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Waiau (Te Waewae) Lagoon 2011

Fine Scale Monitoring and Macrophyte Mapping

Prepared for

Environment Southland

March 2011

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

Ranunculus trichopyllus

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By

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All photos by Wriggle except where noted otherwise.

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WAIAU LAGOON - EXECUTIVE SUMMARY

Waiau / Te Waewae Lagoon

Vulnerability Assessment
Identifies issues and recommends monitoring and management. Completed in 2008 (Robertson and Stevens 2008)

Waiau / Te Waewae Issues
Moderate eutrophication
Excessive sedimentation
Habitat Loss (Saltmarsh, and terrestrial margin)

Monitoring

Broad Scale Mapping
Sediment type
Saltmarsh
Seagrass
Macroalgae
Land margin

5 -10 yearly
First undertaken in 2008.

Fine Scale Monitoring
Grain size, RPD, Organic Content
Nutrients,
Macroalgae

3-4yr Baseline then 5 yearly
Baseline started 2009.
Next survey 2012.

Condition Ratings
Area soft mud, Area saltmarsh, Area seagrass, Area terrestrial margin, RPD depth, Organic content, N and P,

Other Information
Previous reports, Observations, Expert opinion

LAGOON CONDITION
Eutrophication Symptoms
Excessive Muds
Low Toxicity
Habitat Degraded (saltmarsh, terrestrial margin)

Recommended Management

- Limit intensive landuse.
- Set nutrient, sediment guidelines.
- Margin vegetation enhancement.
- Manage for sea level rise.
- Enhance saltmarsh.
- Manage weeds and pests.

This report summarises the results of the second year of fine scale monitoring of Waiau/Te Waewae Estuary, a 4km long coastal lagoon (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) was 1-3cm deep indicating fair oxygenation. RPD depth, which declined from 2009-2010, improved slightly in 2011.
- The indicator of organic enrichment (Total Organic Carbon) was moderate to high.
- Nutrient enrichment indicators for total phosphorus and total nitrogen were at moderate-high concentrations, but slightly lower than in 2010.
- The sediment in deeper areas had very high mud concentrations (~95% mud), but in the lower estuary reaches the concentrations were low and dominated by sands and gravels.
- Moderate nuisance macroalgal cover. Similar cover to 2010 but less extensive surface growths.
- High value native macrophytes (e.g. *Ruppia*) were present in the estuary.

CONDITION RATINGS	2010			2011		
	Site A3	Site E3	Site H3	Site A3	Site E3	Site H3
RPD Profile (Sediment oxygenation)	Fair	Fair	Fair	Fair	Fair	Fair
TOC (Total Organic Carbon)	Poor	Fair	Poor	Poor	Fair	Fair
Total Phosphorus (TP) in sediment	Poor	Poor	Fair	Poor	Poor	Fair
Total Nitrogen (TN) in sediment	Poor	Poor	Poor	Poor	Fair	Fair

LAGOON CONDITION AND ISSUES

The 2011 results showed Te Waewae Lagoon was in a moderate to poor condition. It was in a similar condition to 2010, 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 and depression of high value native macrophytes to only sparse occurrences. 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 or 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

In order to establish baseline conditions, fine scale monitoring (including macroalgal and macrophyte mapping) is recommended annually for the next 1-2 years, then every five years (next scheduled for February 2012). Broad scale habitat mapping is scheduled every 5 years (next due 2013). In order to assess water column trophic status, monthly water quality monitoring should be initiated. To assess the potential for excessive nutrients and sediment entering the lagoon and for reduced flushing, monitor the following key stressors: reduced extent of flushing, catchment landuse, freshwater abstraction, mouth constriction, and changes to water level. In addition, sediment rate monitoring options should be initiated for the fine and easily disturbed sedimentation evident in the estuary east of the Holly Burn.

Five major issues require management 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. Recently, 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 being 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. 2010 monitoring results are presented in Stevens and Robertson (2010).

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 second 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)

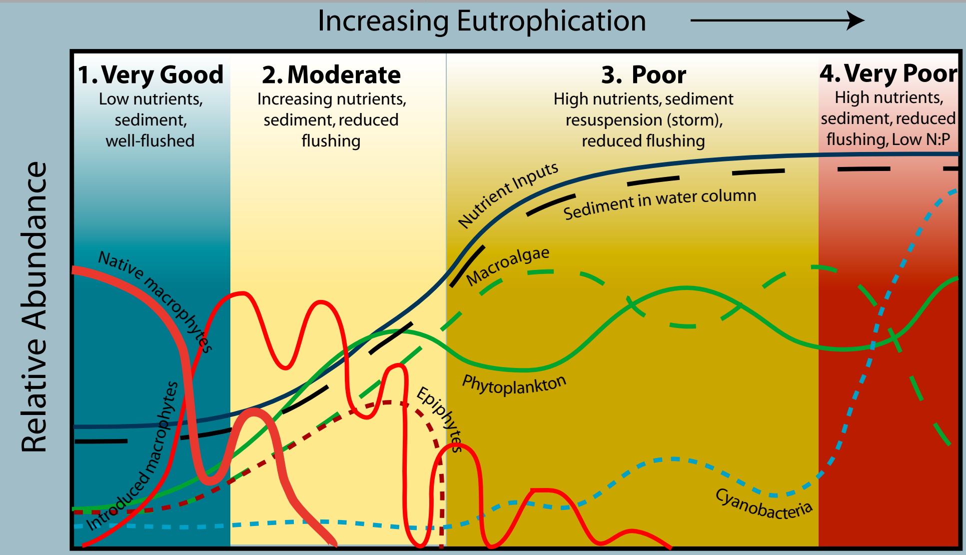
Table 1. Summary of the major issues affecting most NZ estuaries.

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).

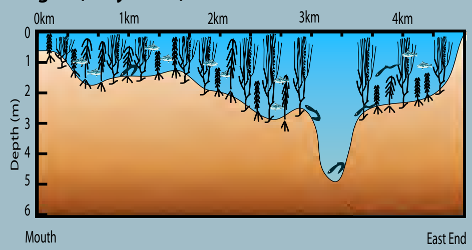
Issue	Indicator	Method
Sedimentation	Soft Mud Area	Broad scale mapping - estimates the area and change in soft mud habitat over time.
Sedimentation	Sedimentation Rate	Fine scale measurement of sediment deposition.
Sedimentation	Sediment Grain Size	Fine scale measurement of sediment grain size, including 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.

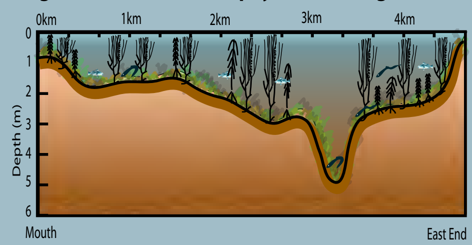


Conceptual representation of response of aquatic vegetation to increased nutrients in coastal lagoons (modified from de Wit et al. 2001, Viaroli et al. 2004, Zaldivar et al. 2008 and information on NZ coastal lagoons - Mitchell 1971, Gibbs 1973, Gerbeaux and Ward 1991, Gibbs 2002, Edwards and Clayton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

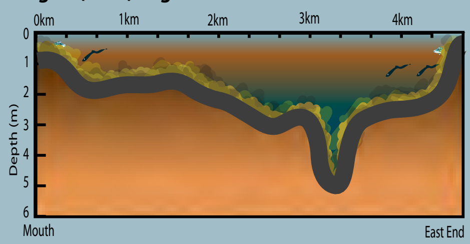
Stage 1 (Very Good) Pristine



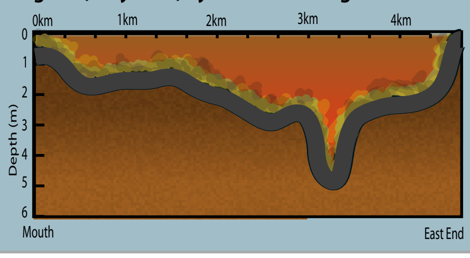
Stage 2 (Moderate) Macrophytes Declining



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. *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 *Enteromorpha*) and phytoplankton are still present. Water clarity is low and sediment quality poor (increasing mud content, anoxic, and sulphide-rich).

2. METHODS

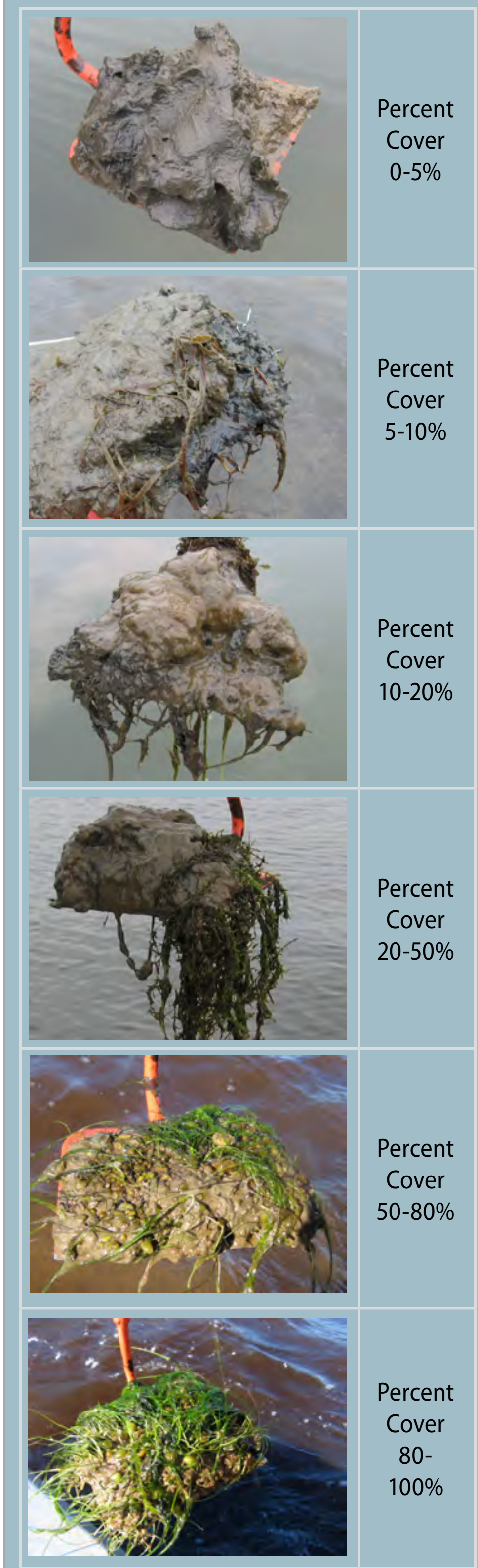


Figure 3. Percent cover categories for aquatic vegetation.

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 26 February 2011 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 1 presents the 2011 field measurements. Previous monitoring results are reported in Robertson and Stevens (2009), and Stevens and Robertson (2010).

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.

Figure 4. Location of sampling sites, Waiau/Te Waewae Lagoon February 2011.

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 26 February 2011 fine scale monitoring of Waiau/Te Waewae Lagoon is presented below, with detailed results of aquatic vegetation, sediment type, sediment oxygenation, and water quality (secchi disc clarity, dissolved oxygen, salinity and temperature), contained in Appendix 1. A summary of the condition ratings are presented in the figures accompanying the sediment chemistry results on page 10.

Table 3. Sediment chemistry results (composite sample) for Waiau/Te Waewae Lagoon, 26 February 2011.

Transect	Site	Depth (m)	RPD (cm)	Salinity (ppt)	TOC (%)	Mud (%)	Sand (%)	Gravel (%)	TN (mg/kg)	TP (mg/kg)
A	A3	3.0	2-3	16.7	5.4	93.5	3.3	3.2	4,600	1,130
E	E3	2.5	3	16.9	4.2	98.7	1.2	< 0.1	3,900	1,240
H	H3	1.1	2	3.0	3.0	89.5	10.4	0.1	2,500	760

Aquatic Macrophyte and Macroalgal Cover

In 2011, rooted aquatic macrophytes covered approximately 25% of the lagoon (Figures 5 and Table 5), the same as in 2010. However, as with the previous year, changes in composition continue to be observed (Table 4). Most notable was a large increase in *Ranunculus trichophyllus* (photo below left) which had become widespread (80-100% cover) in a 2-5m band around the margins of the lagoon (Figure 5, Appendix 2). At the same time there was a significant reduction in the native species *Myriophyllum propinquum* (reduced from 50-100% cover to <1%) and *Potamogeton ochreatus,* particularly near Transects F, G and H. The very extensive growths of *P. crispus* (centre photo below), that were choking the surface of the lagoon by the boat ramp in 2010 were present at a similar density, but were not present as extensive surface growths in 2011 (see Figure 11).

Elsewhere around the lagoon, a similar pattern of banded growth was observed to previous years. *Ulva intestinalis* was common along the shoreline cobblefields in a narrow band, particularly in the lower (west) 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* became dominant in deeper water where it grew extensively, occasionally reaching the surface, but more commonly being observed 0.5-1m below the surface.

Ranunculus trichopyllus

Potamogeton crispus

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

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

February 2009	February 2010	February 2011
• 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.

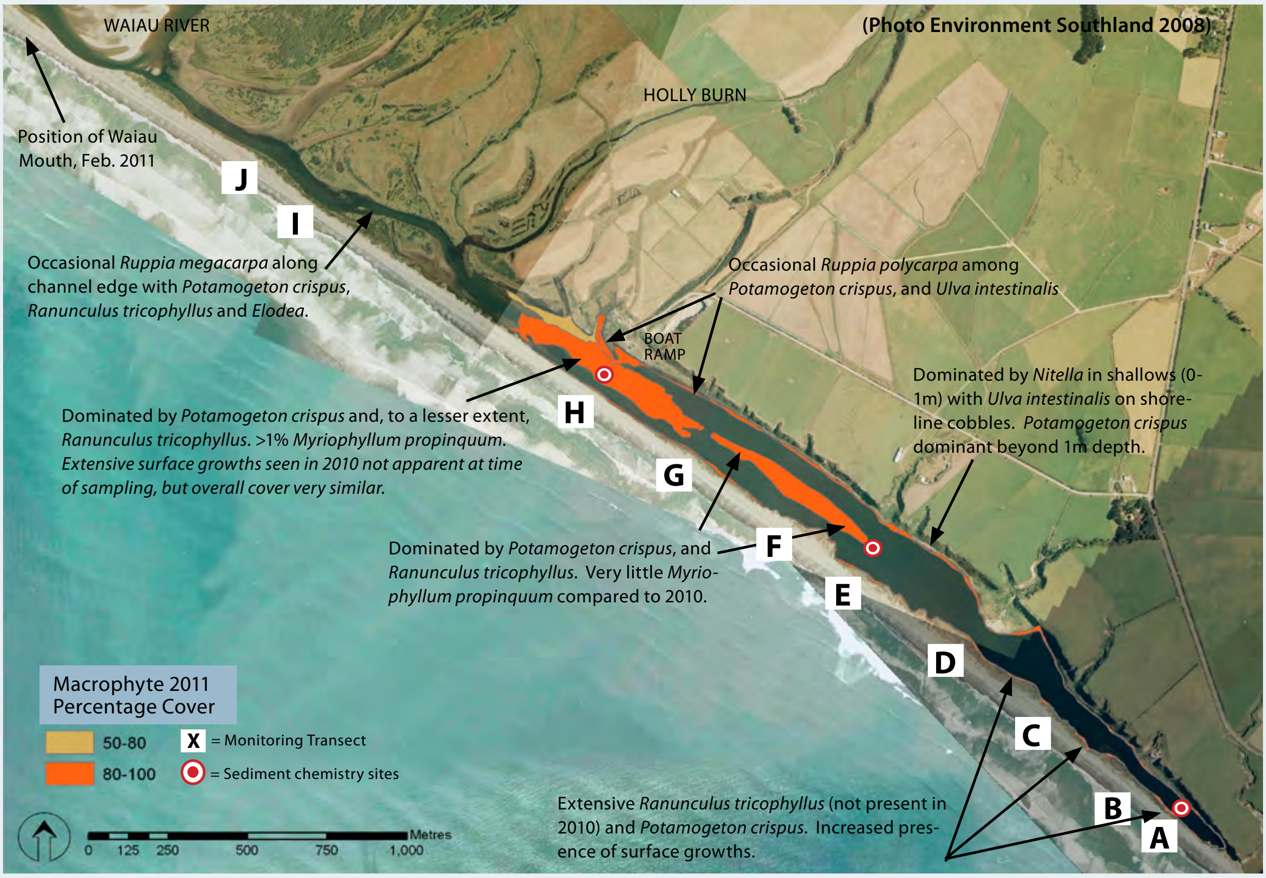


Figure 5. Percentage cover and dominant aquatic vegetation type, Waiau/Te Waewae Lagoon, 26 Feb. 2011.

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. Water level was similar to when the lagoon was previously monitored in 2009 and 2010 and was open to the sea.

The tidal range on 26 February 2011 was 0.9m, and the lagoon water level varied from 1.15m above mean sea level at low tide to 2.05m at high tide. Over the previous year lagoon levels ranged from 1.060 to 3.606m (Environment Southland unpublished data 2011).

Sediment Type and Anoxic layer

The substrate within the lagoon was dominated by sand, gravel and cobble, overlaid with a thick layer of fine muds (Figure 6). Muds were most prevalent in the deeper sections to the east 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.

Surface sediments within the lagoon were generally oxygenated in 2011 (RPD depth range >5cm to 1cm), and slightly improved on those observed in 2010. Black sulphide-rich sediment was present near the surface under rotting macroalgae and macrophytes (Figure 8) in localised areas, but this was not widespread.

Table 5. Dominant macrophytes and macroalgae, Waiau/Te Waewae Lagoon Feb. 2009, 2010, and 2011.

***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)**

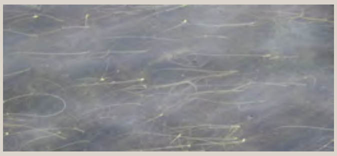
P. ochreatus is a widespread native species that is tolerant of slightly brackish as well as freshwater. It can survive in low light and low temperatures, and prefers high nutrient water. It forms dense mats of vegetation to the surface of the water. These plants germinate in autumn, grow vigorously 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 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.

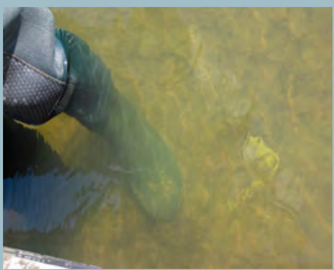
3. Results and Discussion (Continued)

Salinity and Temperature and Dissolved Oxygen

In 2011, stratification was evident in the lagoon with a halocline (shift in salinity) and thermocline (shift in temperature) present at a depth of 1.8m. Results showed the presence of seawater underneath freshwater, which was warmer, saltier, and less well oxygenated compared to surface water as follows:

Depth	m	0-1.8	>1.8
Salinity	ppt	0.7-3.3	15.5-18.3
Temperature	°C	14.1-15.6	17.1-18.3
Dissolved Oxygen	mg/l	9.3-10.9	3.8-7.4
Dissolved Oxygen	% saturation	92-114	42-91

While no stratification was measured in February 2010, 2011 conditions were very similar to those measured February 2009.



Water Clarity (Secchi Disc)

Lagoon water clarity ranged from 2.0-2.2m, ~0.5m better than at the same time in 2010, with the bottom visible throughout most of the estuary. As the 2011 measures were taken when the lagoon was very calm, the increased clarity compared to 2010 results is not considered to reflect an improvement in lagoon conditions. The continued presence of extensive fine muds in the lagoon means that water clarity is likely to quickly decline during windy conditions because of wind generated wave disturbance of the bottom.

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

Well 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**, 26 February 2011.

Figure 7. Grain size at 3 subtidal sites, Waiau/Te Waewae Lagoon, February 2010 and 2011.

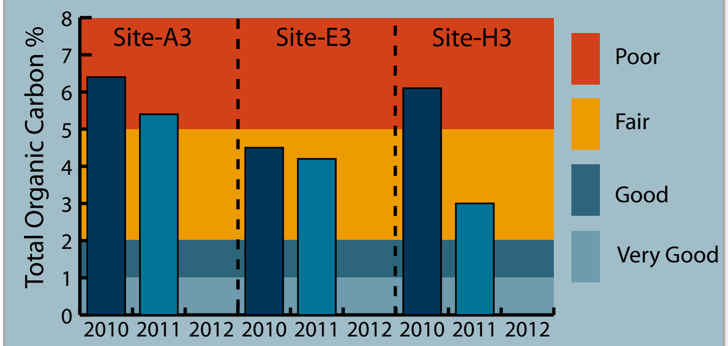


Figure 8. Total organic carbon at 3 subtidal sites, Waiau/Te Waewae Lagoon, February 2010 and 2011.

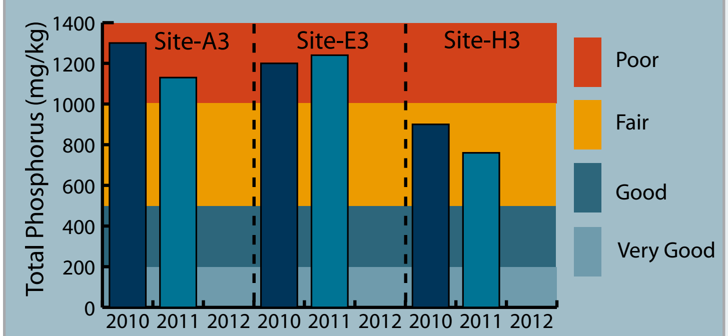


Figure 9. Total phosphorus at 3 subtidal sites, Waiau/Te Waewae Lagoon, Feb. 2010 and 2011.

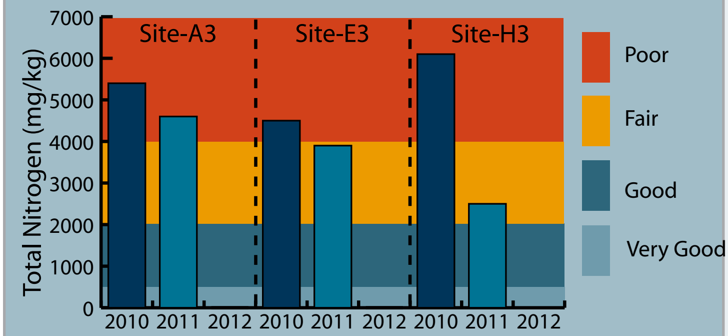


Figure 10. Total nitrogen at 3 subtidal sites, Waiau/Te Waewae Lagoon, February 2010 and 2011.

In 2011, the second year of a 3 year baseline was completed to collect information on key indicators of eutrophication, the primary threat identified to the Waiau Lagoon (Robertson and Stevens 2008, 2009).

GRAIN SIZE (%MUD, SAND, GRAVEL)

Grain size measurements indicate the muddiness of a particular site. Because of greater relative surface area, muds are generally associated with higher organic content and nutrient concentrations than sands and gravels, and thus muddier areas generally act as a sink concentrating these catchment inputs. Results from the 3 transects sampled (Figure 7) show sediments within the deeper parts of the estuary are very much dominated by muds. These locations are therefore likely to concentrate nutrients and be most susceptible to eutrophication symptoms.

ORGANIC MATTER (TOC)

Fluctuations in organic input are considered to be one of the principal causes of faunal change in estuarine and near-shore benthic environments, and elevated organic enrichment causes changes in physical and biological parameters, which in turn have effects on the sedimentary and biological structure of an area.

The indicator of organic enrichment (TOC) in 2011 remained at moderate to high concentrations (3.0-5.4%), a condition rating of “fair” to “poor” (Figure 8).

TOTAL PHOSPHORUS

Total phosphorus (a key nutrient in the eutrophication process) in 2011 remained in the “poor” to “fair” categories indicating “moderate-high enrichment” (Figure 9). This means that the Waiau/Te Waewae Lagoon sediments have a moderate-high store of P in the sediments (sourced from both recent and historical catchment inputs). Although loads will be much lower in the sand and cobble dominated lower (west) estuary (as mud content diminishes), these concentrations mean the deeper parts of the estuary are highly susceptible to eutrophication symptoms.

TOTAL NITROGEN

Total nitrogen (the other key nutrient in the eutrophication process) was rated in the “poor” to “fair”, categories (Figure 10). This means that the Waiau/Te Waewae Lagoon sediments have a large store of N in the sediments (sourced from both recent and historical catchment inputs). Although loads will be much lower in the sand and cobble dominated lower estuary (as mud content diminishes), these concentrations mean the deeper parts of the estuary are highly susceptible to eutrophication symptoms.

Overall, conditions indicate enrichment is greatest in the east, farthest from the mouth and in the deepest parts of the lagoon.

3. Results and Discussion (Continued)

Green colouration of lagoon water suggesting relatively high phytoplankton growth in 2011.

The 2011 results showed Waiau/Te Waewae Lagoon was in moderate-poor condition. Concentrations of TN, TP and TOC ranged from fair to poor, sediment oxygenation (RPD depth) was rated fair, while nuisance macroalgae and macrophyte growth was extensive. While not measured, the green colouration of the lagoon water also suggested phytoplankton growth in the lagoon was relatively high (see inset photo left).

Although visually striking, the apparent reduction from 2010 to 2011 in extensive surface growths of *Potamogeton crispus* just east of the Holly Burn mouth (Figure 11) does not reflects a significant reduction in nuisance growth. The February 2011 cover of *P. crispus* remained at a very similar level to 2010, the only difference being plants were not reaching the surface.

Overall, lagoon conditions were very similar 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 February 2009, 2010, and 2011.

Indicators	February 2009	February 2010	February 2011
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.
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*.
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%
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 mouth Open/ Closed	Lagoon open to the sea	Lagoon open to the sea	Lagoon open to the 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.

3. Results and Discussion (Continued)

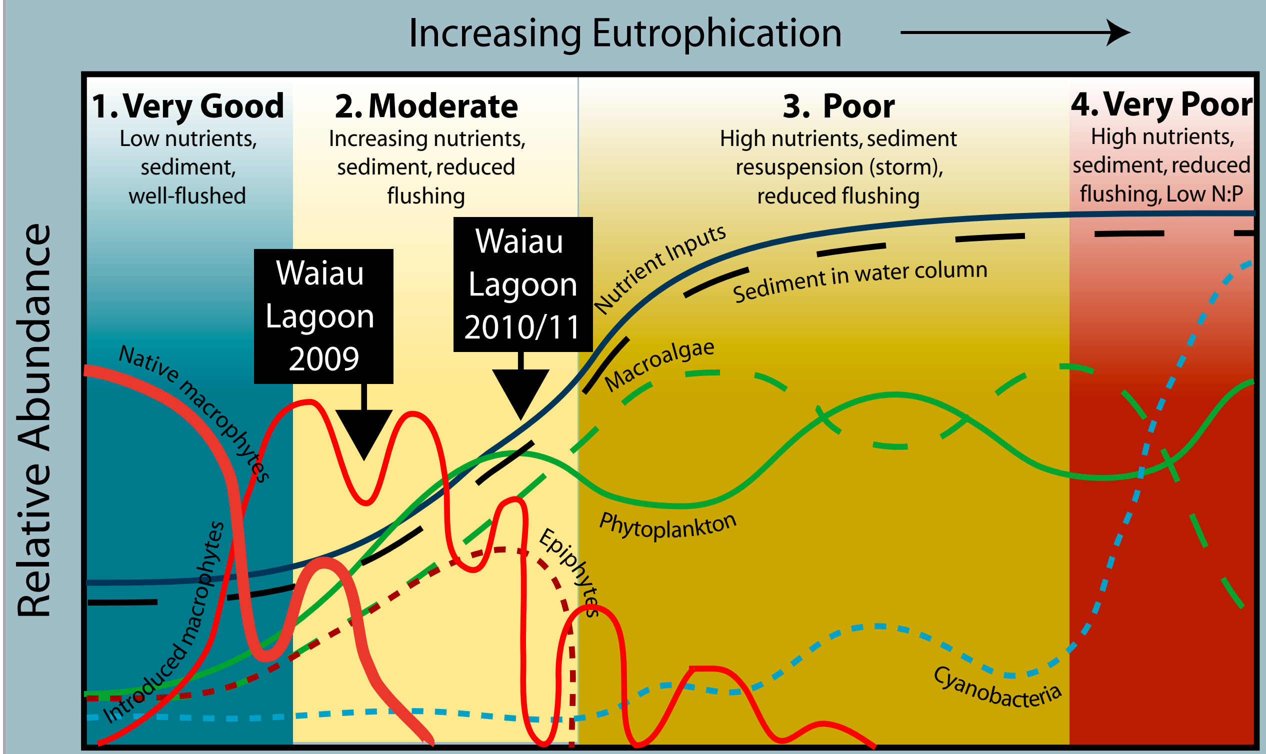
Figure 11. Waiau Lagoon - extensive choking surface growth of ***Potamogeton crispus*** just east of the Holly Burn mouth in 2010 (left) and the same area in 2011 (right) where subsurface growths remain similar, but are not reaching the surface.

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 the current regular tidal exchange and flushing by river flows, and mixing of lagoon waters by wind and wave action. These processes appear sufficient to maintain the lagoon in an oxygenated state. However, because of this, the estuary is very susceptible to further changes in water levels and seawater inputs.

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



3. Results and Discussion (Continued)

Myriophyllum propinquum

Information on the effects of abstraction on the lagoon is currently limited, but any reduction in freshwater inputs from the Waiau River is expected to reduce flushing and replenishment of the lagoon with freshwater. The possible reduction in higher flows due to water abstraction from the Waiau River will directly influence the sedimentation regime in the Lagoon, although the nature and extent of the effects have not yet been determined. In addition, targeted abstraction for hydro-electric power may further influence the opening/closing of the lagoon mouth by changing the way sediments near the mouth accumulate.

Because of this, and as recommended in 2010, methods to measure future changes in sediment inputs 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.

Lower estuary near the Holly Burn

4. MONITORING

Previous assessments (Robertson and Stevens 2008, 2009, Stevens and Robertson 2010) identified a need for regular targeted monitoring, as well as intensive studies, for effective ongoing management of this estuary as follows:

Macrophyte and Sediment Condition
Monitor the condition of macrophyte beds, macroalgal status, and sediment quality, during summer prolonged low river flows (annually for three years to establish a baseline then every five years) as follows:

- 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.

Water Quality
Initiate monthly monitoring from December-March each year for nutrients, water clarity, salinity, chlorophyll a, temperature and dissolved oxygen at the lagoons deepest point (surface and bottom) to assess the condition, trophic status, bottom water stagnation and macrophyte/phytoplankton dominance.

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. In association with this, undertake a study of lagoon hydrology to determine relationships between major drivers of stratification and flushing in the lagoon.

2. Develop Nutrient and Sediment Input Guidelines.
Use the results from the hydrological study above to identify the current extent of lagoon flushing (residence time) and use this information, plus coastal lagoon response data from other 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 1

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 1. 2011 SURVEY DETAILS

Transect	Depth (m)	Secchi (m)	Temp (°C)	Salinity (ppt)	DO (%sat)	DO (mg/L)
A (Sediment chemistry site)	0	-	15.0	3.3	101.4	9.98
	3.0	2.2	17.9	16.7	69.7	5.87
B	0	-	14.6	3.1	114.3	10.68
	2.8	2.1	17.8	16.9	86.0	7.20
C	0	-	14.7	1.5	110.0	10.85
	4.0	2.2	17.1	18.3	63.1	5.21
D	0	-	14.7	3.0	99.9	9.92
	2.0	bottom	17.8	16.5	66.1	6.24
E (Sediment chemistry site)	0	-	14.6	1.8	92.1	9.26
	2.5	2.0	17.6	16.9	75.9	6.42
F	0	-	14.9	0.7	97.1	9.70
	1.8	bottom	17.9	15.5	91.0	7.46
G	0	-	14.6	1.3	94.2	9.35
	1.8	bottom	18.3	16.0	42.0	3.80
H (Sediment chemistry site)	0	-	15.6	3.1	97.7	9.51
	1.1	bottom	15.6	3.1	97.7	9.51
I, J (multiple sites)	0	-	14.1-14.9	1.4-2.6	86.4-96.3	8.61 - 9.90
	max 1.6	bottom	14.1-14.9	1.4-2.6	86.4-96.3	8.61 - 9.90
Stratification of lagoon water indicated by salinity and temperature change at 1.8m.						

APPENDIX 1. 2011 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	Mud over cobble/gravel	2-3	*Ranunculus trichopyllus* (flowering at surface)	2-4	100	1
A2	2097731	5429723	1.0	Mud with some gravel	2-3	*Potamogeton crispus* (0.5m below surface)	2-4	100	1
A3	2097746	5429749	3.0	Very fine mud over cobble	2-3	None			
A4	2097751	5429753	1.2	Mud with some gravel	2-3	*P. crispus* (at surface)	1-2	80-100	1
A5	2097754	5429764	0.2	Gravel/cobble	2-3	*R. trichopyllus* (flowering at surface)	1-2	100	1
B1	2097589	5429850	0.2	Cobble/gravel	3	*R. trichopyllus* (flowering at surface)	1-2	100	1
B2	2097591	5429853	1.5	Mud with some gravel	1	*P. crispus* (0.5m below surface)	1-2	10-20	1
B3	2097610	5429871	2.8	Clean fine mud	1	None			
B4	2097618	5429879	1.5	Clean very fine mud	1	*P. crispus* (0.5m below surface)	1-2	10-20	1
B5	2097626	5429886	0.2	Mud over cobble/gravel	3	*R. trichopyllus* (flowering at surface)	1-2	100	1
C1	2097324	5430085	0.2	Mud over cobble/gravel	>3	*R. trichopyllus* (flowering at surface)	1-2	100	1
C2	2097325	5430089	1.0	Clean mud	1	*P. crispus* (0.5m below surface)	4	100	1
C3	2097355	5430114	4.0	Clean mud	1	None			
C4	2097382	5430125	1.2	Clean mud	1	*P. crispus* (0.5m below surface)	4	100	2
C5	2097392	5430135	0.2	Gravel/cobble	2	*R. trichopyllus* (flowering at surface)	1-2	100	1
D1	2097103	5430271	0.2	Gravel	>3	*Nitella hookerii* (in shallows along shoreline) *R. trichopyllus* (flowering at surface)	0.5 1-2	20-50 100	0.2 2
D2	2097107	5430275	1.0	Mud over cobble	>3	*P. crispus* (at surface)	3	80-100	1
D3	2097127	5430293	2.0	Clean mud	>3	*P. crispus* (1m below surface)	5	30	1
D4	2097143	5430320	1.0	Very fine clean mud	>3	*P. crispus* (1m below surface)	5	30	1
D5	2097146	5430326	0.2	Gravel	>3	*R. trichopyllus* (flowering at surface) *N. hookerii* (in shallows along shoreline)	1-2 0.5	100 20-50	1 0.2
E1	2096759	5430514	0.2	Mud over gravel	3	*N. hookerii* (in shallows along shoreline)	0.5	20-50	0.2
E2	2096753	5430521	0.8	Mud	3	*R. trichopyllus* (flowering at surface)	5	100	1.5
E3	2096785	5430577	2.5	Mud	3	*P. crispus* (1 below surface)	5	80-100	1.5
E4	2096825	5430639	0.5	Mud with sand/gravel	3	*R. trichopyllus* (flowering at surface)	5	100	1
E5	2096834	5430655	0.2	Gravel/cobble	3	*R. trichopyllus* (flowering at surface)	5	100	1
F1	2096634	5430649	0.2	Gravel	1	*N. hookerii* (in shallows along shoreline)	0.5	20-50	0.2
F2	2096636	5430653	1.0	Mud over gravel	2	*R. trichopyllus* (flowering at surface) *P. crispus* (below surface)	3 4	100 20-50	1 1
F3	2096652	5430689	1.8	Clean mud	2	*R. trichopyllus* (flowering at surface) *P. crispus* (below surface)	5 5	100 5	2 1
F4	2096701	5430774	1.2	Mud over gravel	1	*P. crispus* (below surface)	3	10-30	1
F5	2096707	5430784	0.2	Gravel	3	*R. trichopyllus* (flowering at surface) *N. hookerii* (in shallows along shoreline)	1-2 0.5	100 20-50	1 0.2
G1	2096268	5430870	0.2	Mud over gravel	3	*Enteromorpha intestinalis*	0.2	50	0.05
G2	2096275	5430881	1.2	Soft mud	1	*R. trichopyllus* (flowering at surface) *P. crispus* (below surface)	1 4	20 100	1 1
G3	2096305	5430933	2.0	Soft mud	1	*P. crispus* (below surface) *R. trichopyllus* (flowering at surface)	4 4	100 20	1 1
G4	2096346	5430990	0.8	Mud over gravel	1	*P. crispus* (below surface) *R. trichopyllus* (flowering at surface)	4 4	100 20	1 1
G5	2096363	5431018	0.2	Mud over gravel	1	*R. trichopyllus* (flowering at surface)	4	100	1
H1	2095947	5431081	0.2	Mud over gravel/cobble	2	*Enteromorpha intestinalis*	0.2	50	0.05
H2	2095952	5431088	1.0	Mud	2	*R. trichopyllus* (flowering at surface) *P. crispus* (below surface) *Myriophyllum triphyllum* (below surface)	1 4 4	100 20-50 <1%	1 1 0.5
H3	2095981	5431152	1.1	Mud	2	*P. crispus* (below surface) *R. trichopyllus*	4 4	80-100 20	1 1
H4	2096028	5431199	1.2	Mud	2	*P. crispus* (below surface) *R. trichopyllus* (flowering at surface) *M. triphyllum* (below surface)	4 4 4	80-100 20 <1	1 1 0.5
H5	2096035	5431219	0.2	Mud over gravel	2	*R. trichopyllus*(flowering at surface) *E. intestinalis* (below surface)	2 0.2	100 50	1 0.05
I,J	various	various	various	Cobble gravel and sand	2- >5	*Elodea canadensis* (patches in shallows) *R. trichopyllus* (strip along margin) *Ruppia megacarpa* (along edge of channel) *P. crispus* (isolated submerged patches)	0.2 0.5 0.2 1-2	1-5 1-5 5-10 20-50	0.3 1 1 1