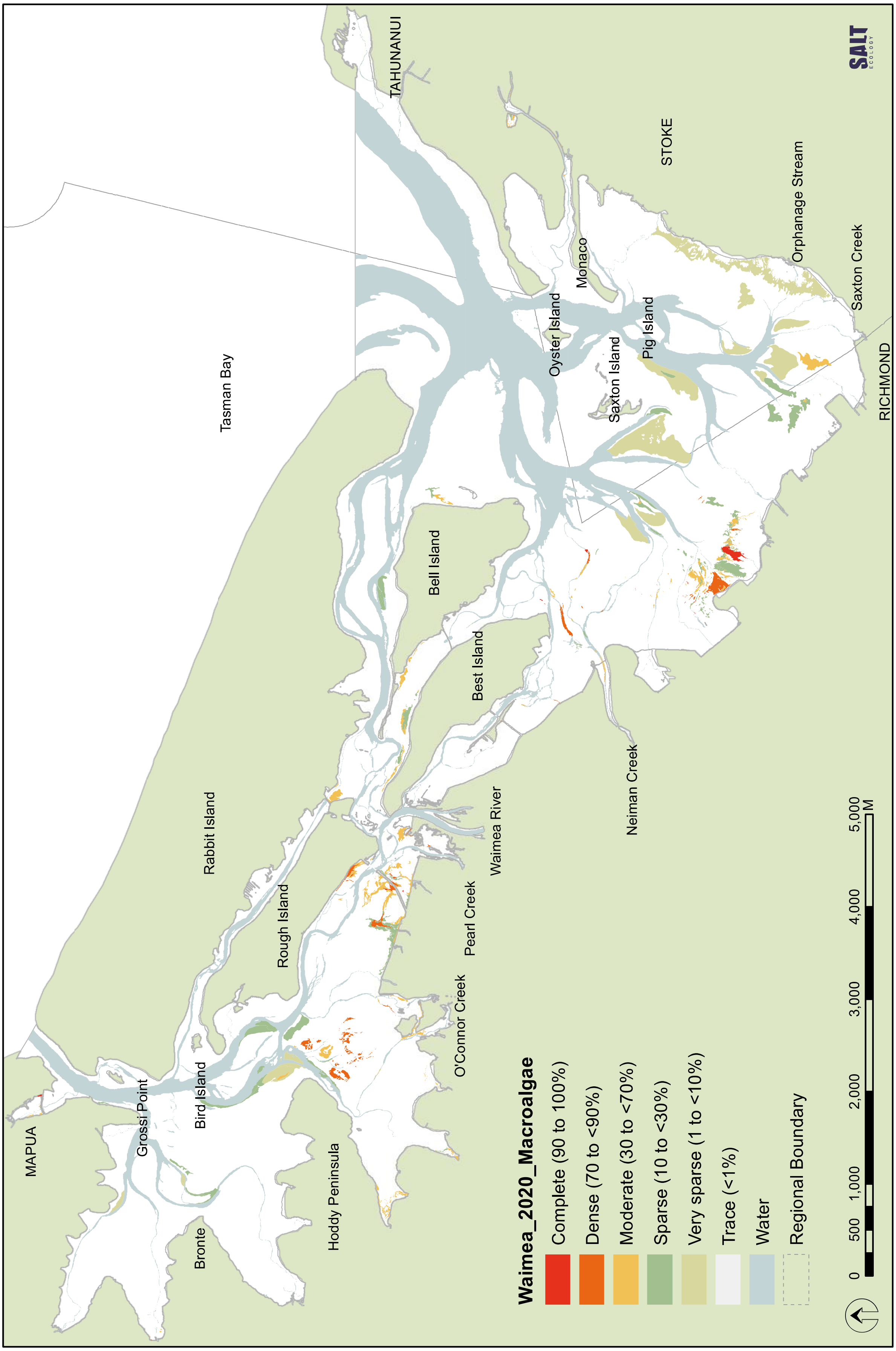


Fig. 1. Distribution and percentage cover classes of opportunistic macroalgae, Waimea Inlet May 2020. Source: Stevens et al. (2020).

The objective of the present study is to determine the relative importance of different local nutrient inputs in the development and growth of the stable macroalgal beds adjacent to the MDF Plant/Bark Processors facility. Nutrients inputs to this part of Waimea Inlet include Neimann and Borck Creeks, groundwater seeps (particularly those around the MDF Plant/Bark Processors facility), industrial discharges, stormwater discharges and accidental discharges (such as aberrational sewage discharges from the pumping stations along the main sewer running along State Highway 6 between Nelson and Richmond (Fig. 2).

Macroalgal patches are also developing in the area between the Beach Road reclamation and Reservoir Creek in the southeast corner of Waimea Inlet. This area is a secondary focus of the study.

Macroalgal beds along the eastern side of the estuary, which overlaps the Nelson City Council boundary, are outside the scope of this study.

1.2 STRUCTURE OF THIS REPORT

Section 2 reviews existing information on potential nutrient sources, including streams, groundwater, industrial and other wastewater discharges. Section 3 describes sediment sampling undertaken for the present study to compare nutrient concentrations in sediments in and around macroalgal beds and potential sources. Section 4 combines existing and new information to present conclusion on the relative importance of different sources, and Section 5 identifies information gaps and makes recommendations for addressing them.

Eagle Technology, Land Information New Zealand, GEBCO, Community maps contributors

Fig. 2. Location of Waimea Inlet and places names referred to in text.

2. EXISTING INFORMATION ON NUTRIENT SOURCES AND SINKS

2.1 GENERAL OVERVIEW

Waimea Inlet is one of the largest intertidally dominated estuaries in the South Island. It covers an area of ~3462ha, and is defined as a well-flushed, shallow, intertidal-dominated lagoon type estuary. The estuary comprises two main intertidal basins, each with side arms and embayments (some separated by causeways), and several islands. It discharges to Tasman Bay via two tidal entrances at either end of Rabbit Island. Residence time in the estuary is less than one day, and most of the intertidal flats are perched high in the tidal range, meaning that the estuary almost completely drains at low tide leaving the intertidal area exposed for much of the tidal cycle.

Because of the large proportion of intertidal area and relatively short residence time, stream discharges are confined to narrow channels at low tide, dispersed across a wider area during high tide, and largely flushed from the estuary by the falling tide.

Although dominated by intertidal sand and mudflats, the well-flushed and often steeply incised low-tide channels are deep and, particularly near the entrances, support a variety of cobble, gravel, sand, and biogenic (oyster, tubeworm, sponge garden) habitats (Asher et al. 2008; Stevens et al. 2020).

Catchment land use (Fig. 3, Table 1) is dominated by indigenous and exotic forestry, and pasture. Catchment geology includes the Dun Mountain "mineral belt" region, which contains rock formations particularly high in metals such as nickel, chromium and copper (Robinson et al. 1996; Rattenbury et al. 1998).

The Waimea River is the main freshwater inflow to the estuary but at least nine small streams also contribute, with the potential for localised impacts on the estuary (Gillespie et al. 2001). In the present context, the most relevant streams are Borck Creek, Neimann Creek and Reservoir Creek, and are discussed further in Section 2.2.

Monthly water quality state-of-the-environment monitoring is conducted in Borck, Neimann and Reservoir creeks (details below), and in the Waimea River (the nearest site to the estuary on the Waimea River is at State Highway 60 at Appleby, ~2.5 km upstream). East of Borck Creek, several smaller creeks enter Waimea Inlet but there does not appear to be any information available on their flow rates or water quality. From west to east, these are: Estuary, Harness, Pastoral, Jimmy Lee, Talbot and McPhearson creeks.

Table 1. Summary of catchment land cover (LCDB5 2018) for Waimea Inlet.

LCDB5 (2018) Class and Name		Ha	%
1	Built-up Area (settlement)	2,356.7	2.5
2	Urban Parkland/Open Space	602.6	0.6
5	Transport Infrastructure	115.1	0.1
6	Surface Mine or Dump	77.3	0.1
10	Sand or Gravel	28.3	0.03
15	Alpine Grass/Herbfield	396.9	0.4
16	Gravel or Rock	592.7	0.6
20	Lake or Pond	112.1	0.1
21	River	15.8	0.02
22	Estuarine Open Water	133.5	0.1
30	Short-rotation Cropland	888.1	0.9
33	Orchard, Vineyard Other Perennial Crop	2,689.9	2.8
40	High Producing Exotic Grassland	18,357.0	19.4
41	Low Producing Grassland	501.1	0.5
43	Tall Tussock Grassland	1,934.1	2
45	Herbaceous Freshwater Vegetation	6.2	0.01
46	Herbaceous Saline Vegetation	91.7	0.1
50	Fernland	67.1	0.1
51	Gorse and/or Broom	959.6	1
52	Manuka and/or Kanuka	2,769.7	2.9
54	Broadleaved Indigenous Hardwoods	2,171.9	2.3
55	Sub Alpine Shrubland	494.4	0.5
56	Mixed Exotic Shrubland	107.9	0.1
64	Forest - Harvested	4,681.5	5
68	Deciduous Hardwoods	198.6	0.2
69	Indigenous Forest	28,614.2	30.3
71	Exotic Forest	25,491.0	27
	Total	**94,455**	**100**

Intensive land development (LCDB classes 30 & 31) on the Waimea Plains. Waimea Inlet in the background.

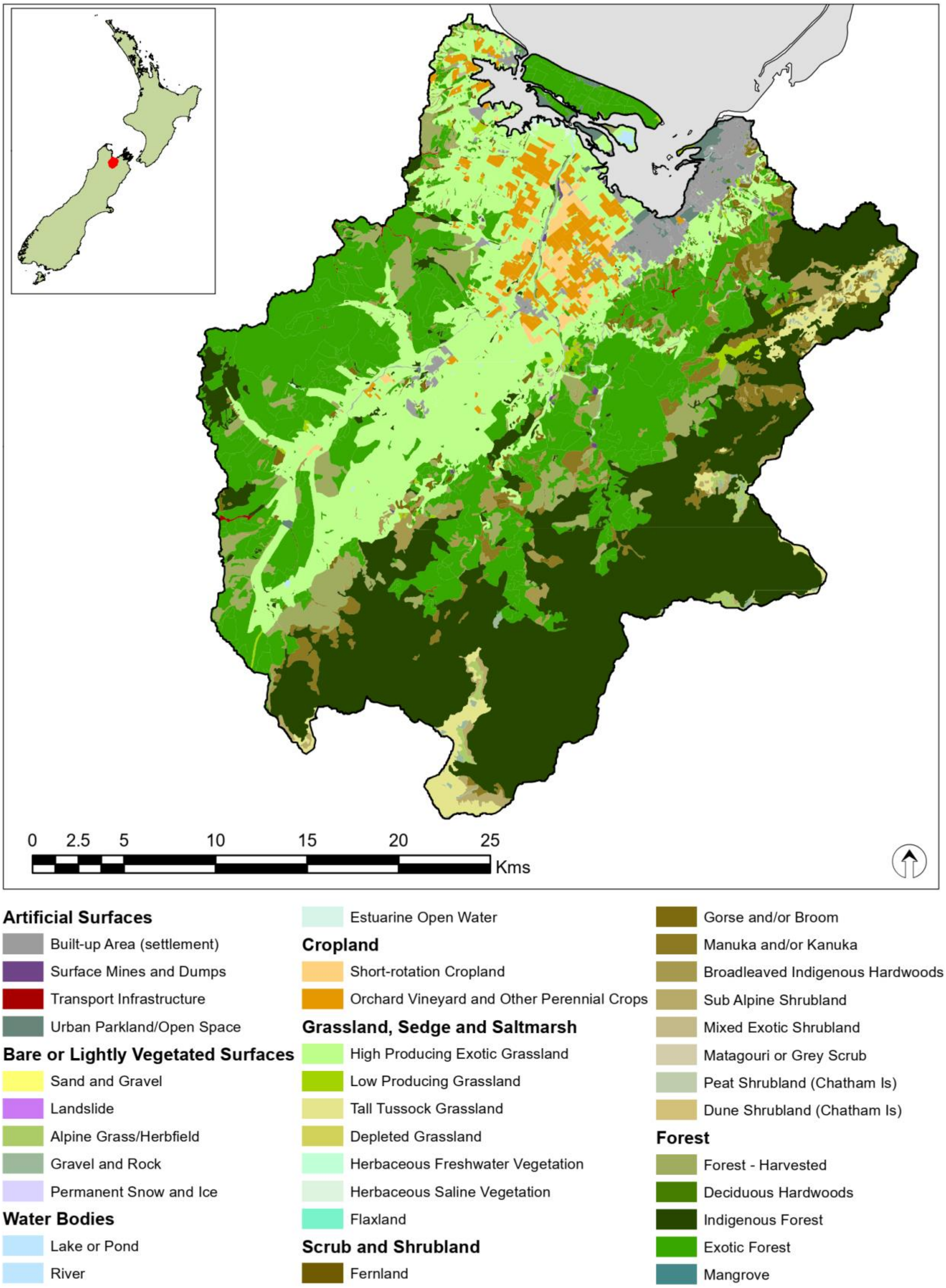


Fig. 3. Waimea Inlet and surrounding catchment land use classifications, LCDB5 2018.

2.2 RIVER WATER QUALITY MONITORING

Information in this section is taken from State of the Environment (SOE) river water quality monitoring reports by James and McCallum (2015), McCallum (2023) and from TDC SOE data in Land, Air, Water Aotearoa (LAWA: downloaded June 2023):

https://www.lawa.org.nz/explore-data/tasman-region/river-quality/.

2.2.1 Borck Creek

Borck Creek is spring-fed with the catchment land use predominantly horticultural and rural-residential, with some plantation forest in the upper catchment and native forest remnants in gullies. Headwater tributaries flow all year. During wetter parts of the year, lower reaches of the creek are fed by tributary streams, but during drier periods (typically 5-6 months per year), there is no surface flow in much of the course of Borck Creek and most of its tributaries. The lower 1.8 km of the creek is only fed by groundwater from the Hope Unconfined Aquifer, but the lowest reach flows all year because of input from a spring 1.2km upstream of the mouth.

Mean annual flow is 321L/s based on data from WRENZ 2013 (NIWA's online Water Resources Explorer tool) presented by James & McCallum (2015). However, the median flow rate from a dataset covering the period from July 1969 to May 2022, provided by TDC[1], was 69L/s. The possible reason for the difference between these values is discussed below.

Water quality was monitored quarterly at base flows up to June 2016 and monthly thereafter at all flows at a site 400 m downstream of Queen Street. Data from 2010-2014 from Borck Creek (400 m downstream of Queen Street) showed high annual median concentrations of nitrate (from 2.4mg/L to >6.9mg/L [2]). TDC SOE data accessed via LAWA provides 5-year median concentrations of: total nitrogen (TN) 6.35mg/L, nitrate nitrogen 6.45mg/L, ammoniacal nitrogen 0.0025mg/L, total phosphorus (TP) 0.016mg/L and dissolved reactive phosphorus (DRP) 0.0052mg/L[2] (Table 2).

Nitrogen and phosphorus are important nutrients for plant growth, with the former generally more often limiting in marine and estuarine environments and the former in freshwater. Total nitrogen and nitrate show a *very likely deteriorating* trend (i.e., increasing concentration) whereas ammoniacal nitrogen, TP and DRP show a *likely* or *very likely improving* trend. A significant discharge of N from a nursery operation has been recently discovered in the upper reaches of Borck Creek (Trevor James, TDC pers. comm.).

2.2.2 Neimann Creek

Neimann Creek is spring-fed and the predominant land uses in the catchment are pasture (beef and sheep) and horticulture (grapes, market gardening).

The online river data tool NZ River Maps (https://shiny.niwa.co.nz/nzrivermaps/) provides an estimated mean flow for Neimann Creek of 0.01m^3/s (10L/s). The median flow rate from data covering the period March 1966 to May 2023, provided by TDC, was 69 L/s, close to the average flow of 77 L/s also provided by TDC. Again, the possible reason for the difference between these values is discussed below.

Water quality was monitored quarterly up to June 2016 and monthly thereafter at a site 600 m upstream of Lansdown Road. Median (5-year) concentrations of nutrients from LAWA are: TN 2.65 mg/L, nitrate nitrogen 2.6 mg/L, ammoniacal nitrogen 0.008 mg/L, TP 0.008 mg/L and TP 0.0067 mg/L (Table 2). Trends in concentrations over the period 2016-2021 are indeterminate for ammoniacal nitrogen but very likely improving for nitrate.

2.2.3 Reservoir Creek

The catchment contains a relatively large area of urban development compared to the other two creeks. Plantation forestry is another major use, and there are also areas of native forest and pasture. Flow rates in the lower parts of the creek are relatively variable because of the large amount of impervious surface. At the time of James and McCallum's report, cattle had access to sections of the creek, increasing concentrations of sediment and faecal coliforms and, presumably, nutrients in the water.

Mean annual flow downstream of Salisbury Road is 571L/s (data from WRENZ 2013 presented by James & McCallum 2015). The median flow rate from data covering the period March 1966 to May 2023, provided by TDC, was 20L/s, noting sampling was quarterly at base flows up until June 2016, then monthly at all flows. The possible reason for the difference between these values is discussed below.

TDC SOE data accessed via LAWA provides 5-year median concentrations of: TN 2.2mg/L, nitrate nitrogen

[1] Data provided by Monique Harvey, TDC, to Don Morrisey 22 June 2023.

[2] 6.9 g/m^3 is the National Bottom Line set out in the National Policy Statement for Freshwater Management (2014).

1.94mg/L, ammoniacal nitrogen 0.007mg/L, TP 0.028mg/L and TP 0.0123mg/L (Table 2). Over the period 2016-2021, trends in concentrations of nitrate, ammoniacal nitrogen and DRP are likely increasing.

fed and average flows are unlikely to be estimated well by the WRENZ model, which is based on surface flow (Martin Doyle, TDC, pers. comm.). The median flow values based on TDC gauging are likely to be more useful for estimating nutrient loads, but both estimates

Table 2. Annual nutrient inputs to Waimea Inlet from Borck, Neimann and Reservoir Creeks. Nutrient concentrations are taken from TDC SOE data accessed via LAWA (see text for details). Estimated inputs are shown separately using average flow rates from WRENZ / NZ River Maps (upper part of table) and median flow rates derived from TDC gauging data. Flow rates were converted from L/s to annual values.

Stream	Nutrient	Median conc (mg/L)	Annual flow (L/s)	Annual discharge (m^3)	Annual loading to estuary (T)
Loadings based on WRENZ (2013) and NZ River Maps flow data					
Borck	TN	6.35	321	10123056	64.3
	NO_3	6.45	321	10123056	65.3
	NH_4	0.0025	321	10123056	0.025
	TP	0.016	321	10123056	0.162
	DRP	0.0052	321	10123056	0.053
Neimann	TN	2.65	10	315360	0.836
	NO_3	2.6	10	315360	0.820
	NH_4	0.008	10	315360	0.003
	TP	0.008	10	315360	0.003
	DRP	0.0067	10	315360	0.002
Reservoir	TN	2.2	571	18007056	39.6
	NO_3	1.94	571	18007056	34.9
	NH_4	0.007	571	18007056	0.126
	TP	0.028	571	18007056	0.504
	DRP	0.0123	571	18007056	0.221
Loadings based on TDC flow data					
Borck	TN	6.35	69	2175984	13.8
	NO_3	6.45	69	2175984	14.0
	NH_4	0.0025	69	2175984	0.005
	TP	0.016	69	2175984	0.035
	DRP	0.0052	69	2175984	0.011
Neimann	TN	2.65	69	2175984	5.8
	NO_3	2.6	69	2175984	5.7
	NH_4	0.008	69	2175984	0.017
	TP	0.008	69	2175984	0.017
	DRP	0.0067	69	2175984	0.015
Reservoir	TN	2.2	20	630720	1.4
	NO_3	1.94	20	630720	1.2
	NH_4	0.007	20	630720	0.004
	TP	0.028	20	630720	0.018
	DRP	0.0123	20	630720	0.008

2.3 NUTRIENT LOADS FROM THE STREAMS TO THE ESTUARY

Combining average or median flow rates and nutrient concentrations provides estimates of TN loading from Borck, Neimann and Reservoir Creeks to Waimea Inlet. Borck and Neimann Creeks are predominantly spring-

of flow are compared in Table 2.

Using the average flow values from James and McCallum (2015) gives TN loads of 64.3T/y, 0.8T/y and 39.6T/y from Borck, Neimann and Reservoir Creeks, respectively (Table 2). Corresponding values for TP are 0.16T/y, 0.003T/y and 0.50T/y.

In contrast, using the median flow rates from TDC's gauging data gives TN loads of 13.8T/y, 5.8T/y and 1.4T/y for Borck, Neimann and Reservoir Creeks, respectively (Table 2). Corresponding values for TP are 0.035T/y, 0.017T/y and 0.018T/y.

These estimates are very rough but indicate that, of the three creeks considered, Borck Creek is the largest contributor of TN to the estuary (by a factor of 2.4 over the second largest, Neimann Creek). The higher nitrogen concentration of Borck Creek elevates its contribution above that of Neimann even though the median flows are the same (Table 2). Note, however, that additional flow and nitrate may enter Neimann Creek downstream of TDC's monitoring site.

Borck Creek is also the largest contributor of TP, by a factor of 2 over Neimann and Reservoir Creeks (Table 2). This is due to a higher median concentration than Niemann Creek and a higher flow rate than Reservoir Creek (Reservoir Creek has the highest TP concentration of the three: Table 2).

CLUES modelling of nutrient loads

NIWA's Catchment Land Use for Environmental Sustainability (CLUES, version 10.3) model was used as an additional means of comparing nutrient loads to the eastern part of Waimea Inlet from different streams (Table 3). CLUES is a GIS-based system that predicts the effects of land-use change and farm practice on water quality at the catchment scale (for detail see https://niwa.co.nz/freshwater/our-services/catchment-modelling/clues-catchment-land-use-for-environmental-sustainability-model).

The model output supports the conclusion that, of the streams for which flow and concentration data were available, Borck Creek contributes the largest load. The CLUES estimated load from Borck Creek is close to that from TDC flow and nutrient concentration data (15.4t/yr and 13.8t/yr, respectively). The load from Neimann Creek is smaller than that estimated from flow and concentration data and is similar to that of several other creeks.

The dominant TN and TP loading from the Waimea River is unsurprising given its much larger flow and has been identified in other studies (e.g., Gillespie & Berthelsen 2017). Perhaps more surprising are the relatively large loads from Seal Creek (compared to other minor creeks), which enters the estuary via a culvert between the Bark Processors facility and the MDF. There are macroalgal beds adjacent to the mouth of Seal Creek (Fig. 4).

Table 3. Output from CLUES modelling of catchment contaminant loads draining to the eastern part of Waimea Inlet. 'TN' total nitrogen, 'TP' total phosphorus, and 'TSS' total suspended solids.

CLUES 10.3 run Sept 2023 Stream/Site	TN t/yr	TP t/yr	TSS kt/yr
Tahunanui Stream	0.73	0.03	0.051
Parkers Rd Drain	1.20	0.06	0.446
Jenkins Creek	3.45	0.42	2.121
Poorman Stream	2.40	0.38	2.288
Orchard Stream	1.31	0.06	0.115
Stoke Industrial area	0.32	0.01	0.003
Orphanage Creek	3.85	0.78	2.977
Saxon Creek	3.35	0.64	1.687
Reservoir Stream	1.64	0.14	0.439
McPhearson/Vercoes	0.76	0.03	0.007
Jimmy Lee Creek	1.48	0.08	0.070
Harness Stream	0.59	0.02	0.002
Borck Creek	15.41	0.57	1.204
Seal Creek	11.23	0.26	0.036
Swamp Road	2.08	0.09	0.005
Neimann Stream	1.35	0.04	0.008
Lansdowne Road Farm	0.25	0.01	0.002
Pearl Creek	2.20	0.08	0.012
Rabbit Island (east side)	0.30	0.03	0.001
Waimea River	255.18	47.56	140.91

Conclusion

The smaller streams entering the southeastern part of Waimea Inlet are the most likely nutrient sources to the macroalgal beds, contributing an estimated 54t/y of TN (12% of total load); and 3.7t/y of TP (5% of total load) to the estuary. Of this, ~27t/y (49%) of the predicted TN load is attributed to two sources - Borck and Seal Creeks. Water quality monitoring data from Borck Creek confirms it is a major source of nitrogen and therefore Borck and Seal Creeks appear to be major contributors to the general development of macroalgal growth in the estuary.

The three creeks for which water quality data were available (Borck, Neimann and Reservoir) all show increasing concentrations of at least some forms of nitrogen over time. Nitrogen loads to Waimea Inlet are, consequently, also likely to increase in the future. This is particularly likely if changes in patterns of rainfall are considered. In addition to those creeks for which monitoring data were available, several other creeks appear to make potentially important contributions to

TN loading, including Seal Creek and several creeks draining to the Nelson coastal area.

2.4 GROUNDWATER

James and McCallum (2015, page 41) reported that nitrate concentrations in Neimann Creek are the highest in Tasman District, but this is not consistent with the concentrations provided by LAWA for the last five years (6.45mg/L and 2.6mg/L for Borck and Neimann Creeks, respectively).

James and McCallum (2015) also noted that groundwater feeding Neimann Creek "*originates from a plume within the Waimea Lower Confined Aquifer and Upper Confined Aquifer which contain high nitrate concentrations due in part to historical discharges from a former piggery in the aquifer recharge area. The up-gradient extent of this plume was around the Ranzau Rd/Patons Rd intersection. Nitrate concentrations in this creek are highest just upstream of Landsdowne Rd (average around 10g/m^3). The pattern of nitrate flux at this site is highly variable and follows closely that of bore #802 located 1.1km SW near SH60. Higher nitrate concentrations appear to follow high groundwater levels and periods of high rainfall. The source of this groundwater is unclear but investigations are underway*".

The most recent five-year median concentrations of nitrate and DRP in TDC's GW32 groundwater-monitoring bore, north of lower Queen Street, were 11 mg/L and 0.02 mg/L, respectively (data from LAWA). In contrast, concentrations at the bore GW802 in Appleby, which correlates with concentrations in Neimann Creek, were much lower (1.9 mg/L and 0.008 mg/L, respectively). The difference in concentrations between these bores reflects those between Neimann and Borck Creeks.

Fenemor (2020) summarised information on nitrates in groundwater in the Waimea Plains and concluded that by 2020 the historic contamination from the former piggery had passed the groundwater monitoring bores in the Ranzau/Bartletts/Blackbyre/State Highway 60 area. The present nitrate contamination in these bores is probably caused by local, intensive land uses upstream, particularly market gardening. This suggests that nitrate concentrations in Neimann Creek have now dropped to below those of Borck Creek, consistent with recent data from LAWA for both stream and groundwater quality. However, Neimann Creek concentrations are still relatively high and exceed the nitrate toxicity limit of 2.4g/L that came into force under the NPSFM in 2020).

Recent data from the Waimea Groundwater Quality Survey 2021 (presented to TDC 1 June 2023, https://www.stuff.co.nz/nelson-mail/132206253/nitrogen-found-in-groundwater-not-associated-with-historic-piggery-plume) show that nitrate concentrations in groundwater in the Ranzau/Bartletts/Blackbyre area have increased lately after decreasing over the previous two decades. The difference in concentration between current values (20-30mg/L) and those of the residual piggery plume (11-16mg/L) suggests that about 10mg/L is being contributed by an unknown source, possibly overlying agricultural and horticultural land use.

Groundwater concentrations are also high at well GW37, in the Ranzau Road/Pugh Road area in Hope (11.0mg/L nitrate and 0.05mg/L for DRP (LAWA). Concentrations in this bore, sampling the Waimea Upper Confined Aquifer, may indicate a possible upstream source of nutrients to Borck Creek.

Conclusion

Nitrate concentrations in groundwater around Neimann Creek appear to have decreased in recent years and, although still elevated, are lower than those in groundwater around Borck Creek. This is consistent with relative concentrations in the water in these creeks. However, there is also more recent evidence that concentrations in groundwater around Neimann Creek may be increasing again, possibly because of agricultural and horticultural land use.

2.5 BELL ISLAND WASTEWATER TREATMENT PLANT

The Bell Island wastewater treatment plant (WWTP) discharges treated effluent into the eastern part of Waimea Inlet from an outfall in the low-tide channel at the eastern end of Bell Island. Discharge occurs over a three-hour period beginning at high tide.

Hydrodynamic modelling for the renewal of the consent to discharge wastewater (MetOcean 2017) indicated that tidal flushing of Waimea Inlet downstream of the discharge is sufficient to prevent a progressive increase in the concentrations of effluent-related nutrients in the eastern inlet over time. Consequently, the receiving environment for the discharge is the area of the Inlet downstream of the outfall, and the adjacent part of Tasman Bay, and does not include the areas considered in this report. Five-yearly monitoring under the consent suggests that dilution of nutrients and other contaminants in the wastewater occurs close to the outfall (and within a 250 m downstream mixing zone).

Based on consent-monitoring data, Gillespie and Berthelsen (2017) assessed the average nutrient concentrations downstream of the discharge as indicating a very low eutrophication status. This assessment suggests that the discharge is unlikely to be contributing to the development of macroalgal beds in the southeastern part of the inlet. However, this was a broad-scale assessment, and it is still possible (and evidence shows this to be the case) that smaller, local inputs of nutrients and local patterns of water circulation may create favorable conditions for macroalgal growth at a smaller spatial scale.

Despite Gillespie and Berthelsen's (2017) assessment, it is still informative to estimate the nutrient load to the receiving environment from the WWTP relative to the loads from the streams (Section 2.2).

Average daily discharge rates from the outfall (based on monthly averages) in 2011, 2016 and 2021 were 13,624 m^3/d, 14,954 m^3/d and 18,081 m^3/d, respectively (data from the Nelson Sewerage Business Unit reported in Morrisey (2022)). Average daily loads of TN to the inlet, using monthly averages derived from effluent monitoring (presented in Morrisey (2022)), were 0.24 t/d, 0.27 t/d and 0.26 t/d in 2011, 2016 and 2021, respectively. Equivalent values for TP were 0.07 t/d in all three years.

These average daily loads were converted to average annual loads by multiplying by 365 (Table 4). Because there is considerable seasonal variation in the nutrient load (being higher in winter when there is less microalgal growth in the treatment ponds to take up nutrients), the minimum and maximum monthly average daily loads were also converted to annual loads to indicate temporal variation (Table 4).

The average annual TN load discharged from the WWPT in 2011 was 87 t (range 35-150 t based on monthly average values), 97 t (range 51-123 t) in 2016, and 96 t (range 35-137 t) in 2021. Equivalent values for TP were 27 t (12-49 t), 27 t (17-37 t), and 26 t (16-39 t).

Conclusion

The TN and TP loads from the WWTP are several times larger than the combined load from Borck, Neimann and Reservoir Creeks – roughly 4.5 times in the case of TN and 380 times in the case of TP.

Overall, the largest estimated sources of TN and TP to Waimea Inlet are the Waimea River (~255 t/y of TN, 58% of total load; and ~48t/y of TP, 59% of total load) and the WWTP (~93t/y of TN, 21% of total load; and ~27t/y of TP, 33% of total load). However, based on the MetOcean (2017) modelling, as much or most of these loads are expelled into Tasman Bay by the ebbing tide, they are likely to have a negligible influence on the areas where macroalgal beds have developed.

Table 4. Annual nutrient inputs to Waimea Inlet from the Bell Island wastewater treatment plant in 2011, 2016 and 2021.

	Discharge m^3/y	TN load T/y	TP load T/y
2011			
Mean	4972760	87	27
Minimum	2041445	35	12
Maximum	8850520	150	49
2016			
Mean	5458210	97	27
Minimum	4064640	51	17
Maximum	7391980	123	37
2021			
Mean	6599565	96	26
Minimum	4767265	35	16
Maximum	9352395	137	39

Discharge rates and loads were recorded by the Nelson Regional Sewerage Business Unit, as presented in Table 1 of Morrisey (2022). Values are averages derived from the average daily rate or load in each of several months in each of the three years (January-August in 2021, January -September in 2011 and January-November in 2021). Discharge rates and loads were converted from m^3/d and kg/d to annual values. 'TN' total nitrogen, 'TP' total phosphorus.

2.6 SEDIMENTS

Some (possibly most) of the nutrient load entering the inlet via streams and surface runoff will be associated with sediment particles, in particular the finer, organically richer fractions. Much of this sediment will settle out along the edges of the intertidal channels downstream from the mouth of the creek. Some of the dissolved nutrients entering the inlet will be taken up by micro- and macroalgae, and thereby incorporated into sediments.

In contrast to dissolved and suspended nutrients in the water column, the concentration of which varies considerably over time, concentrations of nutrients that accumulate in the sediments will be relatively stable and may provide an important source for the development of macroalgal beds in the intertidal area of the eastern inlet. Concentrations of nutrients, particularly nitrogen, in these sediments would therefore be expected to correlate with the presence of macroalgal beds.

As part of the SOE monitoring programme for the Waimea Inlet, concentrations of TN and TP in sediments have been measured annually at three long-term SOE monitoring sites in the eastern end of Waimea Inlet: from 2014-2016 at sites SoE-A and SoE-C, and from 2019-2021 at site FS-E. (Forrest et al. 2021). Since 2016, concentrations at SoE-A and SoE-C have also been measured every five years as part of the consent monitoring for the Bell Island WWTP effluent discharge (Morrisey 2022).

Over the period 2014-2021, concentrations of TN and TP at the three monitoring sites have ranged from <500-800mg/kg and 370-463mg/kg, respectively (Table 5). The percentage of mud in the sediments has ranged from 37-44% at SoE-A, 27-38% at SoE-C and around 10% at FS-E (Table 5).

Concentrations of TN and TP in sediments around the eastern end of Bell Island were measured in December 2021 as part of the consent monitoring for the Bell Island discharge (Morrisey 2022). Concentrations of TN and TP ranged from <500-800 mg/kg and 247-463 mg/kg, respectively (Table 5). Again, these lower concentrations relative to those recorded during the present study (see Section 3) are at least partly due to the coarser texture of sediments off Bell Island (3-37% mud).

Conclusion

Monitoring of sediment quality in the eastern part of the inlet over the last 10 years indicates that TN concentrations are below 800mg/kg and those of TP are below 470mg/kg, providing a baseline to compare with the results of the targeted sampling programme. A survey of concentrations of nutrients and contaminants in sediments around potential sources in the Nelson coastal area, including the mouths of creeks, stormwater and wastewater discharges, has recently been completed and the results will be available in the near future.

Table 5. Concentrations of sediment total nitrogen (TN), total phosphorus (TP), total organic carbon (TOC) and mud in the eastern part of Waimea Inlet from past studies. 'nd' – no data (total organic matter, rather than TOC, was measured in the Bell Island samples).

Bell Island[a]	TN mg/kg	TP mg/kg	TOC %	Mud %
W3B	600 (0)	347 (9)	nd	27 (1.5)
W5B	<500	343 (12)	nd	3.2 (0.9)
W6B	800 (0)	463 (7)	nd	35.8
W7B	<500	383 (23)	nd	5.7 (0.8)
W9B	<500	247 (7)	nd	1.9 (0.5)
SoE-A	<500	433 (9)	nd	36.8
SoE-C	600 (0)	400 (15)	nd	34.6

Waimea[b]	TN mg/kg	TP mg/kg	TOC %	Mud %
A 2014	700 (58)	437 (17)	0.54 (0.02)	42.7
A 2015	633 (33.)	463 (19)	0.35 (0.01)	37.4
A 2016	700 (0)	463 (7)	0.49 (0.01)	44.4
C 2014	733 (88)	370 (15)	0.54 (0.01)	26.6
C 2015	800 (100)	410 (17)	0.42 (0.02)	26.5
C 2016	700 (0)	397 (20)	0.51 (0.01)	37.6
E 2019	<500	310 (10)	0.17 (0.01)	10.1
E 2020	<501	280 (6)	0.18 (0.01)	9.9 (0.4)
E 2021	<502	303 (3)	0.18 (0.01)	10.3

[a] consent monitoring study for Bells Island discharge (Morrisey 2021),
[b] SoE monitoring of Waimea Inlet (Forrest et al. 2021).
Values for the second two surveys are means (SE) of three replicates.

Sediment sampling Site 10.

3. TARGETED SEDIMENT SAMPLING PROGRAMME

Existing information on nutrient concentrations in sediments in the eastern part of Waimea Inlet derives from a small number of locations (see Fig. 4). Additional sampling was therefore done for the present study, targeting areas along the outflow channels of the major creeks and areas where macroalgal beds are present.

Sediment samples were collected at 13 intertidal sites from the discharge channel of Neimann Creek in the west to the stream channels and intertidal flats off McPhearson and Jimmy Lee Creeks near Richmond in the east (for details, see Fig. 4 and Appendix 1). Samples were collected during the low-tide period on 5 May 2023.

The key sampling elements included sediment grain-size distribution (mud, sand, gravel), oxygenation status (measured as the apparent Redox Potential Discontinuity depth; aRPD), nutrients (TN, TP) and total organic content (TOC). At sites 1, 5, 8 and 10 samples were also analysed for trace metals (arsenic copper, chromium, cadmium, lead, mercury, nickel, zinc) and semi-volatile organic contaminants (SVOCs).

Sediment aRPD was measured in the field. For the other variables a single sample for sediment quality analyses at each site was composited from three sub-samples and sent to RJ Hill Laboratories for analysis (see Appendix 2 for methods).

Results were assessed, in addition to the authors' expert interpretation, against established or developing estuarine health metrics ('condition ratings'), drawing on approaches from New Zealand and overseas (Table 6). These metrics assign different indicators to one of four colour-coded 'health status' bands, as shown in Table 6.

Sampling sites (Fig 4 and Appendix 1) are shown in photographs in Table 7 and included the banks of creeks entering eastern Waimea Inlet, areas with varying densities of red macroalgal cover (*Agarophyton* spp.), and reference areas on flats away from macroalgal patches. Sediment texture varied among sites from very soft mud to gravel, sandy-mud and muddy-sand.

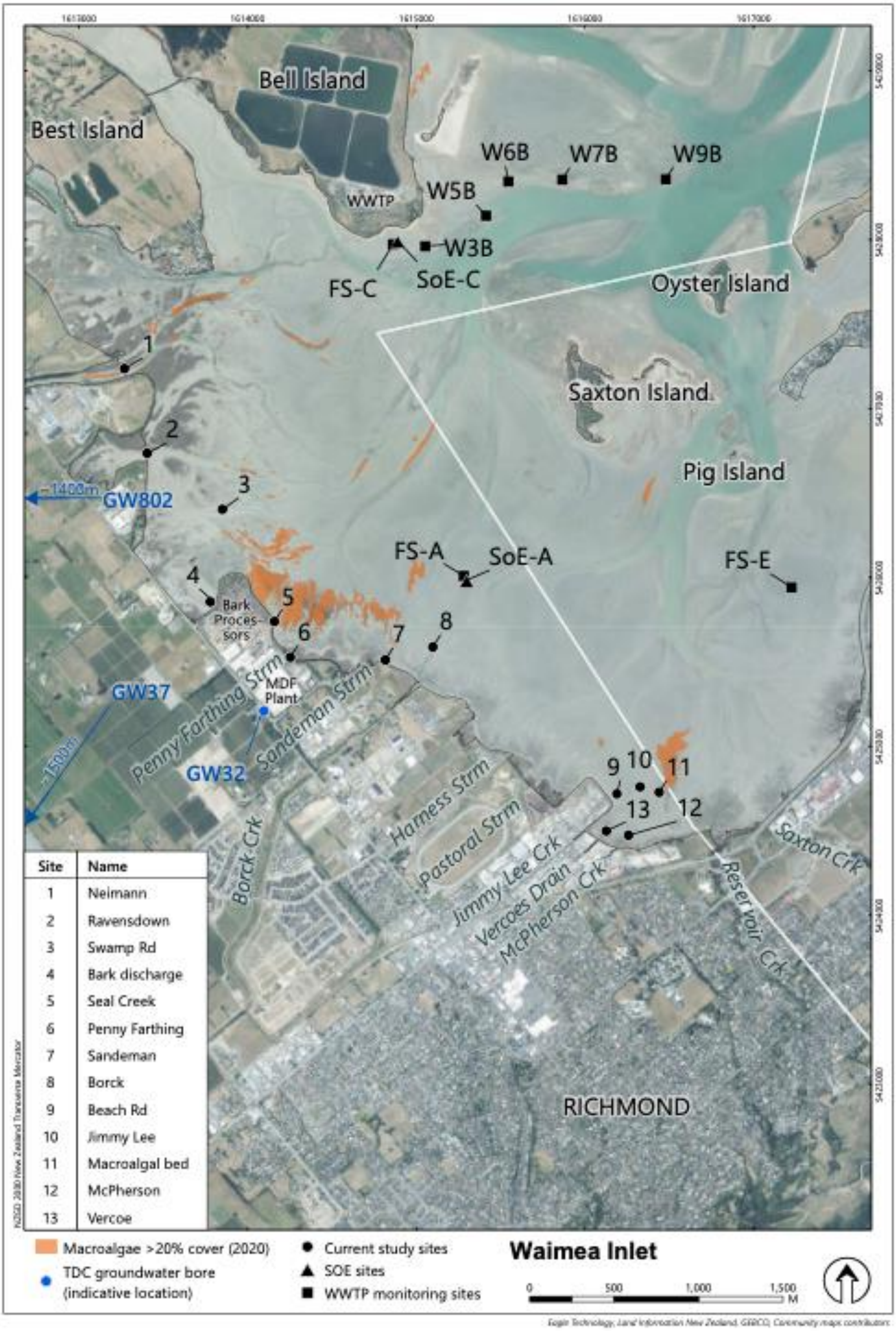
Site 6 was adjacent to Penny Farthing Creek, which is culverted under the MDF plant, immediately downstream from where it discharges into the inlet at the top of the shore via two 600-mm pipes.

Site 6 located on the banks of Penny Farthing Creek, which is culverted under the MDF plant.

Table 6. Indicators used to assess sediment results in the current report. See Glossary for definitions.

Indicator	Unit	Very good	Good	Fair	Poor
Sediment quality					
Mud content[1]	%	< 5	5 to < 10	10 to < 25	≥ 25
aRPD depth[2]	mm	≥ 50	20 to < 50	10 to < 20	< 10
TN[1]	mg/kg	< 250	250 to < 1000	1000 to < 2000	≥ 2000
TP		Requires development			
TOC[1]	%	< 0.5	0.5 to < 1	1 to < 2	≥ 2
Sediment trace contaminants[3]					
As	mg/kg	< 10	10 to < 20	20 to < 70	≥ 70
Cd	mg/kg	< 0.75	0.75 to <1.5	1.5 to < 10	≥ 10
Cr	mg/kg	< 40	40 to <80	80 to < 370	≥ 370
Cu	mg/kg	< 32.5	32.5 to <65	65 to < 270	≥ 270
Hg	mg/kg	< 0.075	0.075 to <0.15	0.15 to < 1	≥ 1
Ni	mg/kg	< 10.5	10.5 to <21	21 to < 52	≥ 52
Pb	mg/kg	< 25	25 to <50	50 to < 220	≥ 220
Zn	mg/kg	< 100	100 to <200	200 to < 410	≥ 410

1. Ratings from Robertson et al. (2016).
2. aRPD based on FGDC (2012).
3. Trace element thresholds scaled in relation to ANZG (2018) as follows: Very good <0.5 x DGV; Good 0.5 x DGV to <DGV; Fair DGV to <GV-high; Poor >GV-high. DGV = Default Guideline Value, GV-high = Guideline Value-high.



Site	Name
1	Neimann
2	Ravensdown
3	Swamp Rd
4	Bark discharge
5	Seal Creek
6	Penny Farthing
7	Sandeman
8	Borck
9	Beach Rd
10	Jimmy Lee
11	Macroalgal bed
12	McPherson
13	Vercoe

Fig. 4. Location map showing sites sampled in the present study.

Table 7. General photographs of each site.

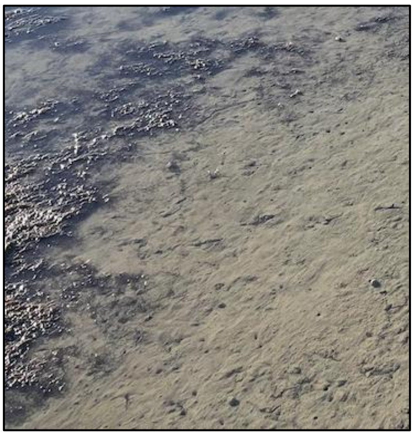
Site#	General overview	Sediment detail
1		
2		
3		
4		

Table 7 (cont.) General photographs of each site.

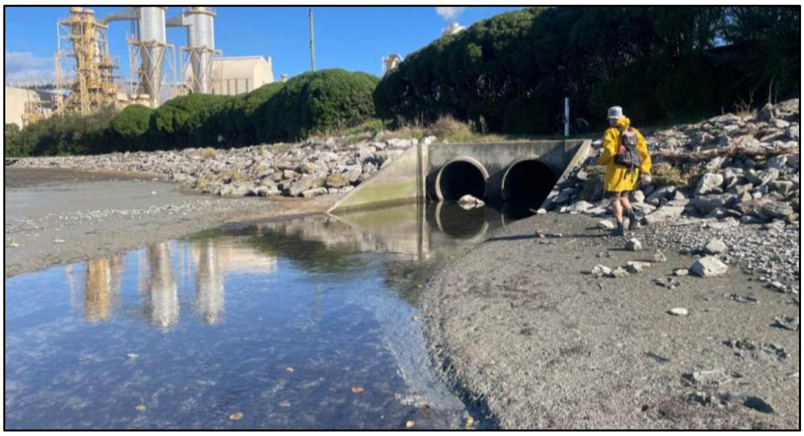
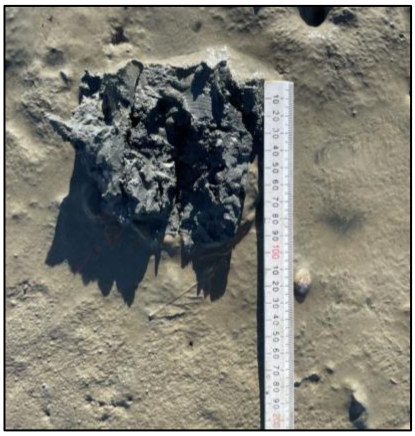
Site#	General overview	Sediment detail
5		
6		
7		
8		

Table 7 (cont.) General photographs of each site.

Site#	General overview	Sediment detail
9		
10		
11		
12		

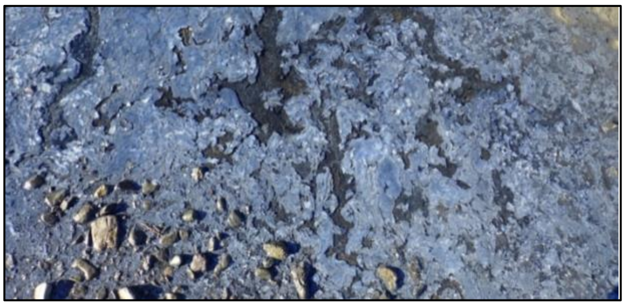
Table 7 (cont.) General photographs of each site.

Site#	General overview	Sediment detail
13		

Of specific note, Site 4 was located adjacent to a seep of anoxic water originating from a stormwater sump in the southwest corner of the Bark Processor's facility (see photos below). At the point where the piped discharge entered the estuary, sediments were anoxic, there was a strong smell of hydrogen sulphide (rotten eggs), and a mat of sulphur-oxidising bacteria was present on the sediment surface the interface of the oxic and anoxic zone.

Site water discharges from the south-western side of the Bark Processor's facility directly to the estuary via a piped outlet.

Site 4 was adjacent to a seep of anoxic water originating from the south-western side of the bark processing plant.



Sulphur-oxidising bacteria on the sediment surface.

3.1 NUTRIENTS, ORGANIC CONTENT AND MUD

General comments

Summaries of data from previous studies, and the 13 sites sampled in the present study, are presented in (Table 5, Table 8, and Fig. 5 5-10).

Concentrations of TN from 12 of the sites sampled during the present study (excluding Site 6 which is discussed separately below) ranged from 700mg/kg (Sites 8, 9 and 13) to 2000mg/kg (Site 1) (Table 8, Fig. 5). Equivalent values for TP were 470mg/kg (Site 13) to 740mg/kg (Site 1) (Table 8, Fig. 6). Percentages of TOC ranged from 0.59% (Sites 8 and 9) to 1.66% (Site 1) (Table 8, Fig. 7). Percent mud content ranged from 38% (Site 13) to 99% (Site 2) (Table 8, Fig. 8).

In terms of potential stress on aquatic organisms, based on the condition ratings presented in Table 6, the TN and TOC values were rated 'fair' (1000-2000mg/kg TN, 1-2% TOC) to 'good' (250-1000mg/kg TN, 0.5-1% TOC). Sediment mud content was rated 'poor' (38-99%).

Table 8. Concentrations of sediment total nitrogen (TN), total phosphorus (TP), total organic carbon (TOC) and mud in the eastern part of Waimea Inlet from the present study.

Site	TN mg/kg	TP mg/kg	TOC %	Mud %
Present study				
1	2000	740	1.66	97.9
2	1200	710	1.04	98.8
3	1000	610	0.95	90.5
4	800	700	0.67	39.0
5	1200	690	1.51	45.3
6	3000	1,480	3.6	61.9
7	900	710	0.83	58.1
8	700	600	0.59	57.1
9	700	630	0.59	74.3
10	1100	590	1.12	90.0
11	1000	540	0.82	85.9
12	1400	650	1.25	92.5
13	700	470	0.8	38.3

Shaded orange rows indicate presence of red macroalgal beds.

Sediments with higher mud contents generally had higher concentrations of nutrients and organic carbon. In the case of TN in the present set of samples, this relationship is not clear at mud contents <90%, but TN concentration increases with the percentage of mud above 90% mud (Fig. 9). A similar, but even less clear, relationships exist for TP and TOC (Fig. 9).

There was a correlation between the concentrations of TN and TOC in the sediments across these 12 sites, but less so for TP and TOC (Fig. 9). There was no evidence of a relationship between the concentrations of TP and TN (Fig. 10). This suggests that the organic material present in the sediments is enriched in nitrogen, but not phosphorus.

Site 6 was excluded from the discussion above because it contained much higher concentrations of both nutrients and TOC (Table 8, Fig. 9). This sample came from adjacent to Penny Farthing Stream that discharges from under the MDF plant via a culvert into an open drain cut through salt marsh. The bed of this stream near its point of discharge consists of very soft, deep and organically rich mud. The creek edge (from where the sample was taken), in contrast, consisted of muddy sand with a relatively low mud content (62%: Table 8, Fig. 8). This emphasises the high level of enrichment of the sediment at this site, which is also evident in the plots of TN and TP versus TOC and TP versus TN (Fig. 10). In terms of estuarine trophic status, these values correspond to "significant" stress (>2000mg/kg TN, >2% TOC: Robertson et al. 2016), and a condition rating of 'poor'.

The coarser nature of the sediments at the SOE and WWTP monitoring sites (see Table 5) relative to those in the present study (range 2-44% mud) is at least partly responsible for their lower nutrient concentrations.

Comparison of sediments in and out of macroalgal beds

Sites 1, 5, 9 and 11 were in or adjacent to macroalgal beds (Fig. 4, Appendix 1), though the bed around Site 9 was patchy and had a relatively low density of *Agarophyton* spp.

The sample from Site 5, adjacent to Seal Creek and the macroalgal bed north of the bark-processing plant, stands out in having a relatively high concentrations of TN and TOC compared with sites away from macroalgal beds but with similar percentages of mud (45%) (Fig. 9). The concentration of TP at Site 5 was less distinctive. Seal Creek had high predicted TN and TP loadings from the CLUES model (Table 3).

Among the muddy sites, Site 1 had relatively high concentrations of TN and TOC (Fig. 9). Again, this difference was not seen in the concentration of TP, which was similar to that at Site 2 where the mud content was high, but the site was in an unvegetated area of mudflat.

In contrast, the concentrations of TN in the samples from Sites 9 and 11 were not different from other samples with similar percentages of mud, even though Site 11 was in a large dense macroalgal bed (see Fig. 4).

3.2 METALS

Concentrations of metals, other than chromium and nickel, were well below ANZG DGV (the concentration at which adverse effects on aquatic species are *possible*) (Table 9). Concentrations of chromium at Site 1 exceeded the DGV and those of nickel exceeded the GV-high (the concentrations at which adverse effects are *probable*) at all four sites. These two metals are elevated in sediments throughout Waimea Inlet and are naturally derived from ultramafic soils in the catchment (Robinson et al. 1996; Rattenbury et al. 1998, Gillespie et al. 2011).

Like nutrients, trace metals adsorb to finer, more organically rich sediment particles. This tendency is reflected for some of the metals in the present study. Concentrations of copper, lead, mercury and zinc are slightly higher in the muddier samples (Sites 1 and 10: Table 9) but this is not the case for the other metals.

3.3 ORGANIC CONTAMINANTS

None of the organic contaminants analysed (including PAH and organochlorine pesticides) were present at concentrations above the methodological limit of detection (LoD). Consequently, it not possible to draw any useful conclusions other than to note that none of the concentrations exceeded ANZG (2018) DGV (for those compounds for which guidelines have been developed,' namely the organochlorine pesticides lindane, DDT, dieldrin and endrin, and for total PAH. In the present case, total PAH values were derived by summing the LoD for each individual compound, and then comparing to the DGV.

Conclusion

As expected, TN concentrations increased with the amount of mud in the sediment, at least for mud content >90%. TN also correlated with TOC content. TP did not show a clear relationship with mud content.

Although sediment TN concentrations were relatively high at some sites where macroalgal beds were present (Sites 1 and 5), the relationship between TN and macroalgae was not particularly clear. The concentrations at Site 11, in a dense bed (see photograph above), was no higher than at other sites with similar mud content away from beds (Sites 2, 3 10 and 12 (Fig. 9).

Table 9. Concentrations of mud and trace metals in sediments in the eastern part of Waimea Inlet from the present study. The ANZG (2018) *default guideline value* (DGV) and *guideline value - high* (GV-high) are also shown. Colour coding reflects condition ratings presented in Table 6.

Site	Mud %	Arsenic	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Zinc
1	97.9	6.9	0.035	91	23	13.6	0.06	117	80
5	45.3	7	0.043	73	19.3	9.9	0.03	104	71
8	57.1	7.5	0.028	73	16.2	9.2	0.03	100	61
10	85.9	7.3	0.043	66	22	12.3	0.04	84	101
DGV		20	1.5	80	65	50	0.15	21	200
GV-high		70	10	370	270	220	1	52	410

Fig. 5. Map showing sediment total nitrogen concentrations (mg/kg). Dots scaled to concentration (see map legend) and coloured to reflect condition band (see Table 6).

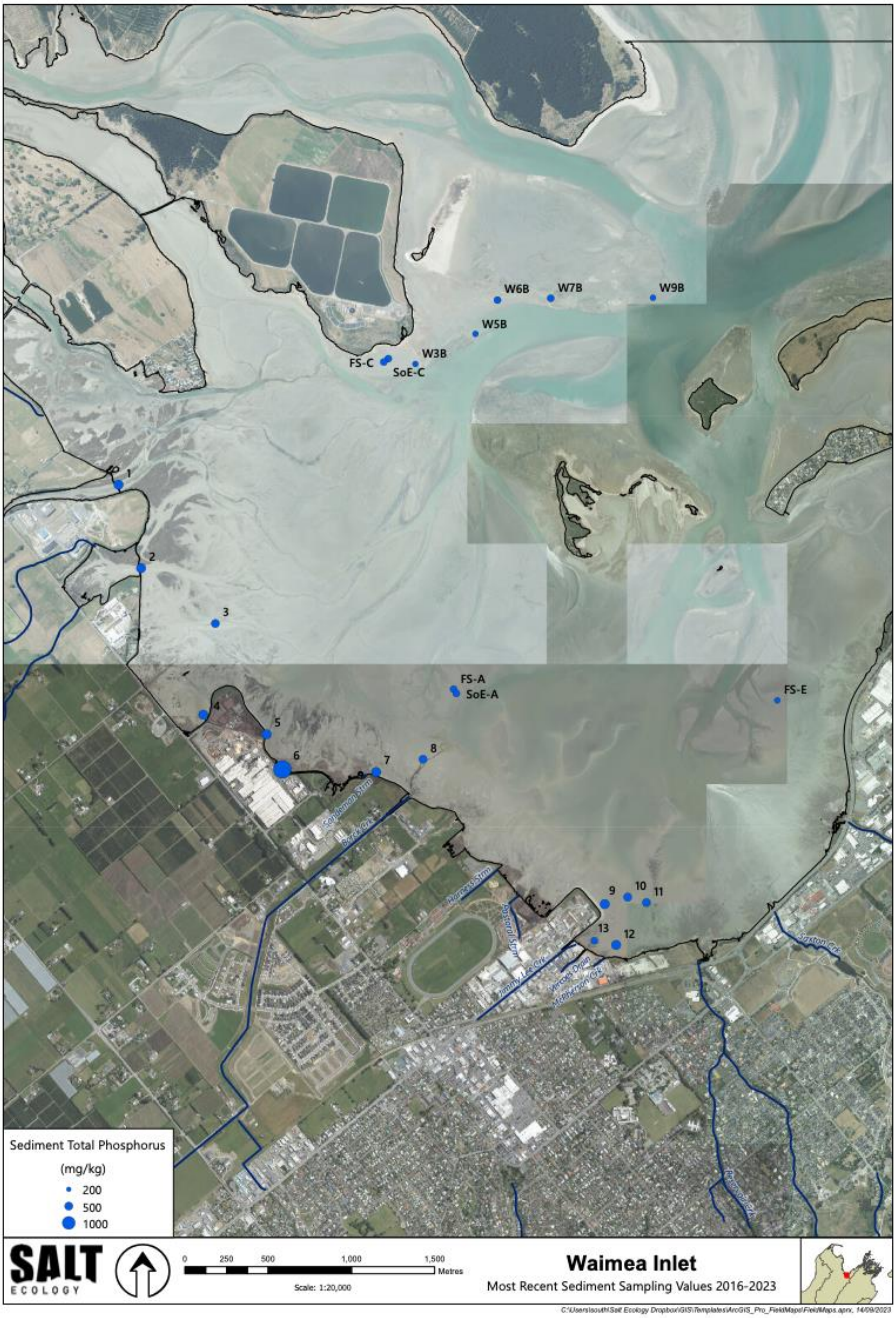


Fig. 6. Map showing sediment total phosphorus concentrations (mg/kg). Dots scaled to concentration (see map legend).

Fig. 7. Map showing sediment total organic carbon concentrations (mg/kg). Dots scaled to concentration (see map legend) and coloured to reflect condition band (see Table 6).

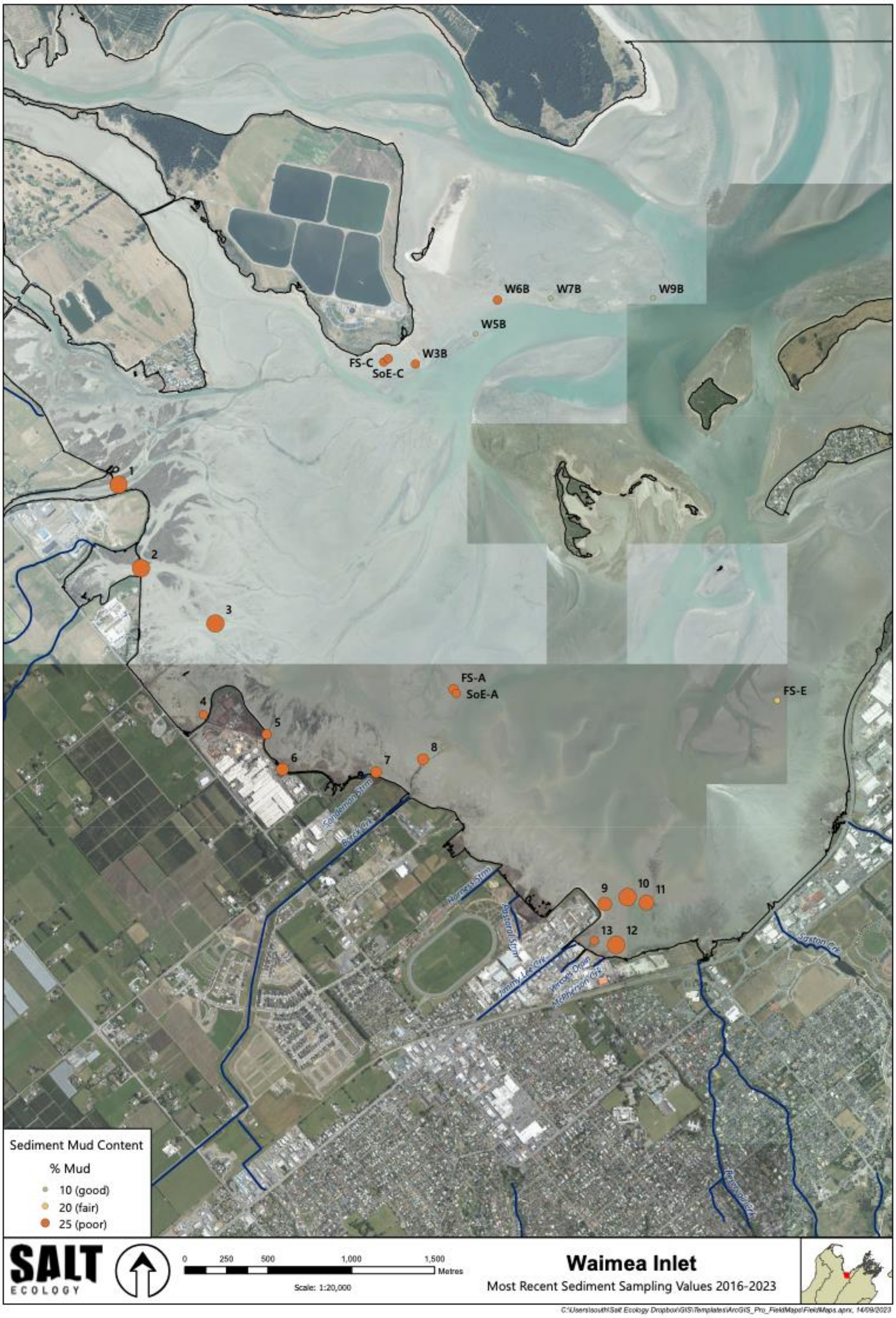


Fig. 8. Map showing sediment mud concentrations (%). Dots scaled to concentration (see map legend) and coloured to reflect condition band (see Table 6).

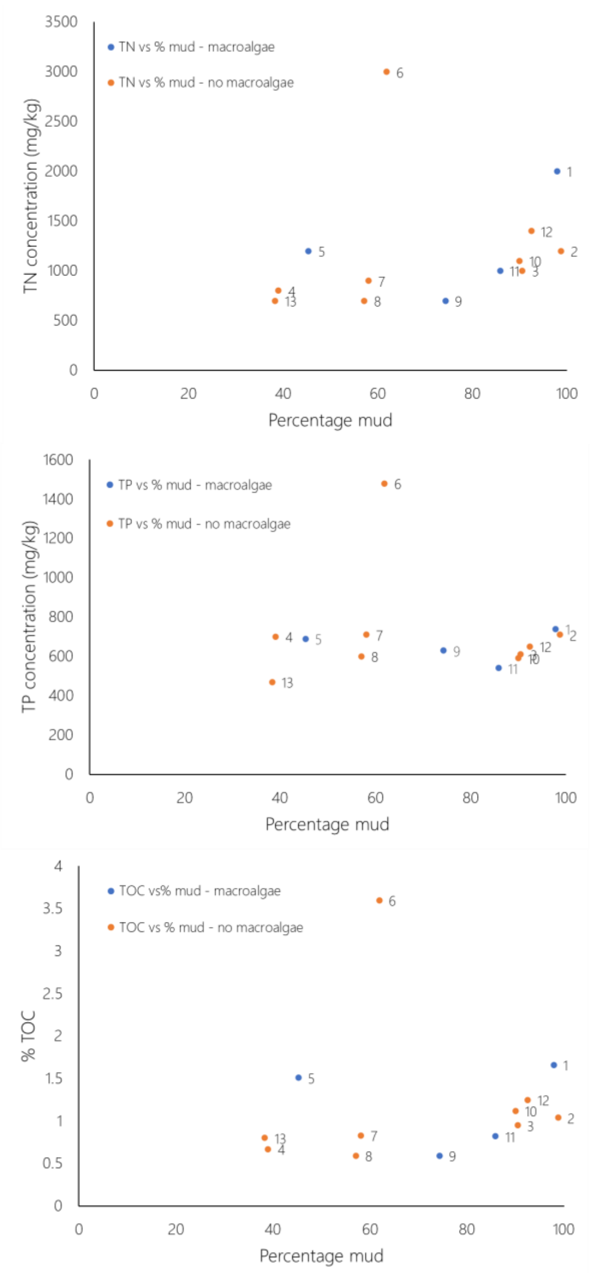


Fig. 9. Concentrations of TN, TP and TOC versus percentage of mud in sediment samples collected for the present study. Site numbers are shown beside each data point. Sites that were within macroalgal beds are shown in blue.

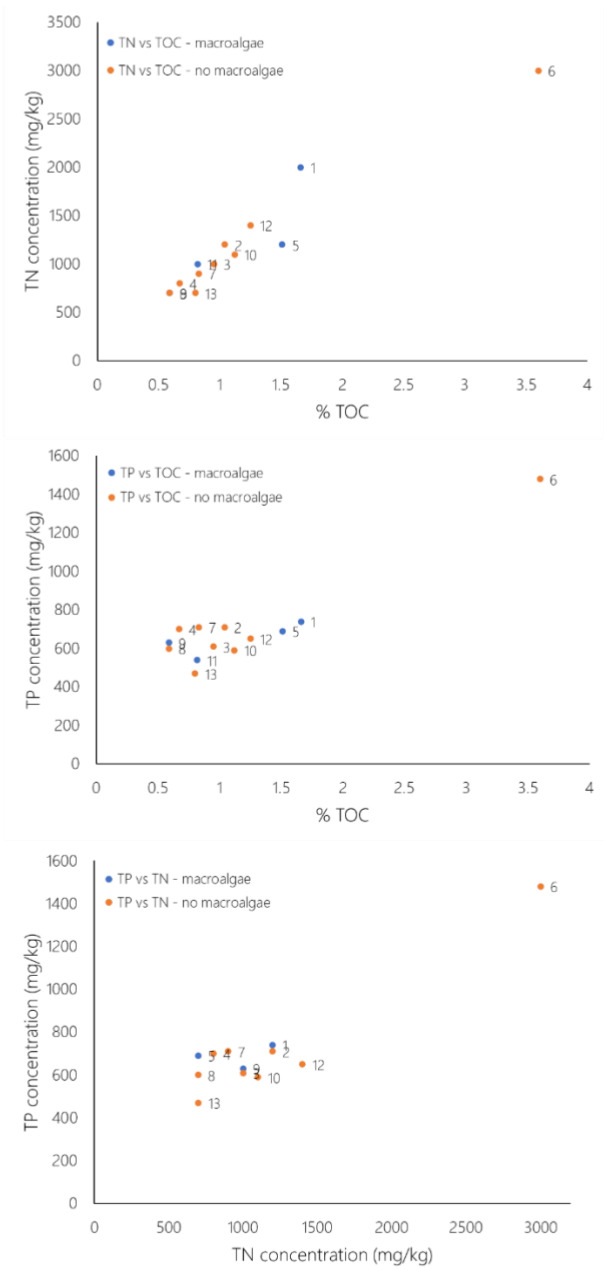


Fig. 10. Correlation plots of concentrations of TN, TP and TOC in sediment samples collected for the present study. Site numbers are shown beside each data point. Sites that were within macroalgal beds are shown in blue.

4. CONCLUSIONS,

This study assessed the relative importance of nutrient sources, particularly nitrogen, in relation to the presence of dense and entrained macroalgal beds that have established adjacent to the MDF plant/Bark Processor sites, in sediments near Neimann Creek, and near the confluence of Reservoir and Jimmy Lee Creeks near Richmond.

Of the larger creeks draining to the southeastern part of Waimea Inlet, Borck and Seal Creeks appear to be the major sources of nitrogen and therefore, perhaps the major contributors to the general development of macroalgal beds. However, individual beds may be influenced by more local sources, such as the beds around the mouth of Neimann Creek and near the confluence of Reservoir and Jimmy Lee Creeks. Patterns of water movement will determine how nutrient-rich water and sediment discharged by creeks is dispersed or concentrated but these are poorly understood in these shallow coastal areas.

Summary findings and conclusions from the study are:

- Beds of macroalgae are highly localised in Waimea Inlet and occur near obvious inputs of nutrients to the estuary, including the Bell Island WWTP outfall, near the mouths of rivers and streams, and seepages around the Bark Processors facility.
- Water quality data show that, of the three larger creeks in the southeastern part of the estuary (Borck, Neimann and Reservoir), Borck Creek appears to be the largest contributor of TN and TP to the eastern side of Waimea Inlet. Concentrations of at least some forms of nitrogen are increasing over time in all three creeks.
- The TN and TP loads from the Bell Island WWTP are several times larger than the combined load from Borck, Neimann and Reservoir Creeks – roughly 4.5 times in the case of TN and 380 times in the case of TP. The Waimea River is also a major source of nutrients – roughly 2.8 times WWTP TN input and 1.8 times the WWTP TP input. However, much or most of the river and WWTP loads are expelled from the inlet into Tasman Bay by the ebbing tide and does not reach the areas where macroalgal beds have developed.
- CLUES modelling of stream water quality at the catchment scale confirms the relatively large TN and TP loadings from Borck Creek. It also demonstrates the expected dominance of the Waimea River in nutrient loading to Waimea Inlet at a broader scale. Seal Creek, near the MDF plant and Bark Processor's facility, also contributes relatively high loadings (TN load eight times that of Neimann Creek).
- Nitrate concentrations in groundwater around Neimann Creek appear to have decreased in recent years and, although still elevated, are lower than those in groundwater around Borck Creek. This is consistent with relative concentrations in the water in these creeks. However, there is also more recent evidence that concentrations in groundwater around Neimann Creek may be increasing again, possibly because of agricultural and horticultural land use.
- Sediment TN and TOC concentrations were relatively high at many of the sites sampled in this survey (Penny Farthing Stream in particular), relative to other shallow, intertidal-dominated estuaries in New Zealand (Robertson et al. 2016).
- There was no clear relationship between sediment nutrient concentrations and water quality data from Borck and Neimann Creeks.
- There was no clear relationship between sediment nutrient concentrations in sites located within, or outside of, macroalgal beds.
- The concentrations of trace metals and semi-volatile organic contaminants in the sediments were well below guideline values at which adverse effects on aquatic organisms might occur, with two exceptions. The exceptions related to naturally elevated concentrations of chromium and nickel, which are apparent throughout Waimea Inlet as a result of catchment geology (the Nelson Mineral Belt).
- The expansion in the spatial extent and density of some of the macroalgal beds between the 2014 and 2020 broad scale mapping surveys (Forrest et al. 2021) is likely to continue. One author (LMS) noted there appears to have been increased macroalgal growth since 2020 near the confluence of Reservoir and Jimmy Lee Creeks.
- Expansion in the spatial extent and density of macroalgal beds may accelerate with the development for housing of land that was formerly rough pasture west of Richmond centre.

5. INFORMATION GAPS AND RECOMMENDATIONS

The following bullets present information gaps identified, and recommended actions to address them:

- The potential source of elevated nutrients to Borck and Seal Creeks should be investigated. Measures can probably be taken fairly easily to assess and address any obvious upstream inputs.
- The source of organic matter and nutrients resulting in high TN and TOC concentrations measured in Penny Farthing Stream (which discharges from a culvert under the MDF plant: Site 6), and from the sump and pipe draining the southeast corner of the Bark Processers yard (Site 4), should be investigated.
- Source tracking of nitrogen compounds may identify the relative contributions of different sources, such as wastewater, livestock and fertilisers. For example, source tracking of nitrate is possible by measuring relative concentrations of the different isotopes of nitrogen and oxygen in the nitrate. Simultaneous analysis of boron isotopes reduces problems of resolution caused by overlapping isotope concentration ranges among sources and natural processing of nitrate after it is released. Other methods, such as analyses of microscopic particles, pinenes and terpenes may help identify inputs from wood dust.
- To better target nutrient reductions, derive more accurate estimates of the nutrient loads from individual stream catchments than are currently available using locally detailed land use maps and predicted loads or concentrations from each land use type, and an assessment of point source inputs. Estimates based on nutrient concentrations should incorporate a range of rainfall events and be modelled and validated with existing flow and water-quality data.
- It is important to ensure that inputs from nearby streams (including sewage overflows), managed by NCC are concurrently assessed in a consistent manner to enable mass loads to the estuary to be determined. NCC is currently undertaking a programme of sampling and analysis of water quality in streams entering the eastern shore of Waimea Inlet.
- Modelling would ideally be undertaken of water movements around the southeastern part of the estuary over the tidal cycle to identify patterns of distribution of stream-derived sediments and nutrients once they enter the estuary.
- Sediment accumulation rates in the areas where macroalgal beds are growing, and measurements of nutrient concentration in the sediments over time, should be made to identify sinks of sediments and associated nutrients.
- To better characterise changes in the distribution of macroalgal beds, map macroalgal areal and percent cover and measure biomass and entrainment at time scales shorter than the current estuarine broad-scale surveys (for example, annually as opposed to 5-10 yearly).

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Appendix 1. GPS coordinates and characteristics of sediments at the 13 sites sampled 5 May 2023.

Site	Location	NZTM East	NZTM North	Sediment Firmness	Sediment Type (Code)	aRPD depth (mm)	Analytes	Notes
1	Neimann Creek	1613269	5427236	soft	Sandy MUD (SM50_90)	2	Suite 1	Stunted entrained *Agarophyton*. Biomass ~2000g/m^2.
2	Ravensdown Crossing	1613405	5426735	very soft	Sandy MUD (SM50_90)	5	Suite 2	Unvegetated
3	Opposite Swamp Road	1613851	5426402	very soft	Sandy MUD (SM50_90)	8	Suite 2	Unvegetated
4	West of Bark Processors	1613779	5425855	soft	Sandy MUD (SM50_90)	10	Suite 2	Unvegetated. Anoxic seep from Bark Processors
5	Seal Creek (north of Bark Processors)	1614159	5425738	very soft	Muddy SAND (MS25_50)	15	Suite 1	Sampled from unvegetated area. *Agarophyton* in stream bed and in patches on bank. Gravel and sand in surface muddy sand layer.
6	Penny Farthing Stream	1614253	5425527	soft	Muddy SAND (MS25_50)	Indet.	Suite 2	Discharge from under MDF plant into drain through salt marsh
7	Sandeman Reserve	1614816	5425511	firm	Muddy SAND (MS25_50)	15	Suite 2	Blind creek outflow from Sandeman Reserve. *Agarophyton* in stream bed and in patches on bank. Sampled from unvegetated area.
8	Borck Stream	1615097	5425588	soft	Sandy MUD (SM50_90)	2	Suite 1	Composite sample from unvegetated mixed habitat with surface gravels. *Agarophyton* in stream bed and in patches on bank.
9		1616189	5424718	very soft	Sandy MUD (SM50_90)	10	Suite 2	Sampled from unvegetated area. 10% entrained *Agarophyton* at site
10	Jimmy Lee Creek, 150m d/s of power lines	1616326	5424760	very soft	Sandy MUD (SM50_90)	3	Suite 1	Sampled from unvegetated area upstream of large *Agarophyton* bed (Site 11).
11		1616439	5424727	very soft	Sandy MUD (SM50_90)	2	Suite 2	*Agarophyton* entrained 100% cover, Biomass ~5000g/m^2
12	Salisbury Stream	1616257	5424473	soft	Sandy MUD (SM50_90)	8	Suite 2	Unvegetated. 40mm sandy mud layer over gravel
13	McPhearson Stream	1616126	5424498	soft	Muddy SAND (MS25_50)	5	Suite 2	Unvegetated. 30mm muddy sand layer over gravel

Indet. = aRPD layer indeterminate;

Suite 1: PGS, TOC, TN, TP, metals, SVOCs,

Suite 2: PGS, TOC, TN, TP

Appendix 2. RJ Hill analytical methods for sediments

Sample Type: Sediment			
Test	**Method Description**	**Default Detection Limit**	**Sample No**
Environmental Solids Sample Drying*	Air dried at 35°C Used for sample preparation. May contain a residual moisture content of 2-5%.	-	1-12
Environmental Solids Sample Preparation	Air dried at 35°C and sieved, <2mm fraction. Used for sample preparation May contain a residual moisture content of 2-5%.	-	1-12
Dry Matter (Env)	Dried at 103°C for 4-22hr (removes 3-5% more water than air dry) , gravimetry. (Free water removed before analysis, non-soil objects such as sticks, leaves, grass and stones also removed). US EPA 3550.	0.10 g/100g as rcvd	13-16
Dry Matter for Grainsize samples (sieved as received)*	Drying for 16 hours at 103°C, gravimetry (Free water removed before analysis).	0.10 g/100g as rcvd	1-12
Total Recoverable digestion	Nitric / hydrochloric acid digestion. US EPA 200.2.	-	1-12
Total Recoverable Phosphorus	Dried sample, sieved as specified (if required). Nitric/Hydrochloric acid digestion, ICP-MS, screen level. US EPA 200.2.	40 mg/kg dry wt	1-12
Total Nitrogen*	Catalytic Combustion (900°C, O2), separation, Thermal Conductivity Detector [Elementar Analyser].	0.05 g/100g dry wt	1-12
Total Organic Carbon*	Acid pretreatment to remove carbonates present followed by Catalytic Combustion (900°C, O2), separation, Thermal Conductivity Detector [Elementar Analyser].	0.05 g/100g dry wt	1-12
Heavy metals, trace As,Cd,Cr,Cu,Ni,Pb,Zn,Hg	Dried sample, <2mm fraction. Nitric/Hydrochloric acid digestion, ICP-MS, trace level.	0.010 - 0.8 mg/kg dry wt	1-12
Semivolatile Organic Compounds Trace in Soil by GC-MS	Sonication extraction, GC-MS analysis. Tested on as received sample. In-house based on US EPA 8270.	0.002 - 6 mg/kg dry wt	13-16
3 Grain Sizes Profile as received			
Fraction >/= 2 mm*	Wet sieving with dispersant, as received, 2.00 mm sieve, gravimetry.	0.1 g/100g dry wt	1-12
Fraction < 2 mm, >/= 63 µm*	Wet sieving using dispersant, as received, 2.00 mm and 63 µm sieves, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-12
Fraction < 63 µm*	Wet sieving with dispersant, as received, 63 µm sieve, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-12


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