coastalmanagement

Waiau (Te Waewae) Lagoon 2012

Fine Scale Monitoring and Macrophyte Mapping

Prepared for
Environment Southland
August 2012

Cover Photo: Waiau Lagoon - extensive macrophyte cover *(Ranunculus trichopyllus*) in the eastern estuary.

Green filamentous algae and Ranunculus trichopyllus

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By

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All photos by Wriggle except where noted otherwise.

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WAIAU/TE WAEWAE LAGOON - EXECUTIVE SUMMARY

This report summarises the results of the third year of fine scale monitoring of Waiau/Te Waewae Lagoon, a 4km long coastal lagoon estuary (100ha) in Te Waewae Bay. It is one of the key estuaries in Environment Southland's (ES's) long-term coastal monitoring programme. An outline of the process used for estuary monitoring and management by ES is presented in the margin flow diagram, and the following sections summarise fine scale monitoring results, condition ratings, overall estuary condition, and monitoring and management recommendations.

FINE SCALE MONITORING RESULTS

- Sediment Oxygen: Redox Potential Discontinuity (RPD) depth was poor-fair throughout the main estuary lagoon, but good in the western end (lower) estuary.
- The indicator of organic enrichment in sediments (Total Organic Carbon) was at high concentrations and sediment nutrient enrichment indicators for total phosphorus (TP) and total nitrogen (TN) were at high concentrations.
- The sediment in deeper areas had very high mud concentrations (~95% mud), but in the western end (lower estuary reaches) the concentrations of mud were low and dominated by sands and gravels.
- The lagoon had excessive nuisance macroalgal cover - particularly around the margins.
- Vegetative cover was dominated by introduced macrophytes, but high value seagrass (*Ruppia*) was present.

CONDITION RATINGS

	2010			2011			2012		
	Site A3	Site E3	Site H3	Site A3	Site E3	Site H3	Site A3	Site E3	Site H3
Sediment oxygenation (RPD)	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair
Total Organic Carbon (TOC)	Poor	Fair	Poor	Poor	Fair	Fair	Poor	Fair	Fair
Total Nitrogen (TN)	Poor	Poor	Poor	Poor	Fair	Fair	Poor	Poor	Fair
Total Phosphorus (TP)	Poor	Poor	Fair	Poor	Poor	Fair	Poor	Poor	Fair

ESTUARY CONDITION AND ISSUES

The 2012 results showed Waiau/Te Waewae Lagoon was in a moderate to poor condition. It was in a similar condition to 2010 and 2011, which followed a marked deterioration from 2009. In brief, the restricted flushing of the estuary has resulted in a high sediment mud content, elevated organic matter and nutrients, and poor and declining sediment oxygenation. In turn, the estuary response has been excessive introduced weed growth which has displaced high value native macrophytes that are now only sparsely present. However, the current level of regular tidal exchange, occasional flushing by river flows, and mixing of lagoon waters by wind and wave action, appears sufficient to maintain the lagoon water in an oxygenated state. Consequently the trophic state rating is moderate/fair. Such conditions indicate high susceptibility to freshwater abstractions, tidal incursions, and sediment and nutrient inputs. The absence of an extensive vegetated margin also places the estuary at risk because the margin assimilates and filters excess nutrients and sediment. A potential for further deterioration also exists through increased stock access to the estuary margin, sea level rise, drainage, vehicle damage, and invasion by plant pests.

RECOMMENDED MONITORING AND MANAGEMENT

Continue fine scale monitoring every 5 years (next scheduled for summer 2017). Also undertake annual monitoring of several low cost eutrophication indicators (RPD, DO, and substrate type) at transect C, and a coarse assessment of vegetative percentage cover of the main body of lagoon.
The 2010-12 fine scale monitoring results reinforced the need to manage five major issues as follows:

1. Ensure adequate freshwater flushing flows,
2. Develop nutrient and sediment input guidelines,
3. Identify catchment hotspots for sediment and nutrient runoff,
4. Develop plans to minimise ecological effects of sea level rise, and
5. Restore saltmarsh and terrestrial margin vegetation.

1. INTRODUCTION

OVERVIEW

Maintaining an understanding of the condition and risks to coastal and estuarine habitats is critical to Environment Southland (ES) in their resource management role for Southland. In 2008, ES undertook a vulnerability assessment of its region's coastline to establish priorities for a long-term monitoring programme for the region (Robertson and Stevens 2008). The assessment identified Waiau Estuary/Te Waewae Lagoon (Figure 1) as a priority for monitoring, which ES began in February 2009; the work being undertaken by Wriggle Coastal Management using the National Estuary Monitoring Protocol (EMP) (Robertson et al. 2002) plus recent extensions.

The monitoring programme consists of three components:

1. **Ecological Vulnerability Assessment** of the estuary to major issues (Table 1) and appropriate monitoring design. This component has been completed for Waiau/Te Waewae Lagoon and is reported on in Robertson and Stevens (2008).
2. **Broad Scale Habitat Mapping** (EMP approach). This component (Table 2), which documents the key habitats within each estuary and changes to these habitats over time, is reported on in Stevens and Robertson (2008).
3. **Fine Scale Monitoring** (Synoptic survey and EMP approach). Monitoring of selected physical and chemical characteristics (water clarity, salinity, depth, sediment oxygenation, muddiness, presence of macrophytes and nuisance macroalgae - see Table 2). This component, which provides detailed information on the condition of the lagoon, began with a synoptic survey in February 2009 (Robertson and Stevens 2009) followed by monitoring scheduled annually for three years to establish a baseline, then every five years or as determined by condition ratings.

A primary aim of the fine scale monitoring is to assess the trophic status of Waiau/Te Waewae Lagoon, particularly its current macrophyte status and sediment nutrient concentrations as they are useful indicators of lagoon condition. As such, this report describes the third year of baseline monitoring of the key fine scale indicators of sediment nutrients - total nitrogen (TN) and phosphorus (TP); total organic carbon (TOC); and grain size, as well as physical and chemical characteristics described in (3) above. The issues of toxicity and disease risk were not incorporated in the baseline monitoring programme as toxicity was considered to be at such a low risk it was not considered necessary to monitor, whilst the presence of disease risk indicators on the Southland coast is assessed separately in ES's recreational water quality monitoring programme.

Figure 1. Waiau/Te Waewae Lagoon looking west towards the mouth.

Recent broad scale studies (Robertson and Stevens 2008, Stevens and Robertson 2008) identified the lagoon as having high human and ecological values, including aquatic macrophyte communities, a successful fishery, and abundant birdlife. However, it was also shown that the lagoon is relatively isolated from the main river flow and, as a consequence, certain areas may be poorly flushed. The main factors that exacerbate such poor flushing were identified as mouth constrictions due to high seas, and/or a decline in high river flows. Also the lagoon was characterised as being susceptible to degradation from intensification of landuse in the catchment, grazing around the margins, and sea level rise.

Eutrophication and sedimentation were highlighted as the greatest risks for the lagoon (Robertson and Stevens 2008). The likely pattern of increasing eutrophication and sedimentation that such lagoons follow, in response to increased nutrients (particularly nitrogen and phosphorus) and fine sediments, is presented in Figure 2.

1. Introduction (Continued)

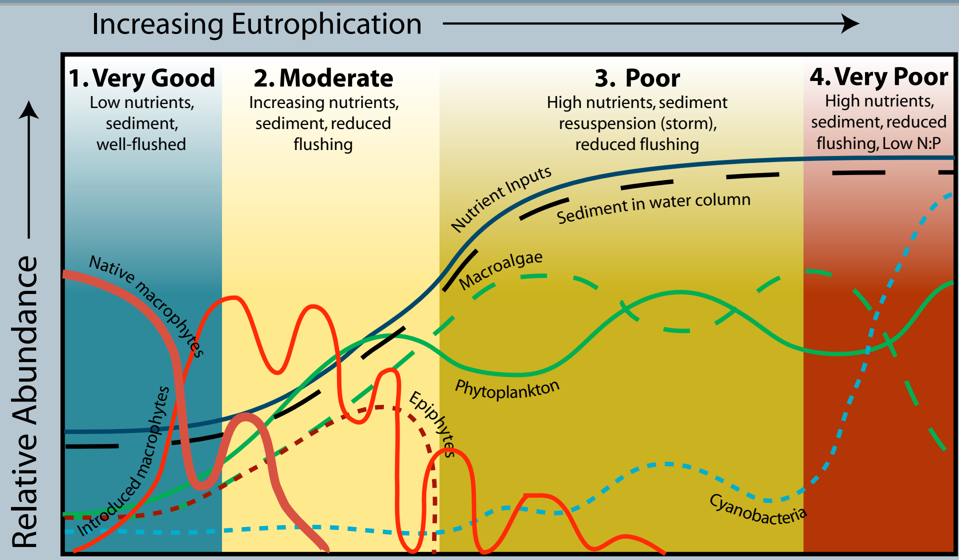
Table 1. Summary of the major issues affecting most NZ estuaries.

Major Estuary Issues	
Sedimentation	Because estuaries are a sink for sediments, their natural cycle is to slowly infill with fine muds and clays. Prior to European settlement they were dominated by sandy sediments and had low sedimentation rates (<1 mm/year). In the last 150 years, with catchment clearance, wetland drainage, and land development for agriculture and settlements, New Zealand's estuaries have begun to infill rapidly. Today, average sedimentation rates in our estuaries are typically 10 times or more higher than before humans arrived.
Eutrophication (Nutrients)	Increased nutrient richness of estuarine ecosystems stimulates the production and abundance of fast-growing algae, such as phytoplankton, and short-lived macroalgae (e.g. sea lettuce). Fortunately, because most New Zealand estuaries are well flushed, phytoplankton blooms are generally not a major problem. Of greater concern is the mass blooms of green and red macroalgae, mainly of the genera *Enteromorpha, Cladophora, Ulva,* and *Gracilaria* which are now widespread on intertidal flats and shallow subtidal areas of nutrient-enriched New Zealand estuaries. They present a significant nuisance problem, especially when loose mats accumulate on shorelines and decompose. Blooms also have major ecological impacts on water and sediment quality (e.g. reduced clarity, physical smothering, lack of oxygen), affecting or displacing the animals that live there.
Disease Risk	Runoff from farmland and human wastewater often carries a variety of disease-causing organisms or pathogens (including viruses, bacteria and protozoans) that, once discharged into the estuarine environment, can survive for some time. Every time humans come into contact with seawater that has been contaminated with human and animal faeces, we expose ourselves to these organisms and risk getting sick. Aside from serious health risks posed to humans through recreational contact and shellfish consumption, pathogen contamination can also cause economic losses due to closed commercial shellfish beds. Diseases linked to pathogens include gastroenteritis, salmonellosis, hepatitis A, and noroviruses.
Toxic Contamination	In the last 60 years, New Zealand has seen a huge range of synthetic chemicals introduced to estuaries through urban and agricultural stormwater runoff, industrial discharges and air pollution. Many of them are toxic in minute concentrations. Of particular concern are polycyclic aromatic hydrocarbons (PAHs), heavy metals, polychlorinated biphenyls (PCBs), and pesticides. These chemicals collect in sediments and bio-accumulate in fish and shellfish, causing health risks to people and marine life.
Habitat Loss	Estuaries have many different types of habitats including shellfish beds, seagrass meadows, saltmarshes (rushlands, herbfields, reedlands etc.), forested wetlands, beaches, river deltas, and rocky shores. The continued health and biodiversity of estuarine systems depends on the maintenance of high-quality habitat. Loss of habitat negatively affects fisheries, animal populations, filtering of water pollutants, and the ability of shorelines to resist storm-related erosion. Within New Zealand, habitat degradation or loss is common-place with the major causes cited as sea level rise, population pressures on margins, dredging, drainage, reclamation, pest and weed invasion, reduced flows (damming and irrigation), over-fishing, polluted runoff and wastewater discharges.

Table 2. Summary of the broad and fine scale EMP indicators (shaded cells used in the current report).

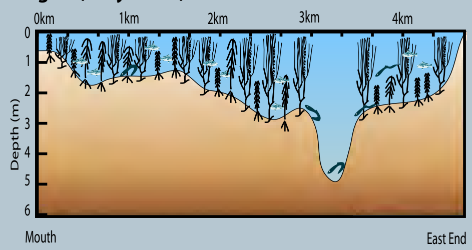
Issue	Indicator	Method
Sedimentation	Soft Mud Area	Broad scale mapping - estimates the area and change in soft mud habitat over time.
Sedimentation	Sedimentation Rate	Fine scale measurement of sediment deposition.
Sedimentation	Sediment Grain Size	Fine scale measurement of sediment grain size, including changes over time.
Eutrophication	Nuisance Macroalgal Cover	Broad scale mapping - estimates the change in the area of nuisance macroalgal growth (e.g. sea lettuce (*Ulva*), *Gracilaria* and *Enteromorpha*) over time.
Eutrophication	Organic and Nutrient Enrichment	Chemical analysis of total nitrogen, total phosphorus, and total organic carbon in replicate samples from the upper 2cm of sediment.
Eutrophication	Redox Profile	Measurement of depth of redox potential discontinuity profile (RPD) in sediment estimates likely presence of deoxygenated, reducing conditions.
Toxins	Contamination in Bottom Sediments	Chemical analysis of indicator metals (total recoverable cadmium, chromium, copper, nickel, lead and zinc) in replicate samples from the upper 2cm of sediment.
Toxins, Eutrophication, Sedimentation	Biodiversity of Bottom Dwelling Animals	Type and number of animals living in the upper 15cm of sediments (infauna in $0.0133m^2$ replicate cores), and on the sediment surface (epifauna in $0.25m^2$ replicate quadrats).
Habitat Loss	Saltmarsh Area	Broad scale mapping - estimates the area and change in saltmarsh habitat over time.
Habitat Loss	Seagrass Area	Broad scale mapping - estimates the area and change in seagrass habitat over time.
Habitat Loss	Vegetated Terrestrial Buffer	Broad scale mapping - estimates the area and change in buffer habitat over time.

Figure 2. Tidal river mouth lagoon response to increasing eutrophication and other events.

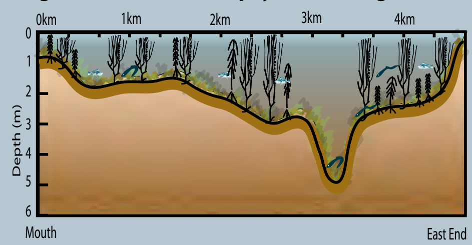


Conceptual representation of response of aquatic vegetation to increased nutrients in coastal lagoons (modified from de Wit et al. 2001, Viaroli et al. 2004, Zaldivar et al. 2008 and information on NZ coastal lagoons - Mitchell 1971, Gibbs 1973, Gerbeaux and Ward 1991, Gibbs 2002, Edwards and Clayton 2002, Stevens and Robertson 2007 and 2007a, Ward 2008).

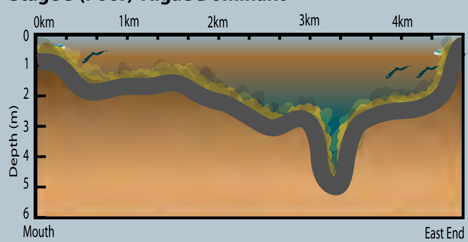
Stage 1 (Very Good) Pristine



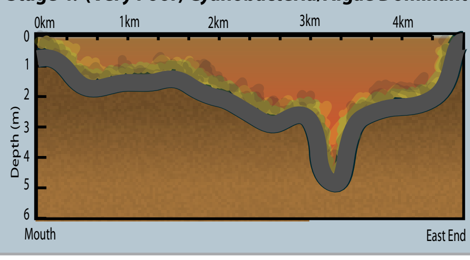
Stage 2 (Moderate) Macrophytes Declining



Stage 3 (Poor) Algae Dominant



Stage 4. (Very Poor) Cyanobacteria/Algae Dominant



Stage 1 (Very Good) Pristine

In their pristine state, these lagoons are well flushed with river and marine tidal waters. Nutrient and sediment inputs are low and their brackish, clear, shallow waters are dominated by extensive meadows of native macrophytes (e.g. *Ruppia*, *Potamogeton*) and possibly some non-aggressive invasive species which take advantage of nutrient supply from the sediment. Sediment quality and biodiversity are high.

Stage 2 (Moderate) Macrophytes Declining

As nutrient and sediment concentrations increase, nuisance macroalgae (e.g. *Ulva* (*Enteromorpha), Bachelotia, Cladophora*), phytoplankton and epiphyte growth increases, while native macrophyte growth, sediment oxygenation and water clarity declines. In addition, introduced and often aggressive macrophytes can become dominant and the sediment bed becomes muddier. A surface sulphide layer is common. If inflows of marine and river waters are reduced (due to freshwater abstraction or constriction of the mouth) then the susceptibility to eutrophication is enhanced and biodiversity declines. During this stage, the dominant aquatic vegetation can alternate in cycles depending on conditions. Generally shallow water (<2m) and good clarity (e.g. secchi disc visible on bottom) tends to favour the presence of macrophytes. Once light becomes limiting (due to excessive nutrients causing phytoplankton blooms, elevated fine sediment inputs, or storms acting to resuspend sediment), then phytoplankton dominate. Storm and waterfowl damage to macrophyte beds can also cause a shift to phytoplankton dominance, especially in situations where the lagoon bed consists of muds rather than sands or gravel.

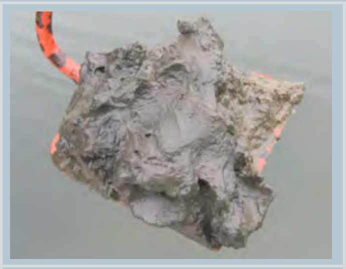
Stage 3 (Poor) Algae Dominant

At the third stage, nutrient inputs are high and the lagoon reaches a threshold where macrophytes are lost from the lagoon and replaced with nuisance short-lived macroalgae and phytoplankton. Water clarity is low, sediments are muddy, anoxic, and sulphide-rich close to the surface, and sediment macrofauna are dominated by high numbers of a few tolerant species only.

Stage 4 (Very Poor) Cyanobacteria/Algae Dominant

At the fourth stage, the nitrogen to phosphorus ratio declines to low levels and results in nuisance cyanobacteria and toxic bloom events. Sediment macrofauna are often absent, but nuisance short-lived macroalgae (e.g. *Bachelotia* and *Ulva*) and phytoplankton are still present. Water clarity is low and sediment quality poor (increasing mud content, anoxic, and sulphide-rich).

2. METHODS



Percent Cover 0-5%

Percent Cover 5-10%

Percent Cover 10-20%

Percent Cover 20-50%

Percent Cover 50-80%

Percent Cover 80-100%

Figure 3. Percent cover categories for aquatic vegetation.

Nine previously established transect sampling sites in Waiau/Te Waewae Lagoon (Robertson and Stevens 2009) are shown in Figure 4 covering a representative cross section of conditions throughout the estuary. They were visited by two scientists on 24 January 2012 when the lagoon was open to the sea. At each site, sampling was undertaken for key indicators of estuary condition as described below. The purpose was to collect information which, through repeat sampling, can be used as a rapid and robust method to indicate change within the estuary.

At each site, a 5-6cm deep layer of the surface sediments was collected with a garden hoe (area 15 x 15cm) and carefully brought to the surface (a dinghy and outboard motor was used for sampling at the deeper sites, and a canoe for shallower sites). At the surface, the sample was photographed and records taken of;

- The taxa, height, percentage cover, and life stage of aquatic vegetation (Figure 3 gives examples of percentage cover estimates for macrophytes).
- The sediment type and depth to the blackened sulphide rich layer (Redox Potential Discontinuity layer - RPD).

Composite samples of the top 20mm of sediment (each approx. 250gms) were collected from sites A3, E3 and H3. These sites, spread throughout the estuary, capture the soft bottom areas in the deep channels where sediments are expected to accumulate. Sediment samples were chilled and sent to R.J. Hill Laboratories for analysis of:

* Grain size/Particle size distribution (% mud, sand, gravel).
* Nutrients - total nitrogen (TN), total phosphorus (TP), and
* Total Organic Carbon (TOC).

Analytical details are provided in Appendix 1.

In addition, the water column at each site was sampled for:

- Secchi disc clarity
- Depth
- Dissolved oxygen (at surface and bottom)
- Temperature (at surface and bottom)
- Salinity (at surface and bottom)

A visual examination of the whole estuary was also undertaken to assess and map the extent of aquatic vegetation occurring outside of the chosen transects. Appendix 2 presents the 2012 field measurements. Previous monitoring results are reported in Robertson and Stevens (2009), and Stevens and Robertson (2010, 2011).

CONDITION RATINGS

A series of interim fine scale estuary "condition ratings" (presented on page 6) have been proposed for Southland's estuaries including the Waiau/Te Waewae Lagoon (e.g. Robertson & Stevens 2006). The ratings are based on a review of estuary monitoring data, guideline criteria, and expert opinion. They are designed to be used in combination with each other (usually involving expert input) when evaluating overall estuary condition and deciding on appropriate management.

2. Methods (Continued)

Figure 4. Location of sampling sites, Waiau/Te Waewae Lagoon, 24 January 2012.

2. Methods (Continued)

CONDITION RATINGS

The condition ratings presented below include an "early warning trigger" to highlight rapid or unexpected change, and each rating has a recommended monitoring and management response. In most cases initial management is to further assess an issue and consider what response actions may be appropriate (e.g. develop an Evaluation and Response Plan - ERP).

Total Nitrogen

In tidal lagoon estuaries like the Waiau, the sediment compartment is often the largest nutrient pool in the system, and nitrogen exchange between the water column and sediments can play a large role in determining trophic status and the growth of algae.

TOTAL NITROGEN CONDITION RATING

RATING	DEFINITION	RECOMMENDED RESPONSE
Very Good	<500mg/kg	Monitor at 5 year intervals after baseline established
Good	500-2000mg/kg	Monitor at 5 year intervals after baseline established
Fair	2000-4000mg/kg	Monitor at 2 year intervals and manage source
Poor	>4000mg/kg	Monitor at 2 year intervals and manage source
Early Warning Trigger	>1.3 x Mean of highest baseline year	Initiate Evaluation and Response Plan

Total Phosphorus

In tidal lagoon estuaries like the Waiau, the sediment compartment is often the largest nutrient pool in the system, and phosphorus exchange between the water column and sediments can play a large role in determining trophic status and the growth of algae.

TOTAL PHOSPHORUS CONDITION RATING

RATING	DEFINITION	RECOMMENDED RESPONSE
Very Good	<200mg/kg	Monitor at 5 year intervals after baseline established
Good	200-500mg/kg	Monitor at 5 year intervals after baseline established
Fair	500-1000mg/kg	Monitor at 2 year intervals and manage source
Poor	>1000mg/kg	Monitor at 2 year intervals and manage source
Early Warning Trigger	>1.3 x Mean of highest baseline year	Initiate Evaluation and Response Plan

Total Organic Carbon

Estuaries with high sediment organic content can result in anoxic sediments and bottom water, release of excessive nutrients, and adverse impacts to biota - all symptoms of eutrophication.

TOTAL ORGANIC CARBON CONDITION RATING

RATING	DEFINITION	RECOMMENDED RESPONSE
Very Good	<1%	Monitor at 5 year intervals after baseline established
Good	1-2%	Monitor at 5 year intervals after baseline established
Fair	2-5%	Monitor at 2 year intervals and manage source
Poor	>5%	Monitor at 2 year intervals and manage source
Early Warning Trigger	>1.3 x Mean of highest baseline year	Initiate Evaluation and Response Plan

Redox Potential Discontinuity

The RPD is the grey layer between oxygenated yellow-brown sediments near the surface and deeper anoxic black sediments. The RPD marks the transition between oxygenated and reduced conditions and is an effective ecological barrier for most, but not all, sediment-dwelling species. A rising RPD will force most macrofauna towards the sediment surface to where oxygen is available. In addition, nutrient availability in estuaries is generally much greater where sediments are anoxic, and the tendency for sediments to become anoxic is much greater if the sediments are muddy, with consequent exacerbation of the eutrophication process.

RPD CONDITION RATING

RATING	DEFINITION	RECOMMENDED RESPONSE
Very Good	>10cm depth below surface	Monitor at 5 year intervals after baseline established
Good	3-10cm depth below sediment surface	Monitor at 5 year intervals after baseline established
Fair	1-3cm depth below sediment surface	Monitor at 5 year intervals. Initiate ERP
Poor	<1cm depth below sediment surface	Monitor at 2 year intervals. Initiate ERP
Early Warning Trigger	>1.3 x Mean of highest baseline year	Initiate Evaluation and Response Plan

3. RESULTS AND DISCUSSION

A summary of the results of the 24 January 2012 fine scale monitoring of Waiau/Te Waewae Lagoon is presented below, with detailed results contained in Appendix 2. A summary of the sediment chemistry results and condition ratings are presented in Figures 8-11, alongside results from surveys undertaken in 2010 and 2011. Background depth, salinity, temperature and water column dissolved oxygen data is presented first, followed by two subsections based on the key estuary problems that the fine scale monitoring is addressing: eutrophication and sedimentation.

Table 3. Sediment chemistry results (composite sample), Waiau/Te Waewae Lagoon, January/February 2010-2012.

	Transect	Site	Depth (m)	RPD (cm)	Salinity (ppt)		TOC (%)	Mud (%)	Sand (%)	Gravel (%)	TN (mg/kg)	TP (mg/kg)
					surface	bottom						
Feb 2010	A	A3	2.2	3	0.97	0.97	6.4	94.6	2.2	3.2	5,400	1,300
	E	E3	2.5	1	0.68	0.68	4.5	97.3	2.7	0.1	4,500	1,200
	H	H3	1.0	1	0.55	0.55	6.1	94.7	4.5	0.8	6,100	900
Feb 2011	A	A3	3.0	2-3	3.3	16.7	5.4	93.5	3.3	3.2	4,600	1,130
	E	E3	2.5	3	1.8	16.9	4.2	98.7	1.2	< 0.1	3,900	1,240
	H	H3	1.1	2	3.1	3.0	3.0	89.5	10.4	0.1	2,500	760
Jan 2012	A	A3	2.5	1	0.6	1.0	6.1	85.9	10.5	3.6	5,700	1,490
	E	E3	2.4	2	1.3	1.2	4.5	85.7	14.3	< 0.1	4,600	1,240
	H	H3	1.9	1	3.3	2.7	3.9	74.3	25.6	0.1	3,700	880

Water Depth and Level

Most of the lagoon was relatively shallow (generally <1.5m water depth) with the deepest areas (4.9m) in the channel at the east end. Over the previous year, lagoon water levels ranged from a low of 1080mm above mean sea level (aMSL) on 23 March 2011 to a high of 3034mm aMSL on 11 July 2011. When sampled on 24 January 2012 the water level varied from 1328mm aMSL at low tide to 1934mm aMSL at high tide. Also notable was that the Waiau mouth briefly closed between 10-12 Jan 2012 (2 weeks before sampling) - Environment Southland, unpublished data 2012.

Measuring water quality, Waiau/Te Waewae Lagoon

Salinity and Temperature and Dissolved Oxygen

In 2012, stratification was present, but to a much more limited extent than in 2011. This was evident as a halocline (shift in salinity) present at a depth of ~2.6m. Results showed the presence of brackish seawater underneath freshwater, but there was little difference in temperature or dissolved oxygen as follows:

Depth	m	0-2.6	>2.6
Salinity	ppt	0.6-3.3	6.1-7.0
Temperature	°C	14.3-16.1	14.7-14.8
Dissolved Oxygen	mg/l	8.8-12.7	7.9-9.3
Dissolved Oxygen	% saturation	86-130	84-96

Water Clarity (Secchi Disc)

Lagoon water clarity ranged from 0.9-1.1m in the main body of the lagoon, ~1.0m less than at the same time in 2011. However, in the more well-flushed channel towards the river mouth, the water clarity was much better at 2m. As the 2012 measures were taken following several windy days, rather than the calmer conditions encountered in 2011, the decreased clarity is not considered to reflect an degradation in lagoon conditions. The continued presence of extensive fine muds in the main body of the lagoon means that water clarity is likely to quickly decline during windy conditions because of wind generated wave disturbance of the bottom.

3. Results and Discussion (Continued)

Sedimentation

Accelerated soil erosion from developed catchments is a major issue for many estuaries in New Zealand as they form a sink for fine suspended sediments. In tidal river plus lagoon estuaries like Waiau/Te Waewae, sedimentation is often an issue because of their poorly-flushed nature. In such estuaries, muddiness is generally restricted to the main lagoon body. In order to assess sedimentation (particularly muddiness) in the Waiau/Te Waewae, grain size, and substrate type were the main indicators.

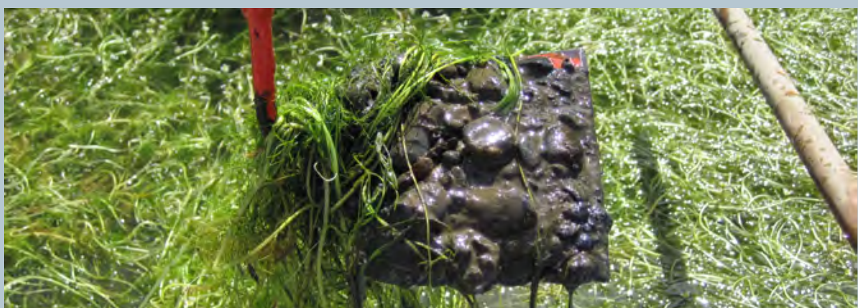
Sediment Type: As in previous years, the substrate within the lagoon was dominated by sand, gravel and cobble, overlaid with a thick layer of mud. Muds were most prevalent in the deeper sections at the east end of the lagoon, and in front of the boat ramp. In the shallow channel between the Waiau mouth and the Holly Burn, the lagoon sediments were mainly clean sands and gravels.

Figure 5. Grain size, at 3 subtidal sites (composite sample), Jan/Feb 2010-2012.

Grain Size: Analytical results from the three transects sampled, (A, E and H - Figure 5) show that the mud content is very high in the main estuary basin. This indicates that mud from the catchment is accumulating predominantly in the deeper reaches of the main lagoon, and indicating it is more at risk of sedimentation effects than the sandier more well-flushed western channel end. However, the results also indicate a substantial decline in mud content compared with previous years. The reason for this decline is currently unknown but one possible explanation is extensive wind driven re-suspension of fine sediment from the estuary bottom coupled with export from the lagoon following mouth closure just prior to sampling. Other possible explanations include catchment management actions to reduce fine sediment loads to streams, an abnormal annual river flow regime, and/or an increase in catchment gravel input loads.

Overall, the findings indicate excessive deposition of fine-muds in Waiau/Te Waewae Estuary.

Sulphide-rich fine soft muds with shallow RPD - 2.5m depth.



Poorly oxygenated cobble margins and moderately oxygenated muds in the middle estuary.

Clean oxygenated muds overlying sand and gravel at 1m depth.

Anoxic sulphide rich sediment associated with decaying vegetation - 3m depth.

Figure 6. Examples of sediment oxygenation, Waiau/Te Waewae Lagoon, 24 January 2012.

3. Results and Discussion (Continued)

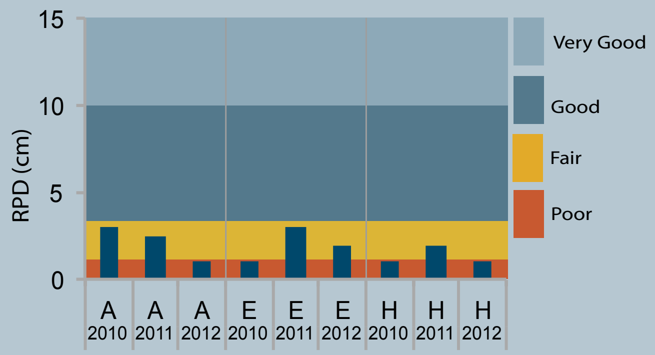


Figure 7. Sediment RPD at 3 subtidal sites.

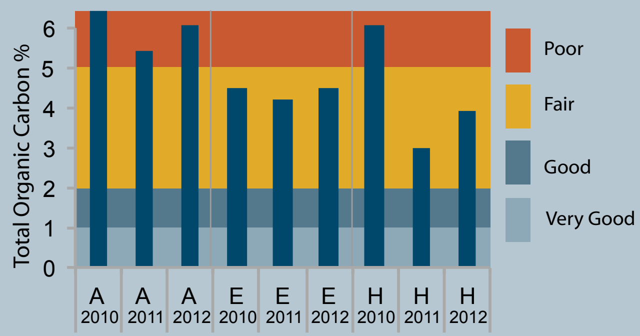


Figure 8. Sediment total organic carbon at 3 subtidal sites.

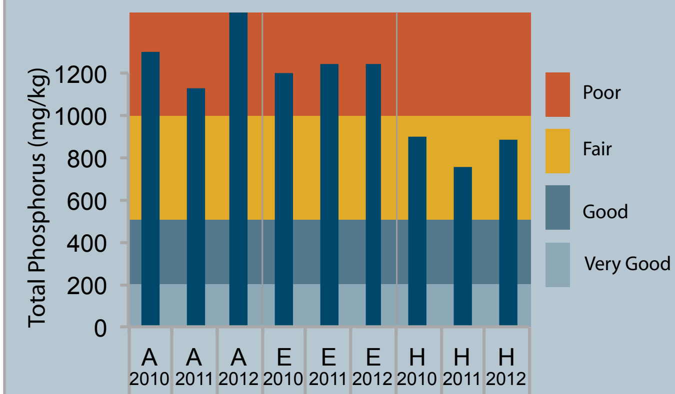


Figure 9. Sediment total phosphorus at 3 subtidal sites.

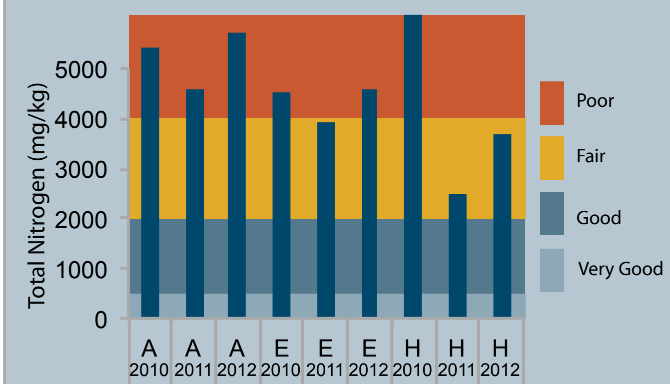


Figure 10. Sediment total nitrogen at 3 subtidal sites.

EUTROPHICATION

Excessive organic input, either from outside or growing within the estuary in response to high nutrient loads, is a principal cause of physical and chemical degradation and of faunal change in estuarine environments. In tidal river estuaries, the sediments become deoxygenated, nuisance algal growth becomes abundant and the number of suspension-feeders (e.g. bivalves and certain polychaetes) declines and deposit-feeders (e.g. opportunistic polychaetes) increase as organic input to the sediment increases (Pearson and Rosenberg 1978). The primary indicators of eutrophication in this survey were grain size, RPD boundary, sediment organic matter, nitrogen and phosphorus concentrations and aquatic plant and algal growth.

Redox Potential Discontinuity (RPD). The depth of the RPD zone provides an indication of the level of sediment oxygenation. Like 2011, in 2012 the surface sediments within the lagoon were generally moderate to poorly oxygenated (RPD depth range >5cm to 1cm). Black sulphide-rich sediment was present near the surface under rotting macroalgae and macrophytes in localised areas (Figure 6), but this was not widespread. Such variable RPD values indicate the changeable conditions often experienced in tidal river estuaries where river flow is a major influence on estuary condition. As a result, the benthic community was likely to be transitional and dominated by organisms and plants tolerant of organic enrichment.

Total Organic Carbon and Nutrients. The concentrations of organic matter (total organic carbon - TOC) and sediment nutrients (total nitrogen- TN and phosphorus - TP) also provide valuable trophic state information. In particular, if concentrations are elevated, and eutrophication symptoms are present (i.e. shallow RPD, excessive algal growth), then TN, TP and TOC concentrations provide a good indication of loadings exceeding the assimilative capacity of the estuary. However, a low TOC, TN or TP concentration does not necessarily indicate an absence of eutrophication symptoms. It maybe that the estuary, or part of an estuary, has reached a eutrophic condition and exhausted the nutrient supply. Obviously, the latter case is likely to better respond to input load reduction than the former.

In relation to Waiau Lagoon sites A, E and H, the results (Figures 8-10) indicate that concentrations of TOC, TP and TN were very high throughout the lagoon ("poor-fair" ratings). Such results indicate an oversupply of organic matter and nutrients in the sediments of the estuary.

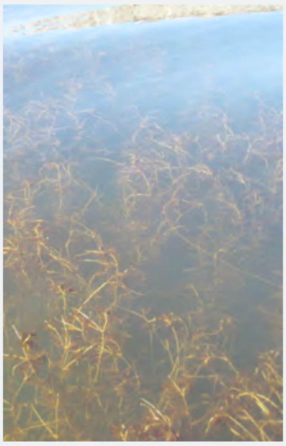
3. Results and Discussion (Continued)

Aquatic Macrophyte and Macroalgal Cover

In 2012, rooted aquatic macrophytes (Table 5) covered approximately 25% of the lagoon (Figure 11), the same as in 2010 and 2011, with thick surface growths similar to those present in 2010. However, as with the previous years of sampling, changes in composition continue to be observed (Table 4). Most notable was a large increase in *Ranunculus trichophyllus* (photo below left) which had displaced most of the *Potamogeton crispus* evident in 2011. At the same time, *Ulva (Enteromorpha) intestinalis* was much thicker and more dominant around the margins and there continued to be a significant reduction in the cover of native species *Myriophyllum propinquum* (<1% cover compared with 50-100% cover in 2010) and *Potamogeton ochreatus,* which was absent. *Ruppia megacarpa* was present in small patches and was more prominent in the lagoon west of the boat ramp than in 2011.

Elsewhere around the lagoon, a similar pattern of banded growth was observed to previous years. *U. intestinalis* was common along the shoreline cobblefields in a narrow band throughout the estuary, while the native stonewort algae *Nitella*, was more common in the upper (east) estuary reaches. Once water got deeper than ~0.5m, *R. trichophyllus* was dominant - luxuriant flowering growths up to 2m long reaching the water surface. *P. crispus* was only seen in deeper water, occasionally reaching the surface, but more commonly being observed 0.5-1m below the surface and largely outcompeted by *R. trichophyllus*.

Ranunculus trichopyllus



Potamogeton crispus

R. trichopyllus and *P. crispus* (1-2m long) at margin in east of the lagoon

Table 4. Summary of major macrophyte changes in Waiau/Te Waewae Lagoon, 2009-2011.

February 2009	February 2010	February 2011	January 2012
• Dominated by introduced and native pondweed *Potamogeton crispus* and *P. ochreatus.* • *Nitella hookeri* present around most of lagoon margin. • Highly invasive Canadian pondweed *Elodea canadensis* relatively widespread near boatramp. • Introduced water buttercup *Ranunculus trichophyllus* present in a few places at low densities.	• Large increase in % cover of *P. crispus* and the native *Myriophyllum propinquum. P. ochreatus* cover reduced. • Decreased presence of *E. canadensis.* • *R. trichophyllus* present in similar abundance to 2009. • Small patches (<0.5m diameter) of *Ruppia polycarpa* near boat ramp.	• *P. crispus* dominant and widespread. • *M. propinquum, E. canadensis* and *P. ochreatus* scarce. • *R. trichophyllus* widespread and abundant. • Small patches of *R. polycarpa* near boat ramp remain, with additional narrow bands (20-50cm wide) of *R. megacarpa* observed at 5-10% cover in 1m deep water west of the Holly Burn towards the Waiau River mouth.	• Thick surface growths of macrophytes were similar to those observed in 2010. • Major change from 2011 to 2012 with extensive cover of *R. trichophyllus* displacing most of the *P. crispus* evident in 2011. • *Ulva intestinalis* much thicker and more dominant around the margins, particularly to the east of the lagoon. • *Ruppia* was more prominent in the lower estuary below the boat ramp than in 2011.

3. Results and Discussion (Continued)

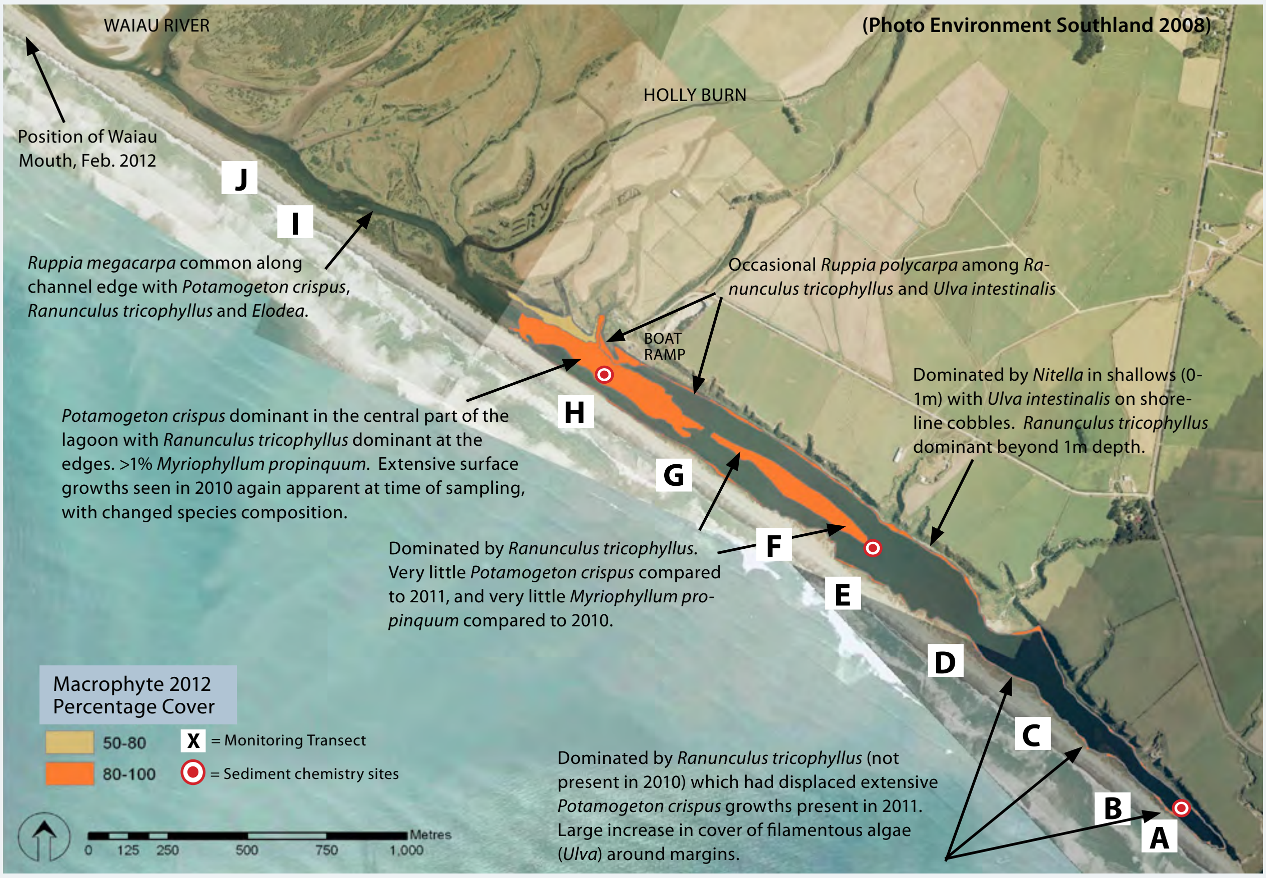


Figure 11. Percentage cover and dominant aquatic vegetation type, Waiau/Te Waewae Lagoon, 2012.

Table 5. Dominant macrophytes and macroalgae, Waiau/Te Waewae Lagoon, 2009-2012.

***Potamogeton crispus* (Curly pondweed)**

P. crispus is an introduced species that is tolerant of slightly brackish as well as freshwater. It can survive in low light and low temperatures, and prefers high nutrient water. It spreads mostly by means of vegetative buds (turions) that germinate in autumn. It forms dense mats of vegetation to the surface of the water. These mats inhibit the growth of native aquatics, and can interfere with boating and other water recreation. These plants germinate in autumn, grow vigorously in spring, and die off in the summer. The decaying plant matter can make the water extremely enriched and encourage nuisance algal mats near the sediment surface. Mainly found in the Waiau Lagoon in the 1-2m depth range.

***Potamogeton ochreatus* (Blunt pondweed)**

P. ochreatus is a widespread native species that is tolerant of slightly brackish as well as freshwater. It can survive in low light and low temperatures, and prefers high nutrient water. It forms dense mats of vegetation to the surface of the water. These plants germinate in autumn, grow vigorously in spring, and die off in the summer. The decaying plant matter can make the water enriched and encourage nuisance algal mats near the sediment surface. Not very common in Waiau Lagoon.

***Nitella hookeri* (Stonewort)**

N. hookeri is a widespread native bottom-dwelling, green charophyte algal species that superficially resembles flowering aquatic plants. *Nitella* sometimes creates dense carpets on freshwater or slightly saline lagoon beds, reaching depths of 30m in some clear lakes (Johnson and Brooke 1989). It is a long stringy looking plant without leaves. Stems "pop" if squeezed. Found in the Waiau Lagoon in the 0-0.5m range, especially around the margins.

***Elodea canadensis* (Canadian pondweed)**

Elodea, an introduced oxygen weed, is an aquatic perennial which can grow easily from fragments and spread via vegetative growth and cause major infestations in many freshwater and slightly saline waterbodies. Classified in "The Lake Managers Handbook - Alien Invaders" (Champion et al. 2002) as a member of the most problematic submerged aquatic weed plant families, i.e. Hydrocharitaceae (genera: *Elodea, Egeria* and *Lagarosiphon*) and Ceratophyllaceae (genus: *Ceratophyllum*). In the Waiau lagoon it was present in patches, particularly in the 0.5-1m depth range.

***Ruppia megacarpa and R. polycarpa* (horses' mane weed)**

Native species growing in relatively shallow water (~2 m). Tolerant of brackish water or saline ponds and lagoons, as well as freshwater lakes and streams. Highly branched slender creeping rhizomes and thread-like long narrow leaves with distinctive small flowers that are terminal on white stalks reaching 30 to 150cm towards the water surface. Found only near the boat ramp in small isolated patches and in the lower estuary.

***Myriophyllum propinquum* and *Myriophyllum triphyllum* (pictured)**

Both are submerged perennial native species that occur throughout New Zealand in both standing and flowing water. Plants grow to 3m tall in deep water up to 3.5m). Tolerant of exposure to lowered water levels where *M. propinquum* may become a prostrate or erect herb up to 10cm high. Small areas of *M. triphyllum* in the Waiau Lagoon, but *M. propinquum* widespread.

***Ranunculus trichophyllus* (Water buttercup)**

R. trichophyllus (Water buttercup) is an introduced species common in freshwater and slightly saline waterbodies. Stems are up to 2m long, leaves are narrow and bright green. Flowers are white with a yellow centre. Found in patches in Waiau lagoon in shallow (<1m deep) water, with cover becoming extensive in 2011.

***Bachelotia antillarum* (Slime macroalgae)**

B. antillarum is a slimy, filamentous, nuisance brown Ectocarpale macroalgae, that is found worldwide, but can grow to nuisance proportions in nutrient enriched estuaries, coastal lagoons and embayments. It can cause sediment deterioration, oxygen depletion, bad odours and have adverse impacts to biota. Moderate growths were found in the Waiau Lagoon.

***Ulva (Enteromorpha) intestinalis* (Green macroalgae)**

U. intestinalis, a nuisance green macroalgae, is found worldwide, but can grow to nuisance proportions in nutrient enriched estuaries, coastal lagoons and embayments. It can cause sediment deterioration, oxygen depletion, bad odours and have adverse impacts to biota. Small areas only were found in the Waiau Lagoon, but at times it can be more abundant.

3. Results and Discussion (Continued)

Like 2011, the 2012 results showed Waiau/Te Waewae Lagoon was in moderate-poor condition. Concentrations of TN, TP and TOC ranged from poor to fair, sediment oxygenation (RPD depth) was rated fair, while nuisance macroalgae and introduced macrophyte growth was extensive.

Overall, lagoon conditions were very similar to those in 2010 and 2011, with no appreciable recovery observed from the decline in lagoon quality since 2009 (Table 6).

Table 6. Summary of conditions monitored in Waiau /Te Waewae Lagoon, 2009-2012.

Indicators	February 2009	February 2010	February 2011	January 2012
Macrophytes	*Potamogeton crispus* and *P. ochreatus* dominant in main body of lagoon, *Nitella hookeri* and *Elodea canadensis* common in shallows. *Ranunculus trichophyllus* present at low density.	Very large increase in cover of *P. crispus* and *Myriophyllum propinquum* in main body of lagoon. Decrease in cover of *P. ochreatus* and *E. canadensis*. *R. trichophyllus* present at low density. Small patches (<0.5m diameter) of *Ruppia polycarpa* near boat ramp.	Dominant cover of *P. crispus* and *R. trichophyllus*. Large decrease in cover of *M. propinquum*. *P. ochreatus* and *E. canadensis* present at low density. *R. polycarpa* still present near boat ramp. *R. megacarpa* observed in channels near the lagoon mouth west of the Holly Burn.	Dominant cover of *R. trichophyllus*. Large decrease in cover of *P. crispus*, *M. propinquum and P. ochreatus* and *E. canadensis* present at low density. *R. polycarpa* still present near boat ramp. *R. megacarpa* observed in channels near the lagoon mouth west of the Holly Burn.
Macroalgae and Epiphytic Growth	Green filamentous *Ulva intestinalis* common around lagoon margins. Moderate growths of the filamentous slime algae *Bachelotia antillarum*.	*U. intestinalis* common around lagoon margins. Moderate growths of *B. antillarum*.	*U. intestinalis* common around lagoon margins. Moderate growths of *B. antillarum*.	*U. intestinalis* prolific around lagoon margins. Moderate growths of *B. antillarum*.
Sediment Quality	Thick fine muds overlaying sand, gravel, and cobble. RPD depth predominantly between 2-3cm in muds, 5-10cm in gravel and cobble. Small patches of black sulphide-rich sediment near the surface under rotting vegetation.	Thick fine muds overlaying sand, gravel, and cobble. RPD depth shallower than in 2009; 1-2cm in muds, 3-5cm in gravel and cobble. Increased presence of sulphide-rich sediment near the surface under rotting vegetation. Sediment nutrients high: TP: 900-1,300mg/kg TN: 4,500-6,100mg/kg TOC: 4.5-6.4%	Thick fine muds overlaying sand, gravel, and cobble. RPD depth slightly improved compared to 2010; 1-3cm in muds, 3-5cm in gravel and cobble. Similar extent of sulphide-rich sediment near the surface under rotting vegetation. Sediment nutrients moderate-high: TP: 760-1,130mg/kg TN: 2,500-4,600mg/kg TOC: 3-5.4%	Thick fine muds overlaying sand, gravel, and cobble. RPD depth slightly improved but similar to 2011; 1-3cm in muds, 3-5cm in gravel and cobble. Similar extent of sulphide-rich sediment near the surface under rotting vegetation. Sediment nutrients high: TP: 880-1,490mg/kg TN: 3,700-5,700mg/kg TOC: 3.9-6.1%
Water Quality	Lagoon stratified - surface waters: salinity: 0.7-3.3 ppt, temperature: 15.7-17.6 °C, DO: 98-109 %saturation Bottom waters (>1.8m) sal: 13.5-17.7 ppt, temp: 16.2-19.9 °C DO: 95-117 %sat. Secchi Disc clarity moderate: 1.3-1.9m. Reported low at other times.	Lagoon unstratified sal: 0.6-1.0 ppt, temp: 16.1-16.8 °C DO: 97-107 %sat. Secchi Disc clarity moderate: 1.5-1.8m. Reported low at other times.	Lagoon stratified - surface waters: sal: 0.7-3.3 ppt, temp: 14.1-15.6 °C DO: 92-114 %sat. Bottom waters (>1.8m) sal: 15.5-18.3 ppt, temp: 17.1-18.3 °C DO: 42-91 %sat. Green water indicates phytoplankton growth relatively high. Secchi Disc clarity moderate: 2.0-2.2m. Reported low at other times.	Lagoon mostly unstratified in relation to DO and Temp: DO: 86-129 %sat. Temp: 14.3-16.1 °C Salinity stratification below 2.6m. Surface sal: 0.8-3.3 ppt, bottom salinity 6.1-7.0ppt. No obvious green tinge in water indicates phytoplankton growth not high. Secchi Disc clarity low: 1.0m. But 2m in western channel. Reported low at other times.
Open/Closed	Lagoon open to the sea	Lagoon open to the sea	Lagoon open to the sea	Lagoon open to sea
Trophic Stage	FEBRUARY 2009 Stage 2. Towards the PRISTINE side of Stage 2.	FEBRUARY 2010 Stage 2. Towards the increasing eutrophication side of Stage 2.	FEBRUARY 2011 Stage 2. Towards the increasing eutrophication side of Stage 2.	JANUARY 2012 Stage 2. Towards the increasing eutrophication side of Stage 2.

3. Results and Discussion (Continued)

The results indicate strong eutrophication symptoms which indicate the estuary remains in a transition from a Stage 2 "moderate" towards a Stage 3 "poor" state (Figure 12). In particular, despite expected moderate catchment inputs, the high sediment nitrogen and phosphorus concentrations indicate the deeper muddy parts of the estuary continue to concentrate catchment nutrients within sediments.

The main reason preventing the lagoon from expressing further eutrophication symptoms is considered to be regular tidal exchange and flushing by relatively low nutrient river flows, and regular mixing of the lagoon waters by wind and wave action. Introduced macrophytes, despite reducing lagoon diversity, also help maintain sediment stability and water clarity, and oxygenation of the sediments and water column.

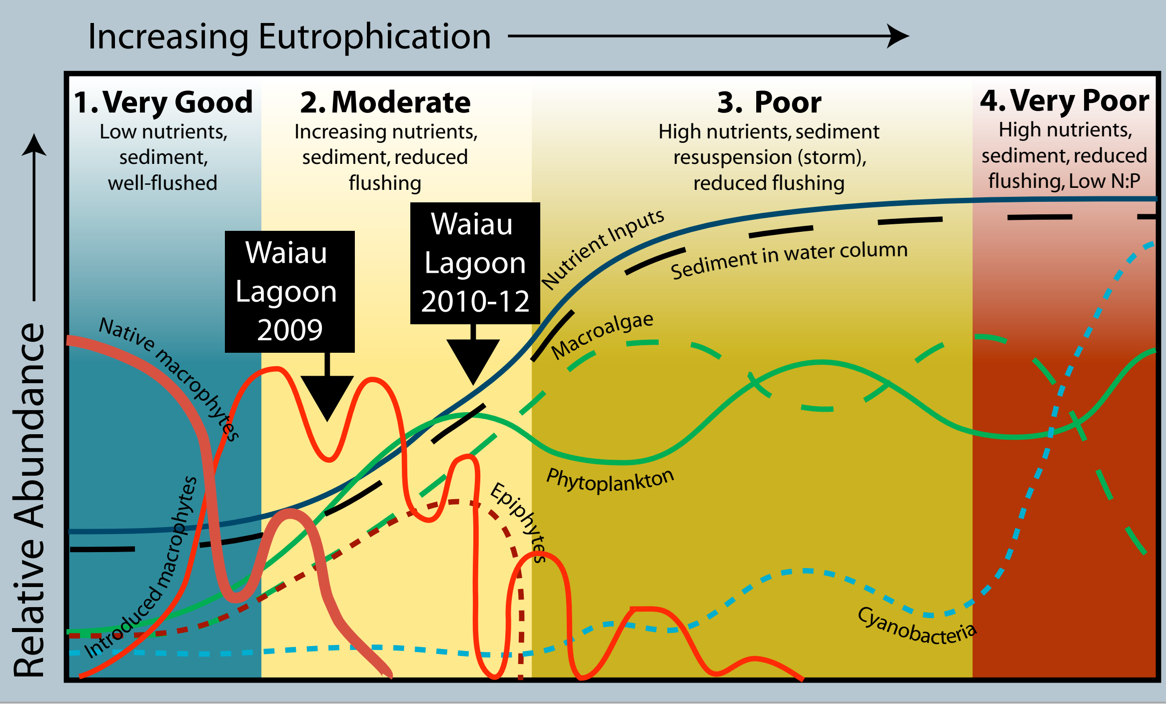
These processes appear sufficient to maintain the lagoon in an oxygenated state. However, because the lagoon relies predominantly on tidal exchange and flushing to maintain its current state, it is very susceptible to changes in water levels, flows and seawater inputs. As a consequence, actions that reduce Waiau River flows, or increase the incidence of mouth closures, are likely to exacerbate sedimentation and eutrophication symptoms within the lagoon. Because of this, and as recommended in 2010 and 2011, methods to measure future changes in sediment inputs, and associated nutrients, should be investigated, particularly given the dominance of fine, readily re-suspended soft mud in the lagoon sediments.

Other important changes in water levels exist in relation to predicted sea level rise which is likely to see an increase in salinity of the lagoon that may increase stratification under calm conditions. This may in turn cause a decline in oxygen in deeper parts of the lagoon releasing sediment bound nutrients. In turn, these nutrients will fuel further nuisance macrophyte and macroalgal growth that are predicted to displace the remaining native aquatic macrophyte community and limit both the human and ecological value of the lagoon. Such a shift, could also trigger the "flipping" of the estuary into a turbid, low value, phytoplankton dominated state. Gaining a better understanding of lagoon hydrodynamics is vital to understanding the extent of such influences.

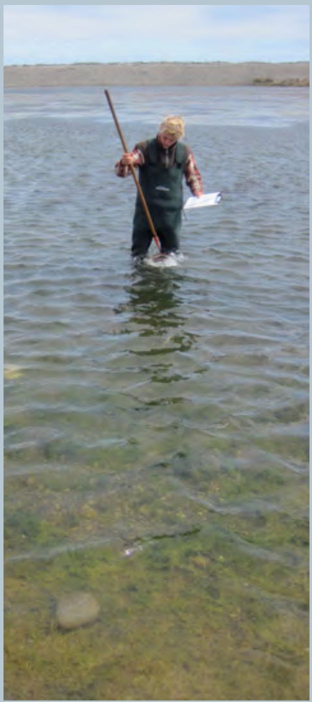
The overall health of the estuary also depends on the protection and enhancement of remaining saltmarsh and terrestrial margin habitat, as maintaining these habitats in good condition will help other important parts of the ecosystem (e.g. macroinvertebrates, fish and birdlife) to thrive, as well as providing important filtering and uptake of sediment and nutrient inputs.

Pathogen input is the other key issue facing the estuary and these are currently being addressed by Environment Southland as part of their bathing water monitoring programme.

Figure 12. Waiau/Te Waewae Lagoon - condition rating and current trophic state.



4. MONITORING



Waiau/Te Waewae Lagoon has been identified by ES as a priority for monitoring, and is a key part of ES's coastal monitoring programme. Based on the current monitoring results and those reported previously (Robertson and Stevens 2008, 2009; Stevens and Robertson 2010, 2011), it is recommended that monitoring continues as outlined below:

Fine Scale Macrophyte and Sediment Condition. Continue fine scale monitoring once every 5 years (next scheduled for Jan/Feb. 2017). That is;

- Map aquatic macrophytes and nuisance macroalgae presence, location, % cover and life stage (including salinity, depth and clarity at established transect sites).
- Monitor sediment quality - broad scale (depth to RPD layer, sediment type) and fine scale (grain size, total nitrogen, total phosphorus and total organic carbon) at 3 sites.

In order to address the issues of eutrophication and sedimentation, it is recommended that cost effective indicator monitoring be undertaken annually in Jan-Feb as follows: RPD, water column DO, salinity, substrate type at the deepest part of the lagoon (Transect C) and a coarse assessment of vegetative percentage cover of main body of lagoon.

Undertake broad scale habitat mapping every 5 years (next due in summer 2013).

Catchment Landuse, Freshwater Abstractions, Mouth Geomorphology
To assess the potential for excessive nutrients and sediment entering the lagoon and for reduced flushing, monitor the following key stressors: reduced flushing, catchment landuse, freshwater abstraction, mouth constriction, and changes to water level. Any significant changes to stressors should trigger an evaluation of the likely impact on estuary susceptibility.

5. MANAGEMENT

Five major issues require management as follows:

1. Ensure Adequate Freshwater Input Flushing Flows.
Ensure the lagoon is well-flushed at critical times, particularly ensuring the action of flood flows from the Waiau River and spring tide entry to the lagoon are not reduced.

2. Develop Nutrient and Sediment Input Guidelines.

Undertake appropriate studies to develop appropriate nutrient and sediment input guidelines for the lagoon.

3. Identify Nutrient and Sediment "hotspots" in the catchment.
Catchment runoff is one of the major stressors to estuaries. Likely ecological responses are lowered biodiversity, aesthetic and recreational values. To prevent avoidable inputs, best management practices (BMPs) should be identified and implemented to reduce nutrient, sediment, and pathogen runoff from catchment "hotspots".

4. Plan to Minimise Ecological Impacts of Sea Level Rise
Develop a plan to minimise the loss of ecosystem services of the Waiau/Te Waewae Lagoon that are vulnerable to climate change effects, particularly sea level rise.
Avoid artificial opening of the estuary without a thorough environmental risk assessment of potential impacts.

5. Saltmarsh and Terrestrial Margin Restoration.
It is recommended a plan be developed to encourage saltmarsh and terrestrial margin re-vegetation, and to support community restoration initiatives.

6. ACKNOWLEDGEMENTS

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APPENDIX

Analytical Methods, Site locations, Field Survey Results and Aquatic Vegetation

APPENDIX 1. ANALYTICAL METHODS

Indicator	Laboratory	Method	Detection Limit
Grain Size	R.J Hill	Air dry (35 degC, sieved to pass 2mm and 63um sieves, gravimetric - (% sand, gravel, silt)	N/A
Total Organic Carbon	R.J Hill	Catalytic combustion, separation, thermal conductivity detector (Elementary Analyser).	0.05g/100g dry wgt
Total Recoverable Phosphorus	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	40 mg/kg dry wgt
Total Nitrogen	R.J Hill	Catalytic combustion, separation, thermal conductivity detector (Elementary Analyser).	500 mg/kg dry wgt

APPENDIX 2. 2012 SURVEY DETAILS

Transect	Depth	Secchi	Temp	Salinity	DO	DO
	(m)	(m)	(°C)	(ppt)	(%sat)	(mg/L)
A (Sediment chemistry site)	0	-	14.9	0.6	102.0	10.4
	2.5	1.1	15.1	1.0	96.0	9.96
B	0	-	15.1	0.6	104.4	10.35
	1.7	1.1	14.2	0.7	86.0	8.82
C	0	-	15.1	0.8	108.5	10.84
	+4.0	0.9	14.7	6.1	83.7	7.92
D	0	-	15.1	0.9	110.0	11.02
	2.8	1.1	14.8	7.0	95.7	9.28
E (Sediment chemistry site)	0	-	14.8	1.3	112.2	11.30
	2.4	1.1	14.7	1.2	111.6	11.20
F	0	-	15.0	1.3	109.0	11.17
	1.8	1.15	14.3	1.3	112.3	11.44
G	0	-	15.3	0.9	126.0	12.61
	1.4	1.2	15.1	1.1	125.3	12.55
H (Sediment chemistry site)	0	-	15.7	3.2	129.9	12.74
	1.9	1.5	15.7	2.7	129.3	12.44
I (multiple sites)	0	-	16.0-15.3	1.0	126.1	12.40
	max 2.0	bottom (2m)	15.7-15.3	1.8	123.1	11.51
J (multiple sites)	0	-	16.1	2.2	120.0	11.83
	max 2.0	bottom (2m)	16.0	3.2	127.2	12.30

Stratification of lagoon water indicated by salinity change at 2.6m.

APPENDIX 2. 2012 SURVEY DETAILS

Site	NZMG East	NZMG North	Depth (m)	Sediment Type	RPD (cm)	Macrophyte	Width of growth (m)	% cover	Height (m)
A1	2097730	5429718	0.2	Cobble/gravel with mud	>5	*Ulva (Enteromorpha) intestinalis* *Ranunculus trichopyllus* (flowering at surface)	1.0 2-4	100 100	0.1 1.1
A2	2097731	5429723	1.7	Soft mud	1	*Potamogeton crispus* (at surface)	2-4	5	1.0
A3	2097746	5429749	2.5	Very soft mud over cobble	1	None			
A4	2097751	5429753	1.6	Very soft mud over cobble	0-1	None			
A5	2097754	5429764	0.3	Cobble/gravel with mud	1	*U. intestinalis* *R. trichopyllus* (flowering at surface)	1.0 2-4	100 100	0.1 1.0
B1	2097589	5429850	0.5	Cobble/gravel with mud	>5	*U. intestinalis* *R. trichopyllus* (flowering at surface)	0.5 2-4	100 100	0.1 1.1
B2	2097591	5429853	1.4	Cobble/gravel with mud	1	*R. trichopyllus* (flowering at surface) *P. crispus* (0.5m below surface)	2-4 0.5	100 50	1.1 1.2
B3	2097610	5429871	1.7	Very soft mud over cobble	1	None			
B4	2097618	5429879	0.8	Soft mud over cobble	1	*R. trichopyllus* (flowering at surface)	2-4	100	1.2
B5	2097626	5429886	0.2	Cobble/gravel with mud	>5	*U. intestinalis* *R. trichopyllus* (flowering at surface)	1.0 2-4	100 100	0.1 1.1
C1	2097324	5430085	0.3	Cobble/gravel with mud	>5	*U. intestinalis* *R. trichopyllus* (flowering at surface)	1.0 2-3	100 100	0.1 1.5
C2	2097325	5430089	1.3	Soft mud over cobble	1	*R. trichopyllus* (flowering at surface)	2-3	100	1.5
C3	2097355	5430114	>4	Very soft mud	1	None			
C4	2097382	5430125	1	Very soft mud	1	None			
C5	2097392	5430135	0.2	Cobble/gravel with mud	>5	*U. intestinalis* *R. trichopyllus* (flowering at surface)	1-2 2-4	80-100 100	0.1 1.2
D1	2097103	5430271	0.2	Cobble/gravel with mud	>5	*U. intestinalis* *R. trichopyllus* (flowering at surface)	1.5 3-5	100 100	0.1 1.2
D2	2097107	5430275	0.8	Soft mud	0-1	*R. trichopyllus* (flowering at surface)	3-5	100	1.2
D3	2097127	5430293	2.8	Very soft mud	1	*P. crispus* (1m below surface)	0.1	1	0.3
D4	2097143	5430320	1	Soft mud	1	*R. trichopyllus* (flowering at surface)	2.0	20-50	1.2
D5	2097146	5430326	0.2	Cobble/gravel with mud	>5	*U. intestinalis* (on gravel stream fan)	8.0	80-100	0.1
E1	2096759	5430514	0.35	Cobble/gravel with mud	>5	*U. intestinalis* *R. trichopyllus* (flowering at surface)	1.0 2-4	100 5-10	0.1 0.5
E2	2096753	5430521	1	Very soft mud	1	*R. trichopyllus* (flowering at surface)	2-3	100	1.1
E3	2096785	5430577	2.4	Very soft mud	2	Dead roots and stems of *P. crispus*			
E4	2096825	5430639	1	Cobble/gravel with mud	3	*R. trichopyllus* (flowering at surface)	2-3	100	1.1
E5	2096834	5430655	0.5	Cobble/gravel with mud	>5	*U. intestinalis* *R. trichopyllus* (flowering at surface) *Nitella hookerii* (in shallows along shoreline)	1-2 2-4 1-2	100 5-10 100	0.1 1.1 0.3-0.5
F1	2096634	5430649	0.4	Cobble/gravel with mud	>5	*U. intestinalis*	2-3	80-100	0.1
F2	2096636	5430653	1.2	Soft mud	1	*R. trichopyllus* (flowering at surface)	2.0	100	1.1
F3	2096652	5430689	1.4	Very soft mud with sand	3	*R. trichopyllus* (flowering at surface) *P. crispus* (below surface)	25 25	100 5	1.6 1.4
F4	2096701	5430774	0.5	Very soft mud	1	*R. trichopyllus* (flowering at surface) *Myriophyllum triphyllum* (below surface)	2.0 2.0	100 20	1.2 0.5
F5	2096707	5430784	0.4	Cobble/gravel with mud	>5	*U. intestinalis*	2-4	80-100	0.1
G1	2096268	5430870	0.4	Cobble/gravel with mud	>5	*U. intestinalis* *R. trichopyllus* (flowering at surface)	2-3 2-3	100 5-10	0.1 0.5
G2	2096275	5430881	1.3	Soft mud over gravel	3	*R. trichopyllus* (flowering at surface) *P. crispus* (below surface)	2-3 2-3	100 5	1.2 0.8
G3	2096305	5430933	2.7	Soft mud	1	*P. crispus* (below surface)	4.0	10	0.5
G4	2096346	5430990	1.3	Soft mud	3	*P. crispus* (below surface)	4.0	20	0.5
G5	2096363	5431018	0.3	Mud over gravel	>5	*U. intestinalis*	2-3	80-100	0.1
H1	2095947	5431081	0.5	Mud over gravel/cobble	>5	*U. intestinalis*	2-3	100	0.1
H2	2095952	5431088	0.8	Soft mud	0	*R. trichopyllus* (flowering at surface) *P. crispus* (below surface)	10 10	100 50-80	1.1 0.6
H3	2095981	5431152	1.9	Very soft mud	1	*P. crispus* (below surface)	4.0	80-100	1.2
H4	2096028	5431199	0.6	Mud over gravel/cobble	>5	*U. intestinalis*	2-3	60-80	0.3
H5	2096035	5431219	0.4	Mud over gravel/cobble	>5	*U. intestinalis*	5.0	60-80	0.1
I,J	various	various	0.2-2	Cobble gravel and sand	2- >5	*Elodea canadensis* (patches in shallows) *R. trichopyllus* (strip along margin) *Ruppia megacarpa* (along edge of channel) *P. crispus* (thick submerged patches)	0.2 0.5 0.5 1-2	1-5 1-5 5-10 20-30	0.3 1.0 1.0 1.0