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Waiau Lagoon 2009

Synoptic Survey, Macrophyte Mapping and Vulnerability Assessment

Prepared
for

Environment Southland

May 2009

Cover Photo: Waiau Lagoon - entrance to lagoon arm.

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By

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EXECUTIVE SUMMARY

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 the late 1990's, ES initiated a long term coastal monitoring programme which targets vulnerable coastal habitats throughout Southland. In 2008, the Waiau Lagoon, a 4km long coastal lagoon (100ha) in Te Waewae Bay, was identified as being vulnerable to various problems and in need of synoptic monitoring and risk assessment. The current report presents the results of the February 2009 synoptic survey of the lagoon and identifies issues and monitoring and management recommendations.

RESULTS

Results of the survey showed that the lagoon was generally shallow (mean depth 1-1.5m) and well-flushed, except in deeper areas which were subject to stratification under neap tides and low river flow conditions. Aquatic macrophytes (mainly introduced species) covered 20% of the lagoon area and the lagoon sediments were predominantly a thick layer of fine muds overlaying sand and gravels. A thin layer of black, sulphide-rich, sediment was sometimes present near the sediment surface under rotting macroalgae and macrophytes. Salinity varied from approximately 1ppt at the surface to 17ppt in the deep water, and dissolved oxygen levels were relatively high (>95% saturation).

ISSUES

The report identified three key issues, or vulnerable components of Waiau Lagoon, as important for monitoring and management. The three key vulnerabilities were;

1. Aquatic Macrophyte Community. Shallow brackish lagoons, like Waiau Lagoon, are typically in one of two contrasting states; a clear state with submerged macrophytes (either native or introduced communities), or a more eutrophic, turbid state dominated by phytoplankton and macroalgae. The survey confirmed that the Waiau Lagoon was in a modified submerged macrophyte stage, with mainly introduced species and macroalgae present, and was very vulnerable to further degradation. The major threats were identified as:

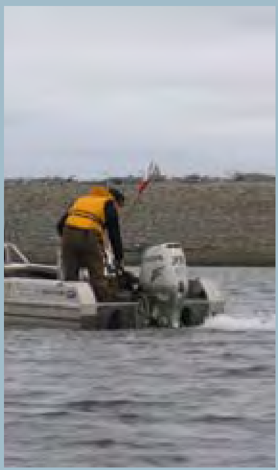
a. Reduced flushing, from further freshwater abstraction or mouth changes
b. Catchment landuse intensification and increased nutrient runoff
c. Invasive weeds or pests
d. Accelerated sea level rise
e. Storm damage

2. Poorly Flushed Deeper Areas. Deeper areas (5m deep) at the eastern end of the lagoon become isolated during low river flows as a result of salinity stratification. Such stratification makes the lagoon susceptible to bottom water stagnation and oxygen depletion problems and hence a reduction in the ecological and human value of the lagoon. The regular entry of flushing flows from Waiau River floods and spring tide marine waters to the lagoon are therefore considered vital for maintaining healthy bottom water conditions. The major threat was identified as reduced flushing due to increased freshwater abstraction or changes in river mouth geomorphology.

3. Saltmarsh and Terrestrial Margin. Estuaries function best with a large area of saltmarsh and a healthy natural vegetated terrestrial margin. Recent broad scale mapping showed there was little saltmarsh remaining around the lagoon and the terrestrial margin was highly modified. However, restoration of parts of these areas has already commenced. The major threats to further deterioration in saltmarsh and terrestrial margin communities were increased stock access to the lagoon margin, plant pests, and vehicle damage.

EXECUTIVE SUMMARY (Continued)

MONITORING



Maintenance of Waiau Lagoon in its semi-modified condition, as well as restoration in certain areas, is considered important if the relatively high human use and ecological status of the lagoon is to be maintained. This survey has identified a need for regular targeted monitoring of the following, as well as intensive studies, for effective ongoing management:

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

Macrophyte Mapping. To assess the condition of macrophyte beds and sediment quality: undertake annual monitoring during likely worst case conditions (February to March), of the following:

- Aquatic macrophytes and nuisance macroalgae presence, location, percent cover and life stage on fixed transects (include salinity, depth and clarity at each site).
- Sediment quality - broad scale (depth to depleted oxygen or RPD layer, sediment type) and fine scale (grain size, total nitrogen, total phosphorus and total organic carbon) at three representative sites.

Sedimentation. To assess the extent of sedimentation or shallowing of key areas in the lagoon, undertake sedimentation rate monitoring by deploying sedimentation plates at key locations and monitor annually.

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: catchment landuse intensity, freshwater abstractions, mouth opening/constrictions and water level. Because of the susceptibility of the lagoon, any changes in the key stressors should trigger an evaluation of the likely impact on the lagoon.

MANAGEMENT

Four major issues require management as follows:

Ensure Adequate 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. The findings of this study should also be used to help set appropriate guidelines for nutrient and sediment loads for Waiau lagoon (see below).

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.

Saltmarsh and Terrestrial Margin Restoration. Because of the importance of the saltmarsh and a natural vegetated terrestrial margin to human use and ecological values of the lagoon, it is recommended that a plan be developed to encourage its re-establishment, and to support community restoration initiatives.

Plan to Minimise Ecological Impacts of Sea Level Rise. Develop a plan to minimise the loss of ecosystem services of the Waiau Lagoon that are vulnerable to climate change effects, particularly sea level rise.

1. INTRODUCTION

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.

Waiau Lagoon (100ha) and associated wetland (3ha), centred in Te Waewae Bay in Western Southland (Figure 1), is a moderate-sized "tidal river mouth" estuary. It's main feature is a 4km long, shallow, brackish lagoon formed on the coastal plain between the barrier beach and mudstone and alluvial cliffs. The estuary is fed by the Waiau River, which currently has a mean flow of $156m^3.s^{-1}$, but prior to 1969 and hydro-electric power diversions it was $501m^3.s^{-1}$, and the Holly Burn (mean flow $0.58m^3.s^{-1}$). These rivers drain developed pastoral lowlands, and also in the case of the Waiau, extensive areas of native bush. The lagoon is separated from the sea by a spit or barrier beach, and drains to the sea through a gap that migrates at the western end. Historically, the lagoon was surrounded by peat bog, the remnants of which give the lagoon water its characteristic brown humic stain.

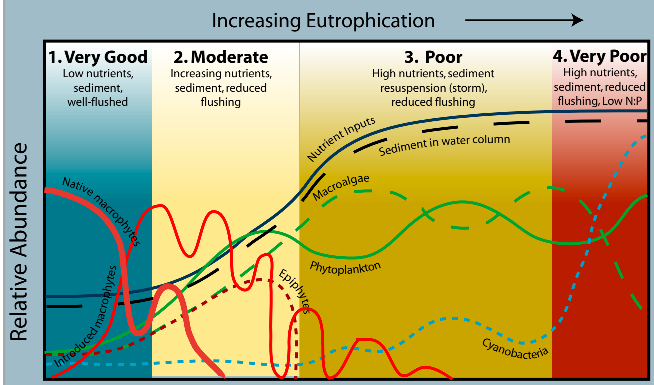
Figure 1. Waiau Lagoon looking west towards the mouth.

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 increases in intensity 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.

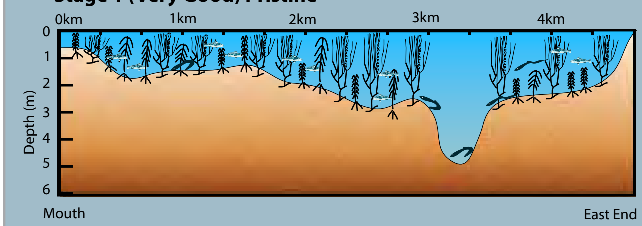
1. Introduction (Continued)

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

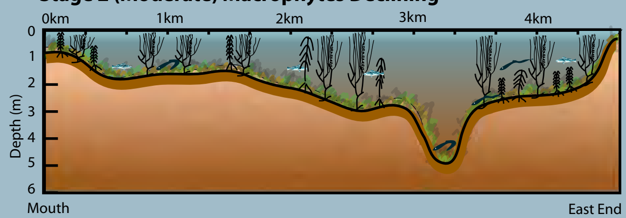


Conceptual representation of response of aquatic vegetation to increased nutrients in coastal lagoons (modified from de Wit et al. 2001, Viaroli et al. 2004, Zaldivar et al. 2008 and information on NZ coastal lagoons - Mitchell 1971, Gibbs 1973, Gerbeaux and Ward 1991, Gibbs 2002, Edwards and Clayton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

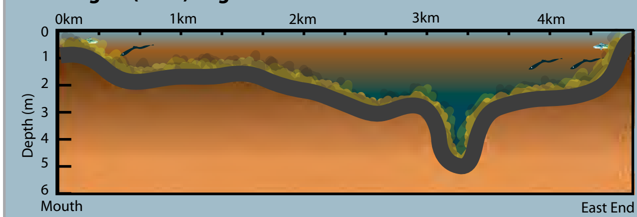
Stage 1 (Very Good) Pristine



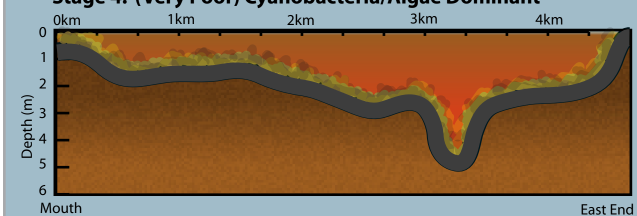
Stage 2 (Moderate) Macrophytes Declining



Stage 3 (Poor) Algae Dominant



Stage 4. (Very Poor) Cyanobacteria/Algae Dominant



The response to increased nutrients/eutrophication can be divided into four main stages as follows (Figure 2):

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).

1. Introduction (Continued)

A primary aim of the present survey was to assess the trophic status of Waiau Lagoon, particularly its current macrophyte status, as it provides a useful indicator of the lagoon condition. The main parameters assessed in the survey were water clarity, salinity, water depth, sediment oxygenation, muddiness, and presence of macrophytes and nuisance macroalgae. A previous survey (Stevens and Robertson 2008) assessed the condition of the intertidal and terrestrial margin habitats of the lagoon.

This report identifies the Waiau Lagoon and catchment characteristics to provide an overview of the primary ecological issues, to enable further monitoring and management recommendations.

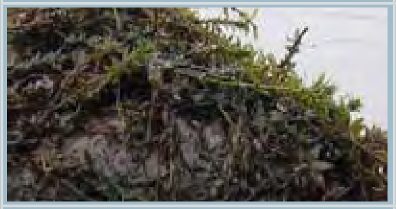
2. SYNOPTIC SURVEY METHODS

Percent Cover 0-5%

Percent Cover 5-10%

Percent Cover 10-20%

Percent Cover 20-50%



Percent Cover 50-80%

Percent Cover 80-100%

In order to assess the Waiau Lagoon, various key indicators of tidal river mouth lagoon condition were monitored on 19 February 2009. The methodology involved sampling georeferenced sites along transects which, through future repeat sampling (and replication), can be used as a rapid and robust technique to indicate change.

Details of the 2009 sampling methodology are as follows:

Prior to sample collection, the nine proposed transects, and the sites within those transects, were identified on an aerial photo for guidance in the field. A photo showing site locations is shown in Appendix 1.

During field sampling (undertaken by three scientists using a dinghy and outboard motor), the boat was positioned above each site and a sediment sample was collected by digging up a 5-6cm deep layer of the surface sediments with a garden hoe (hoe area 15 x 15cm) or van Veen Grab sampler and carefully bringing the contents to the surface.

At the surface, the sample was photographed and records taken of;

- the aquatic vegetation (taxa, height, percentage cover and life stage),
- the sediment type and depth to the blackened sulphide rich layer (redox potential discontinuity layer - RPD). Examples of percentage cover estimates for macrophytes are shown in the margin figure.

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

- secchi disc clarity,
- depth,
- temperature and
- salinity (at surface and bottom).

Geo-referenced sampling positions and photographs, and field measurements were recorded and are presented in Appendix 1. The data are also available as an ArcMap GIS layer containing georeferenced digital field photos (GPS- Photolink).

3. RESULTS

A summary of the key findings is presented below, along with other relevant information. Of particular value was a series of measurements made by ES during a recent flood on 28 January 2009. Data collected included salinity, clarity, and dissolved oxygen which has enabled a good picture to be developed of lagoon functioning under different flow conditions.

Aquatic Macrophyte and Macroalgal Cover

The results of the dominant macrophyte and macroalgal survey (Figures 3 and 4) indicated that rooted aquatic macrophytes covered approximately 20% of the lagoon area. The dominant plants were:

- The pondweeds, *Potamogeton crispus* (introduced) and *Potamogeton ochreatus* (native) in the 1-2m depth range,
- *Nitella hookeri* (a native stonewort algae) in the 0-5m depth range (around most of the lagoon margin) and
- *Elodea canadensis* (the highly invasive Canadian pondweed - introduced) in patches in the 0.5-1m depth range.
- *Ranunculus trichophyllus* (water buttercup - introduced) was also present in some places.

Such macrophytes are all common inhabitants of modified freshwater and slightly saline waterbodies. The densest patches were found in shallow waters less than 1m deep. Also present on the sediment surface, and as epiphytic growth in many places, were the slimy filamentous brown macroalgae *Bachelotia antillarum*, and accompanying black, anoxic, sulphide-rich surface sediments.

Figure 3. Percentage cover and dominant aquatic vegetation type, Waiau Lagoon 19 February 2009.

Water Depth and Level

Low River Flow 19 February 2009. The lagoon water depth was relatively shallow over much of the lagoon (<1.5m) but was much deeper (4.9m) in the channel at the east end (Figure 5). Water level varied from 1.04m above mean sea level at low tide to 1.52m at high tide. The tidal range on 19 February was 0.5m but over the previous year it ranged from 0.05 to 1.6m (Environment Southland unpublished data 2008).

High River Flow 28 January 2009. The lagoon level can be raised to high levels by floodwaters and occasionally reaches 4m above sea level. A recent flood on 28 January 2009 (which was also monitored for other parameters - see subsequent sections) raised the lagoon level to 1.9m above mean sea level.

Figure 4. Dominant macrophytes and macroalgae, Waiau Lagoon 19 February 2009.

***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.

***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.

***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.

***Enteromorpha* (Green macroalgae)**

Enteromorpha, 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.

Figure 5. Water depth Waiau Lagoon, during low flow period 19 February 2009.

Salinity and Temperature

Low River Flow 19 February 2009. The lagoon was stratified during low flows and at low tide. Salinity varied from approximately 1ppt at the surface to 17ppt below 3m deep (Figure 6a). An area of rapid change in salinity (halocline) and temperature (thermocline) was present at approximately 1.8m deep. Water temperature varied from 15.6°C at the surface to 18.8°C below 3m depth. At high tide on the same day, salinity remained the same as at low tide, suggesting that freshwater from the river, and not tidal marine water, was responsible for the 0.5m increase in tidal height.

Low Flow Salinity 19 February 2009

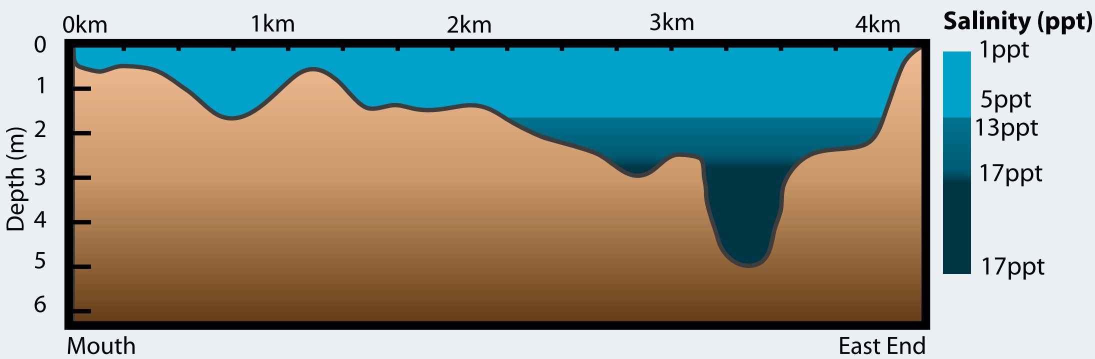


Figure 6a. Water salinity Waiau Lagoon, during low flows.

3. Results (Continued)

High River Flow 28 January 2009. During the flood on 28 January, the lagoon was unstratified and salinity was low (<2ppt) throughout the lagoon (Figure 6b).

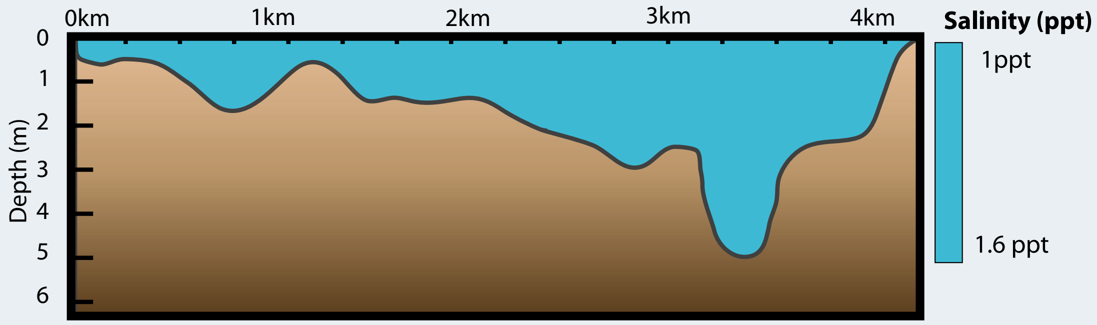


Figure 6b. Water salinity Waiau Lagoon, during high flows.

Water Clarity (Secchi Disc)

Low River Flow 19 Feb 2009. In general, the lagoon has a brown humic stain that reduces visual clarity, but during low flows on 19 February, water clarity was relatively poor at approximately 1.5-1.7m (Figure 7). Such water clarity is typical of shallow lakes with muddy beds under calm conditions. During windy conditions, water clarity is known to decline further.

High River Flow 28 Jan 2009. During the flood on 28 January, water clarity measured by secchi disc was much lower than measured during low flow conditions (0.3-0.74m).

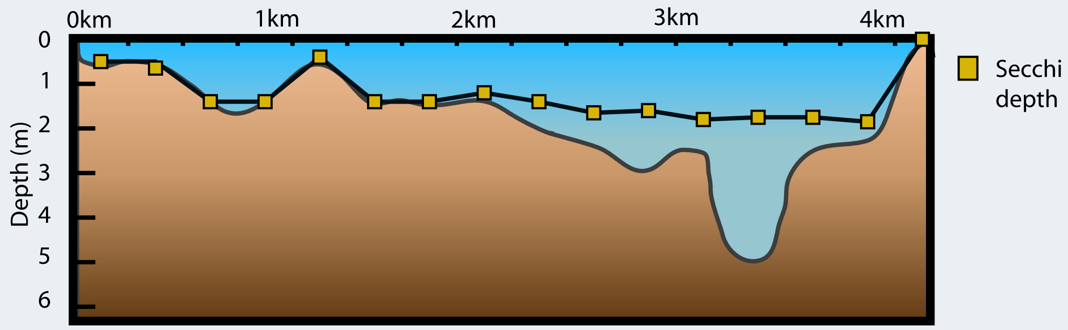


Figure 7. Secchi depth at Waiau Lagoon, 19 February 2009.

Sediment Type and Anoxic layer

The substrate type was predominantly a thick layer of fine muds overlaying sand and gravels. A thin layer of black sulphide-rich sediment was sometimes present near the surface under rotting macroalgae and macrophytes (Figure 8). A deeper anoxic layer was also present below 1-5cm sediment depth, particularly in the sediments below weed beds. Around the shallow margins, clean cobbles were common, particularly at the eastern end. In the shallow channel between the Waiau Mouth and the Holly Burn, the lagoon sediments were mainly clean sands.

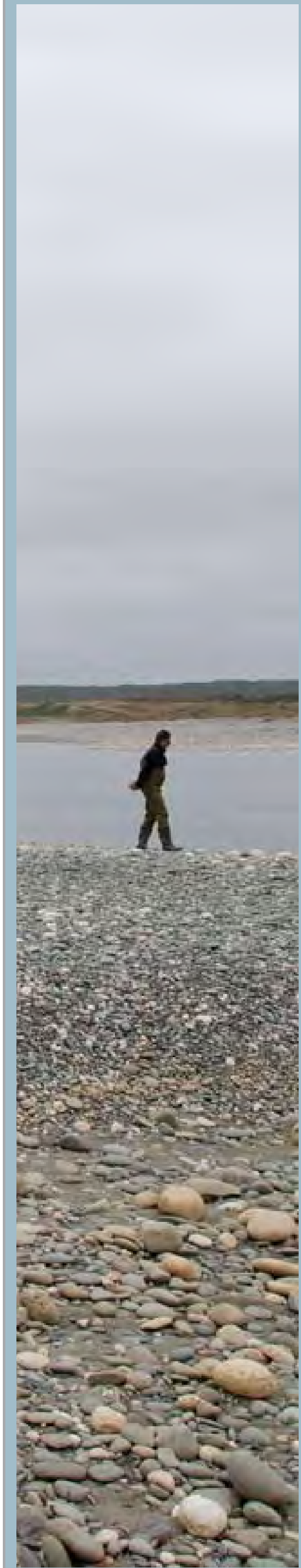


Figure 8a. Typical shallow sediment from Waiau Lagoon - clean muds at 1m depth.

Figure 8b. Typical deep sediment from Waiau Lagoon - dark anoxic sulphide rich sediments from 4m deep.

Dissolved Oxygen

Dissolved oxygen concentrations in the water column were relatively high on 19 February (95 to 117% saturation). Similar concentrations were measured on 28 January during high river flows.

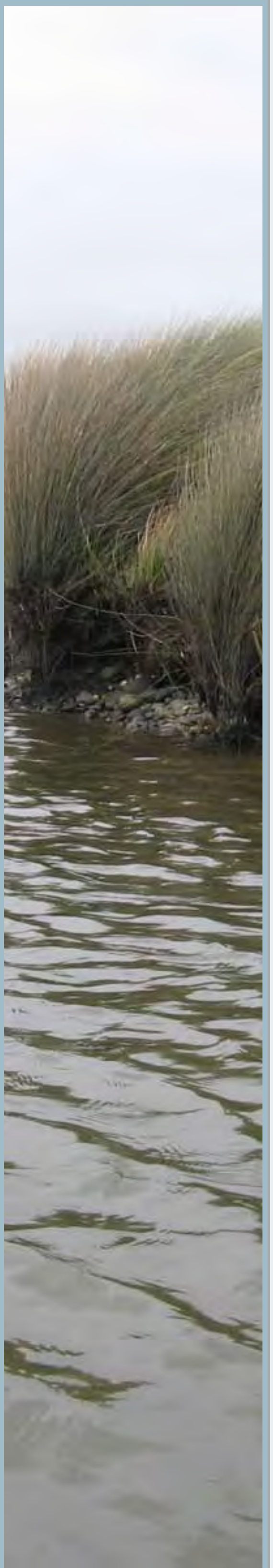
Terrestrial and Saltmarsh Vegetation

The extent of terrestrial margin vegetation, saltmarsh, and unvegetated intertidal substrate in the Waiau Lagoon was mapped in 2008 (Stevens and Robertson 2008). The results showed a relatively low incidence of saltmarsh (5% of estuary area), a highly modified terrestrial margin, and a small intertidal area (20% of estuary), with the unvegetated section dominated by gravels and soft muds (Table 1). No nuisance macrophyte growth was present on the intertidal area.

Table 1. Terrestrial margin vegetation, saltmarsh, and unvegetated intertidal substrate in the Waiau Lagoon 2008 (area east of mouth only included).

Habitat	Area (ha)	% of Estuary
Saltmarsh	3.1	5.0
Unvegetated intertidal	9.2	14.9
• Cobble field	0.6	0.9
• Gravel field	4.6	7.4
• Soft mud	1.5	2.5
• Very soft mud/sand	2.5	4.1
Water	49.8	80.1
Total Estuary Area	**62.1**	**100.0**
Terrestrial Margin	**% of margin**	
• Tussockland	7	
• Grassland	76	
• Scrub/Forest (exotics)	16	
• Quarry	1	

3. Results (Continued)



Vulnerability Assessment 2008

The 2008 vulnerability assessment (Robertson and Stevens 2008) of the Southland coast from Te Waewae Bay to Waiparau Head in the Catlins identified the following in relation to Waiau Lagoon (its uses and values, existing condition, stressors, susceptibilities and overall vulnerabilities). Additional background data is provided in Table 2.

Summary Information from 2008 Vulnerability Assessment
Uses and Values. Human use of the estuary is high and is popular for whitebaiting, fishing, birdlife, swimming, duckshooting and its scenic beauty. Brown and rainbow trout are important recreational species in the lagoon, along with whitebait, flounder, eels, and mullet.
Ecological Values. Ecologically, habitat diversity is moderate-high, given the presence of considerable areas of saltmarsh, herbfields, and freshwater aquatic macrophytes. Fish, bird and invertebrate life is also expected to be high. The lagoon and spit are important roosting and feeding areas for spotted shags, oyster catchers, banded dotterels, mottled petrels, and gamebirds.
Existing Condition. Salinities vary depending on the extent of tidal inflow and constriction of the mouth but are generally low (around 1ppt). The water is humic-stained and its clarity varies depending on river flows. The sediments are mixed with little sign of anoxic conditions near the edges. Currently the water quality in the Waiau River is high (low nutrient and *E. coli* concentrations), reflecting the dominant native forest/pasture landuse and large catchment area. Estimated nitrogen (the major driver of eutrophication) loadings are low, but suspended solids loadings are high. Because the estuary is primarily riverine, its surface quality is expected to be similar to that of the river.
Presence of Stressors. The presence of stressors is expected to be moderate. Stressors include; water abstraction, stock grazing saltmarsh, landuse intensification (already have high dairy cow numbers), weed and pest invasions, and sea level rise.
Susceptibility to Stressors. The lagoon is relatively isolated from the main river flow and consequently certain areas may be poorly flushed, which can be exacerbated when the mouth constricts or closes due to high seas. At such times, a salt wedge may form, water quality may deteriorate and cause symptoms of eutrophication. In addition, because the lagoon and coastal plain are low lying, predicted sea level rise may alter lagoon hydrodynamics (shift to higher salinity regime) and cause loss of saltmarsh and aquatic macrophyte habitat. Given these characteristics, the estuary ecology is susceptible to: any increase in the intensity of landuse in the catchment, loss of flushing flows, grazing in the margins, and constriction of the estuary mouth.

Table 2. Summary of key Waiau Lagoon characteristics (from 2008 Vulnerability Assessment).

General	Type	Tidal river mouth. Category C - where the mouth of the main river channel connects to shallow lagoons
	Mouth Closure	Open, but constricts at times. Mouth migrates over a distance of 1.5km west of Waiau River channel. Local information indicates mouth opened to sea at eastern end of lagoon at times.
	Mean depth (m) and Volume (m^3)	Approx 1.0-1.5m at low water - 0-4.9m depth range. Volume approximately 1-1.5 million m^3.
	Depth of central basin (m)	2-4m
	Estuary Area (ha)	101ha
	Salinity regime April 2008	Stratified under low flow conditions.
	Length of salinity intrusion	4km into lagoon. Salinity intrusion only on spring tides.
	Residence Time and Flushing	Bottom water saline water is likely to have long residence time - only flushed out in floods or spring tides. Surface low salinity water (<1.5m depth) is likely to be flushed to a moderate extent on most tides, given the 0.5m mean tidal height, shallow depth and low salinity. Estimated retention time of surface waters likely to be approx 1-3days.
	Slope of Catchment	Variable
	Lagoon Wind Exposure	Mod-High. Strong fetch along main axis of lagoon.
	Mean Tidal Range (m)	0.05-1.6m range. Water level generally 1-2m above mean sea level.
	Mean Freshwater Inflow (l/s) - Estimated	156,000 l/s. Water abstraction (the Manapouri Hydro-Electric Power Scheme in 1969 diverted up to 400 cumecs of flow) is likely to have contributed to more frequent mouth closures, and reduced flushing of the lagoon, in recent times.
	Catchment Area (km2)	7904 km2
	Limiting Nutrient (N or P)	Likely to be P.
Habitat Diversity	Sheltered fringe areas	Several small sheltered ponds connected to lagoon.
	Salt Marsh/Dune Area (ha)	3.1ha or 5% of estuary.
	Seagrass/Macrophyte Abundance	Significant growths of aquatic macrophytes (predominantly *Potamogeton crispus* and *Nitella* sp) over 20% of lagoon area.
	Tidal Flats present	Low area of unvegetated intertidal flat, 9.2ha or 14.9% of estuary.
	Sediments in Estuary	Dominated by muds over sands, gravels and cobbles.
	Margin buffer	Mainly pasture. 16% is scrub/forest - mainly exotic willows on river flats.
Stressors	Catchment Rock Type	Mixture - Igneous, Gravels, Sandstone/Siltstone
	Landuse	43% native forest/scrub, 17% high producing pasture, 26% low producing pasture, 5% exotic forest, 0.4% sand/gravel/rock.
	Number Dairy Cows	9266
	Catchment SS yield (t/km2/yr)	Mod 157 (WRENZ model prediction - NIWA website, http://wrenz.niwa.co.nz.
	Catchment TN yield (kg/ha/yr)	Low 1.1 (WRENZ model prediction - NIWA website, http://wrenz.niwa.co.nz.
	Point Source Inputs	U/S dairy effluent, and small urban sewage discharges.
	Input Water Quality	Mean 0.30 mg/l total nitrogen 0.014 mg/l total phosphorus, 2.3 NTU turbidity, 135 cfu/100ml *E. coli.* (ES Monitoring data)
	Areal Nutrient Loading to Lagoon (mg.$m^{-2}d^{-1}$) - Estimated	TN input (mg/day) / Estuary area (m^2) . Assume inflow to lagoon is mean tidal height (0.5m) x estuary area x tides per day (2). = 0.5 x 1,000,000 x 2 = 1,000,000 m^3/d.. TN input/day = 0.3 g.m^{-3} x 1,000,000 m^3/d. = 300,000 g/d. Areal Loading TN = 300,000,000 mgTN/d / 1,000,000 (m^2) = 300 (mg.$m^{-2}d^{-1}$). Areal Loading TP = 14,000,000 / 1,000,000 = 14 (mg.$m^{-2}d^{-1}$).
	Sea Level Rise Impact	Expected that beach barrier spit will erode, estuary likely to expand.
	Other Stressors	Vehicles occasionally drive along barrier spit and cause damage to herbfield vegetation and impacts to birdlife. Growth of introduced weeds around estuary margin is a moderate problem.
Existing Condition	Macroalgal Blooms	Elevated macroalgae at times, mainly the slime filamentous brown algae *Bachelotia antillarum* and the green algae *Enteromorpha* sp.
	Phytoplankton Blooms	Likely to be low given low input nutrient concentrations.
	DO depletion	Unlikely except in deep stratified bottom water after prolonged period of low flushing.
	HABs offshore	Low risk.
	Anoxic sediments	Anoxic layer is relatively deep in most places except for thin surface anoxic layer under mats of filamentous algae during growth periods.
	Sediment Quality	No Data
	Water Quality	No Data. Because retention time is <3 days then mean N and P likely to be similar to River Inflow N and P.
	Potential for Habitat Improvement	Protection of Waiau Spit herbfields and revegetation.

4. DISCUSSION AND CONCLUSIONS

The combined results of the 2009 synoptic monitoring, the 2008 broad scale habitat mapping, and the 2008 vulnerability assessment provide a relatively comprehensive framework to identify issues and appropriate monitoring and management recommendations for Waiau Lagoon. The results show that three key issues, or vulnerable components of Waiau Lagoon, can be identified as important for immediate management. The results also indicate that if management was effective, a healthy coastal lagoon with high ecological and recreational values would result. The three key vulnerabilities were; (1) the aquatic macrophyte community, (2) poorly flushed deeper areas, and (3) saltmarsh and terrestrial margin habitat. All these areas have been shown as vital for the overall health of the lagoon and if these were maintained or restored to good condition, other important parts of the ecosystem (e.g. macroinvertebrates, fish and birdlife) would thrive. A discussion of each of these issues and their main causes of decline follows.

1. Aquatic Macrophyte Community

Shallow brackish lagoons, like Waiau Lagoon, are typically in one of two contrasting states:

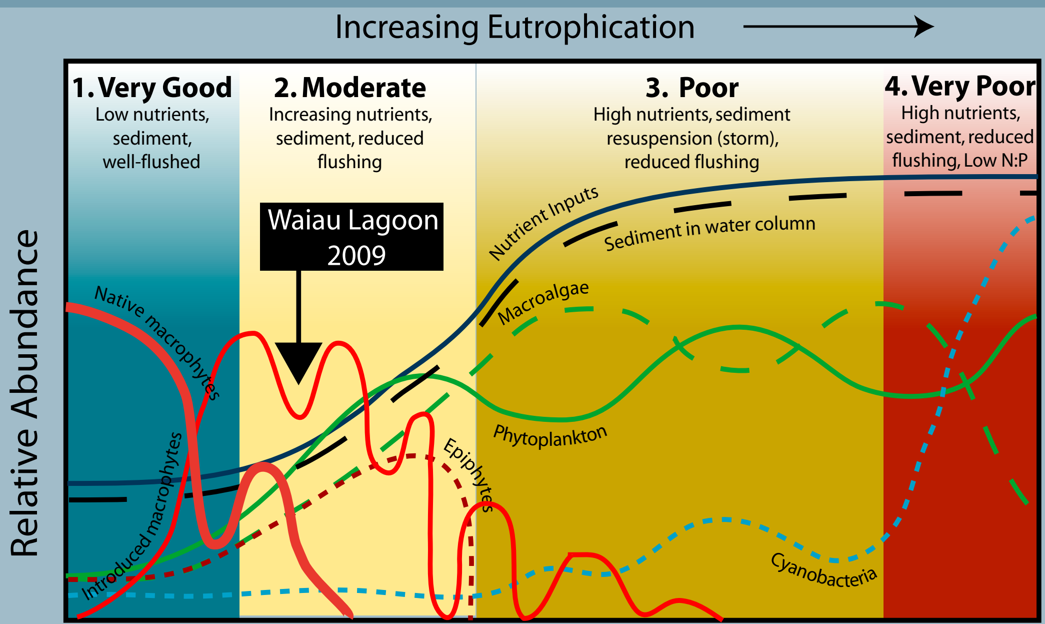
- A clear state with submerged macrophytes; either native or introduced communities (i.e. Stages 1 and 2 in Figure 9).
- A turbid state dominated by phytoplankton and macroalgae (i.e. Stages 3 and 4 in Figure 9).

The synoptic survey confirmed that the Waiau Lagoon is currently in the Stage 2 (Moderate) condition (Figure 9). This rating was based on the following findings:

- low incidence of native macrophytes (*Nitella* near edges, and some *Potamogeton ochreatus)*
- dominated by introduced species (including the highly invasive *Elodea*)
- low-moderate incidence of nuisance macroalgae and oxygen-poor sediments
- predominantly muddy bottom (high inputs of suspended solids)
- presence of available bare habitat
- macrophytes restricted to shallow depths (<1.8m) by low water clarity

In addition, it is likely that the lagoon has a moderate input loading of nutrients.

Figure 9. Waiau Lagoon - Condition Rating of Current Trophic State.



Conceptual representation of response of aquatic vegetation to increased nurients 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, 1992, Gibbs 2002, Edwards and Clayton 2002, Stevens and Robertson 2007 and 2007a, Ward 2008)

4. Discussion and Conclusions (Continued)

Looking up the Waiau River, Waiau Lagoon channel entrance on left.

Waiau River mouth on 19 February 2009. In April 2008, it was located 1km further towards the west.

Wind fetch in the lagoon is two directional, NW and SE.

The primary threat to the aquatic macrophyte community in the Waiau Lagoon is change to the key variables that could cause a switch to a low clarity, algal (phytoplankton and macroalgae) dominated system. Identifying these variables is therefore considered important for ongoing lagoon management. Studies have shown that the major variables that drive the macrophyte/algal switch-point are; (a) water residence time, (b) wind fetch, (c) nutrient concentrations, (d) substrate type, (e) extent of saltmarsh, and (f) water depth (Janse 2005). Because these factors vary between lagoons, and within lagoons over time, there are no simple, stand-alone guidelines that could be used for lagoon management. Instead, equations or models are used to identify specific lagoon responses to a shift in any of these variables. Unfortunately, such tools do not exist for NZ lagoons and shallow lakes, and consequently identification of switch-point guidelines for the Waiau is currently difficult. In this situation, a review of the major switch-point drivers, as they relate to the Waiau Lagoon, can be helpful in identifying priorities for monitoring and management of this coastal lagoon.

(a) Residence Time

In relation to the long term maintenance of aquatic macrophytes, the lower the residence time the less likelihood of a switch to algal dominance. As the tidal range is approximately 30% of the high water lagoon volume, the water residence time in the Waiau Lagoon is currently expected to be low (i.e. 1-3 days, well flushed - Table 2), but will be longer in the deeper areas if they are stratified. In addition, the synoptic survey indicates that the water input and output from the lagoon is expected to be mainly freshwater from the Waiau River. Such findings indicate that a reduction in the main river flows would likely result in a decrease of flushing of the lagoon. In addition, reduced river flows would mean a lower erosive capacity and greater incursion of marine and fluvial sediments into the lagoon entrance channel, causing shallowing. Such entrance constriction may lead to an increased frequency of entrance closure in the lagoon, a large increase in lagoon residence time and subsequent issues of extreme changes in flushing and estuarine biogeochemistry. A gradual build-up in fine sediments, nutrients, lower water clarity, loss of macrophytes and a shift to phytoplankton and macroalgae dominance would likely result.

Historically, changes in flushing flows to the lagoon have been large and have almost certainly contributed to a shift away from the original pristine status of the lagoon. The lower Waiau was one of New Zealand's largest rivers until, in 1976, a 4.7m high weir was built across it to control the water level of Lake Manapouri for hydro power generation. Today the river flow is greatly reduced, but is augmented below Monowai by numerous tributaries (mean flow now $150m^3.s^{-1}$). However, pressure for further freshwater abstraction is still occurring, primarily from dairy conversions, and hydro electric and mining developments, but currently the flow available for abstraction is fully allocated. Information on the effects of abstraction on the lagoon is limited.

Another factor that could cause a change to lagoon residence time is the location and extent of constriction of the main river mouth. Currently, this occurs mainly in response to high seas and river flows - the mouth regularly migrates between the lagoons at the western end and the point at which the Waiau River enters the estuary. Local knowledge also indicates that the mouth has in the past been situated at the eastern end of the lagoon. Currently, detailed information on lagoon and river mouth dynamics is limited and restricted to supporting evidence for recent HEP consent applications. The influence of predicted accelerated sea level rise (Ministry for the Environment 2008) is also a key factor to consider in this regard.

(b) Wind Fetch

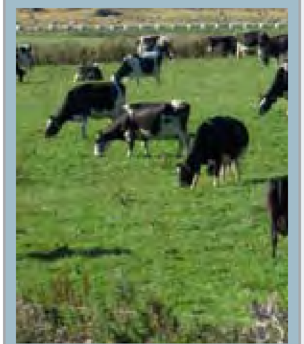
Fetch is the maximum length of open water over which the wind can blow. In relation to the long term maintenance of aquatic macrophytes, the lower the wind fetch the less likelihood of a switch to algal dominance. Currently wind fetch in the Waiau Lagoon is relatively low (approximately 2km), and is significant in two directions only, northwest and southeast.

4. Discussion and Conclusions (Continued)

(c) Substrate Type

Substrate type (muds, sands or gravels), influences the likely water clarity of a lagoon, the stability of macrophytes under strong wind events, the sediment quality, and hence the macrophyte quality. As a consequence, the finer the sediment type the greater the risk of a switch to algal dominance. Currently, the Waiau Lagoon is dominated by muds and therefore has an increased risk of switching to algal dominance compared with the situation where it is dominated by sands or gravels. Ensuring low inputs of fine sediment to the lagoon in conjunction with adequate flushing or natural removal of existing fine sediments from the bed of the lagoon, would enhance long-term lagoon condition.

(d) Nutrient Concentrations



Landuse intensification in Waiau catchment through increase in dairy conversions.

Excessive nutrient concentrations (mainly nitrogen and phosphorus) encourage nuisance algal growth, low water clarity, and loss of macrophytes. As a consequence, the higher the nutrient concentration the greater the risk of a switch to algal dominance.

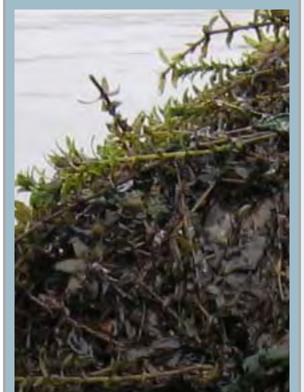
Currently, the nutrient concentrations in the Waiau Lagoon have not been measured, but are likely to be relatively low and similar to those measured in the upstream river water (i.e. mean 0.3mgN/l and 0.014mgP/l, Environment Southland monitoring data 1989-2004). Because the lagoon consists primarily of 1-3 day old river water rather than seawater, the Waiau is very responsive to river inputs.

Given these relatively low nutrient concentrations, the risk of a switch to algal dominance in the Waiau Lagoon under current conditions is low. However, an increase in nutrients in the lower Waiau River, and hence the lagoon, due to landuse intensification is considered likely. Water quality in the lower Waiau at Tuatapere has shown a significant degradation since 1989, particularly for water clarity and nitrogen (Scarsbrook 2006). Accompanying this decline has been a large increase in dairy conversions in the catchment, which is a possible contributing factor.

Ensuring on-going low nutrient inputs to the lagoon would therefore enhance long-term lagoon condition. Initial estimates indicate that phosphorus is the major nutrient that should be managed given an N:P weight ratio of 21:1 (which is greater than the 7:1 Redfield ratio above which P is limiting).

Saltmarsh area is low.

Sea level rise vulnerability is high.



Waiau Lagoon - presence of highly invasive *Elodea canadensis*

(e) Saltmarsh

Saltmarsh acts to increase the ability of an estuary to assimilate fine sediment and nutrients and thereby decreases the risk of a switch to algal dominance. Currently, the area of saltmarsh in the Waiau Lagoon is relatively low, at 5% of the estuary area, and much lower than it likely was historically (Stevens and Robertson 2008). Hence the risk of a shift to algal dominance is greater than when the lagoon had more saltmarsh cover. Encouraging restoration of saltmarsh within the lagoon would therefore enhance long-term lagoon condition. The issue of saltmarsh loss is also considered in more detail on page 16.

(f) Water Depth

As water depth increases, the light available for macrophyte growth declines. In situations like the Waiau, where secchi disc water clarity is in the 1-2m depth range, aquatic macrophyte growth is restricted to areas less than 2m deep. Only 40% of the lagoon is in this shallow depth range, and 20% of that area is situated in the channel where salinity variations are extreme, hence macrophyte growth currently occupies only 20% of the lagoon. Ensuring low fine sediment inputs to the lagoon and/or flushing or removal of existing fine sediments from the bed of the lagoon would act to limit further macrophyte damage or provide new suitable habitat.

(g) Invasion of Weeds

Another factor affecting the aquatic macrophyte community is invasion by introduced weed species. Invasive species can have severe impacts on biodiversity, the economy and human health. The low stature and vigour of most native aquatic species compared to many of the introduced species can lead to either a complete elimination of native species from a water body, or (more commonly) exclusion from more favourable sites (to either the deeper more light-limited or shallower more exposed sites).

Recent incursions of nuisance invasive aquatic species such as Didymo (*Didymosphenia geminata*) and *Elodea* in the lower Waiau system, and *Lagarosiphon* in the Oreti system, highlight the vulnerability of Waiau Lagoon to such problems. *Lagarosiphon,* and to a lesser extent *Elodea,* are extremely invasive and given the right conditions, out-compete other plant growth and quickly colonise slow moving reaches of water. In a sheltered, brackish lagoon like the Waiau, *Elodea* is likely to find an ideal habitat, but *Lagarosiphon* is likely to be less tolerant of the elevated salinity. Didymo, is a very aggressive diatom algae and can form massive nuisance blooms on the bottom of streams, rivers, lakes and brackish lagoons (Kilroy et al. 2006). Currently, Didymo and *Elodea* are already in the lower Waiau system, including the lagoon, however, the recent survey of the lagoon for aquatic macrophytes and macroalgae showed little evidence of widespread Didymo blooms.

4. Discussion and Conclusions (Continued)

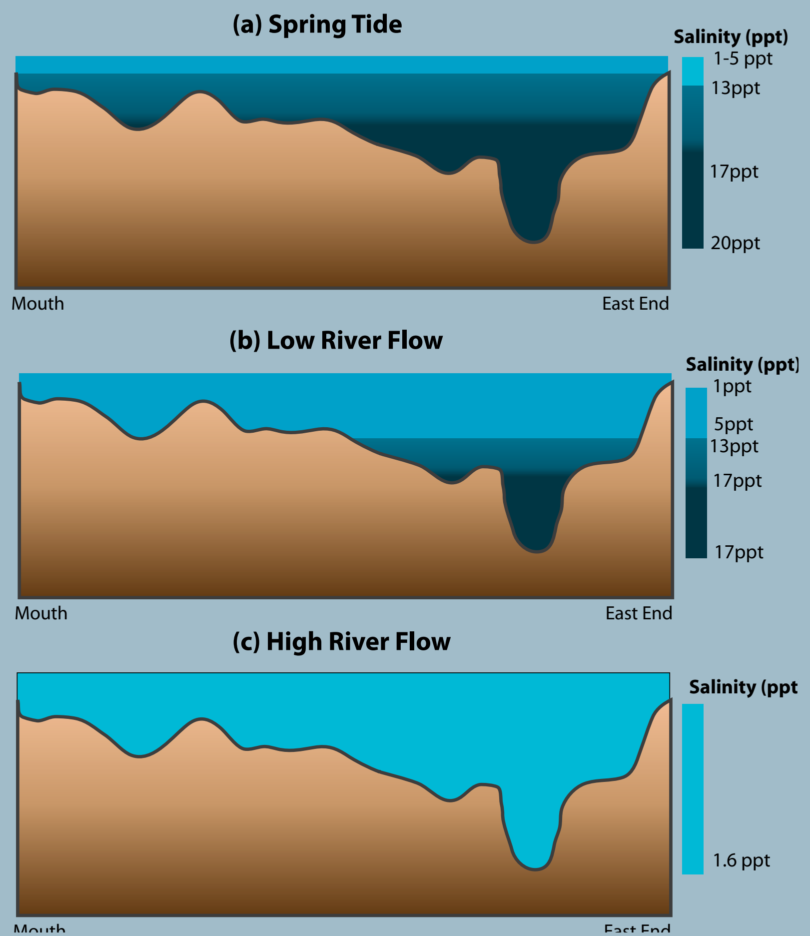
2. Vulnerable Poorly Flushed Deep Areas

Also important was the presence of areas at the eastern end up to 5m deep, which become isolated during low river flows as a result of salinity stratification. As is often the case with such lagoons, most of the main river flow tends to bypass the lagoon entrance and be carried out to sea. In addition, it is likely that saline marine water only enters the lagoon during spring tides. As a consequence, flushing is most likely to occur during high river flows and/or spring tides (Figure 10), but detailed knowledge of the relationship between the extent of flushing and river flow or tidal height is limited.

Such characteristics make the lagoon susceptible to bottom water stagnation and oxygen depletion problems and reduce the ecological and human use values of the lagoon. Ensuring the regular entry of flushing flows from Waiau River floods and spring tide marine waters to the lagoon should maintain healthy bottom water conditions.

Stagnant bottom water conditions may be exacerbated by increased freshwater abstraction and mouth constriction.

Figure 10. Waiau Lagoon - Flushing Flow Scenarios.



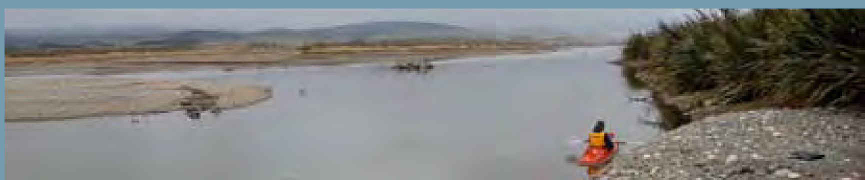
This figure shows 3 scenarios:

(a) Spring Tide
Under spring tide conditions, salt water is expected to enter the lagoon and because of its greater density, mix and sink below the freshwater surface layer and enter deeper areas where it displaces bottom water with clean seawater.

(b) Low River Flow
Under low river flow, neap tide conditions, the tide is expected to go in and out each day in the lagoon but the incoming tidal water is fresh (as was found during low river flows on 19 February 2009) not saline. Flows are not strong enough to flush seawater from the deeper holes.

(c) High River Flow
When the river floods, the lagoon level increases significantly (up to 4m above sea level) and also cleans out the deeper areas of seawater and fills them with freshwater (as was found in the flood of 28 January 2009).

Mouth of Waiau Lagoon in forefront, shallow channel leading to main lagoon in background.



Waiau Lagoon near boat ramp on main lagoon.

3. Saltmarsh Vegetation and Terrestrial Margin

Estuaries function best with a large area of rooted vegetation, i.e. aquatic macrophytes, saltmarsh and seagrass, as well as a healthy vegetated terrestrial margin. Recent broad scale mapping showed there was very little saltmarsh around the lagoon and the terrestrial margin was highly modified.

The narrow extent of saltmarsh vegetation can be attributed to historical drainage of wetland areas to create pasture, combined with the freshwater dominance of the estuary, meaning many terrestrial plants are able to establish to the waters edge (Stevens and Robertson 2008). Modification of the natural vegetated terrestrial margin can be attributed to forest clearance, drainage and reclamation, stock grazing, vehicle access tracks, and erosion protection.

Loss of this habitat reduces wildlife, recreational, and aesthetic values, while also adversely impacting on its role in flood and erosion protection, contaminant mitigation, sediment stabilisation, and nutrient cycling.

The major threats to further deterioration in saltmarsh and terrestrial margin communities are as follows:

Sea Level Rise

- In the past century, sea level rise has averaged approximately 2.1mm/year, but this is predicted to increase up to 7mm/year or more in the next 100 years (Ministry for the Environment 2008). The most vulnerable coastal areas are like the Waiau Lagoon, low lying, soft-shore areas, with high erosion, a large predicted rise in sea level, high wave energy, and a low tidal range. The likely response is increased erosion of the barrier spit and greater inundation of the lagoon with sea water and potential alteration in the saltmarsh and aquatic macrophyte community and other parts of the ecosystem. Currently, information on erosion and inundation scenarios for the lagoon due to accelerated sea level rise over the next 100 years is very limited.

Increased stock access to the lagoon margin

- The most effective factor in degrading the lagoon saltmarsh and terrestrial margin vegetation is grazing and trampling by cattle and to a lesser extent sheep. The current situation in relation to stock access to the lagoon margin is unknown.

Plant Pests

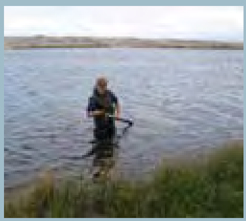
- A variety of plant pests, particularly gorse (*Ulex europaeus*), blackberry (*Rubus fruticosus*), and tall fescue (*Festuca arundinacea*), can degrade the saltmarsh community and terrestrial margin. These are established in many areas around the lagoon.

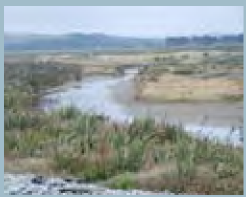
Vehicle Damage to Spit Plant Ecology

- Vehicle access tracks currently weave along the spit to various hunting and fishing huts. Disturbance of the spit ecosystems by the presence of occasional vehicles is currently occurring but the impacts are unknown.

Restoration opportunities for the saltmarsh and terrestrial margin communities are extensive. Already, along the margins of tributaries in the east of the estuary, a series of linked ponds and wetland plants have been established as part of local restoration efforts to improve the availability of whitebait spawning habitat. Furthermore, widespread restoration of the lagoon saltmarsh and terrestrial margin habitats is considered relatively straightforward and easily attainable, given the easy access and limited extent of current land development adjacent to the lagoon.

5. MONITORING





Maintenance of Waiau Lagoon in its semi-modified conditions, as well as restoration in certain areas, is considered important if the relatively recreational and ecological status of the lagoon is to be maintained. This survey has identified a need for regular targeted monitoring of the following, as well as intensive studies, for effective ongoing management:

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

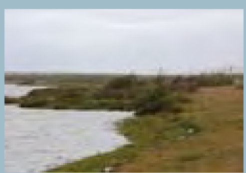
Macrophyte Mapping
To assess condition of macrophyte beds and sediment quality, undertake annual monitoring during likely worst case conditions (February to March), of the following:

- Aquatic macrophytes and nuisance macroalgae presence, location, percent cover and life stage on fixed transects (include salinity, depth and clarity at each site).
- Sediment quality - broadscale (depth to depleted oxygen or RPD layer, sediment type) and fine scale (grain size, total nitrogen, total phosphorus and total organic carbon) at 3 representative sites.

Sedimentation
To assess the extent of sedimentation or shallowing of key areas in the lagoon, undertake sedimentation rate monitoring by deploying sedimentation plates at key locations and monitor annually.

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: catchment landuse intensity, freshwater abstractions, mouth opening/constrictions and water level. Because of the susceptibility of the lagoon, any changes in the key stressors should trigger an evaluation of the likely impact on the lagoon.

6. MANAGEMENT



Four major issues require management as follows:

Ensure Adequate 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 is undertaken.

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.

Saltmarsh and Terrestrial Margin Restoration
Because of the importance of the saltmarsh and a natural vegetated terrestrial margin to recreational and ecological values of the lagoon, it is recommended that a plan be developed to encourage its re-establishment, and to support community restoration initiatives.

Plan to Minimise Ecological Impacts of Sea Level Rise
Develop a plan to minimise the loss of ecosystem services of the Waiau Lagoon that are vulnerable to climate change effects, particularly sea level rise.

7. ACKNOWLEDGEMENTS

This survey and report has been undertaken with help from various people, in particular: Greg Larkin (Coastal Scientist, Environment Southland) who provided and skippered the boat, and provided heaps of information, enthusiasm and support; local farmers who allowed access across land; and Maz Robertson for editing.

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APPENDIX 1

Sampling Locations, Aquatic Vegetation, and Site Details

Map of Waiau Lagoon showing the location of sampling transects and sites.

Station	Depth	Secchi	Temp	Salinity	DO	NZMG	NZMG	Sed Type	RPD	Macrophyte
	(m)	(m)	(°C)	(ppt)	(%sat)	East	North		(cm)	
A1	0.20	0.00	16.20	1.56	101.40	2097730	5429718	Soft mud over cobble and gravel	>10	None
A2	0.80	0.00	16.20	1.56	101.40	2097731	5429723	Clean very fine mud	1	None
A3	2.00	1.85	18.60	16.15	109.10	2097746	5429749	Clean very fine mud	1	None
A5	0.20	0.00	16.20	1.56	101.40	2097754	5429764	Gravel	>10	20-30cm wide band of *Nitella*
A4	2.25	1.70	19.90	16.68	98.60	2097751	5429753	Clean muddy sand	2	None
B1	0.20	0.00	16.20	1.56	101.40	2097589	5429850	Thin layer of soft mud over cobble and gravel	>10	*Enteromorpha*
B2	2.00	0.00	16.20	17.70	104.00	2097591	5429853	Clean fine mud	5	None
B3	2.60	1.75	18.30	16.86	114.70	2097610	5429871	Clean fine mud	1	None
B4	2.00	1.70	18.80	16.84	111.20	2097618	5429879	Clean very fine mud	1	None
B5	0.20	0.00	16.20	1.56	101.40	2097626	5429886	Cobble	>10	*Nitella*
C1	0.20	0.00	16.50	1.67	107.00	2097324	5430085	Cobble	>10	*Nitella, P. ochreatus* in shallows. Band of *Elodea* slightly deeper
C3	3.40	1.72	18.20	16.85	115.30	2097355	5430114	Clean mud	>10	None
C4	4.90	1.75	18.20	16.99	113.80	2097382	5430125	Clean muddy sand	5	None
C5	0.20	0.00	16.50	1.67	107.00	2097392	5430135	Cobble	>10	100 cm wide band of *Nitella*
C2	1.80	1.65	18.60	16.73	116.50	2097325	5430089	Clean mud	5	None
D1	0.20	0.00	16.70	1.96	101.30	2097103	5430271	Clean mud	5	*Nitella* in shallows along shoreline
D2	0.80	0.00	16.70	1.96	101.30	2097107	5430275	Clean mud	1	None
D3	2.40	1.83	18.10	17.16	112.40	2097127	5430293	Clean mud	1	None
D4	2.00	1.73	17.70	16.57	107.10	2097143	5430320	Very fine clean mud	1	None
D5	0.20	0.00	16.70	1.96	101.30	2097146	5430326	Gravel	>10	*Elodea* bed in shallows
E1	0.20	0.00	16.70	1.96	101.30	2096759	5430514	Sand/cobble	>10	*Nitella* in shallows along shoreline, *Elodea* at 1m
E2	1.10	0.00	17.00	3.31	99.00	2096753	5430521	Clean sand	5	None
E3	2.10	1.50	18.20	17.26	105.70	2096785	5430577	Clean mud	1	None
E4	2.85	1.60	17.90	15.16	102.60	2096825	5430639	Clean soft mud	5	None
E5	0.20	0.00	16.70	1.96	101.30	2096834	5430655	Gravel/cobble	>10	Band of *Nitella* on cobbles
F1	0.20	0.00	16.70	1.96	101.30	2096634	5430649	Soft mud	5	*Nitella* in band along shore, Elodea at 1m depth
F2	2.25	1.65	18.30	15.40	102.30	2096636	5430653	Clean mud	5	None
F3	1.00	0.00	16.50	2.45	101.80	2096652	5430689	Clean mud	5	50-80% cover *Elodea, Nitella, P. crispus, P. ochreatus*
F4	1.70	1.65	17.70	14.10	101.20	2096701	5430774	Clean mud	5	None
F5	0.20	0.00	16.70	1.96	101.30	2096707	5430784	Clean very fine mud	1	*Nitella* in band along shore, Elodea at 1m depth
G1	0.20	0.00	16.70	1.96	101.30	2096268	5430870	Soft mud	3	*Nitella* in band along shore, Elodea at 1m depth
G2	1.00	0.00	17.20	2.31	99.20	2096275	5430881	Soft mud	3	*Nitella* and *Elodea* to 1m
G3	1.80	1.40	17.20	5.09	99.10	2096305	5430933	Clean soft mud	3	50-80% cover *Nitella, P. crispus, P. ochreatus* through centre of lagoon
G4	1.90	1.40	18.71	13.46	94.80	2096346	5430990	Clean mud	5	None
G5	0.20	0.00	16.70	1.96	101.30	2096363	5431018	Clean soft mud	5	*Nitella* in band along shore, *Elodea* at 1m
H1	0.20	0.00	16.70	1.96	101.30	2095947	5431081	Soft mud	5	80-100 *Nitella* band along shore to 40cm. 50-80% cover deeper than 40cm.
H2	0.40	0.00	17.50	2.66	105.60	2095952	5431088	Clean mud	5	None
H3	1.20	0.00	17.30	2.31	98.50	2095981	5431152	Clean mud	5	5-20% cover *Nitella, P. crispus, P. ochreatus. Nitella* dominant at depths <40cm
H4	1.00	0.00	17.50	2.93	101.30	2096028	5431199	Clean soft mud	1	None
H5	0.20	0.00	16.70	1.96	101.30	2096035	5431219	Clean very fine mud	1	*Nitella* band along shore

Station	Depth (m)	Secchi (m)	Temp (°C)	Salinity (ppt)	DO (%sat)	NZMG East	NZMG North	Sed Type	RPD (cm)	Macrophyte
I1	0.30	0.00	17.39	1.00	109.30	2095718	5431361	Soft mud	3	None
I2	1.40	0.00	17.55	2.17	101.80	2095667	5431304	Soft mud	1	None
I3	1.40	0.00	17.39	2.24	99.40	2095656	5431364	Soft mud	1	None
I4	1.40	0.00	17.36	2.20	99.10	2095515	5431466	Thin layer of sand over mud	5	None
I5	1.80	0.00	17.38	2.19	99.40	2095434	5431598	Sand over gravel/cobble	>10	None
I6	0.40	0.00	17.36	2.17	101.10	2095241	5431704	Sand over gravel/cobble	>10	None
I7	1.60	1.30	17.22	2.13	99.50	2095049	5431734	Sand over gravel/cobble	>10	None
I8	1.40	0.00	17.22	2.11	101.00	2094998	5431805	Sand over gravel/cobble	>10	None
I9	0.50	0.00	17.35	2.17	101.00	2094871	5431902	Clean sand	>10	None
I10	0.50	0.00	17.31	2.14	101.10	2094706	5431997	Clean sand	>10	None
I11	0.50	0.00	17.42	2.14	107.80	2094551	5432119	Clean sand	>10	None
I12	0.50	0.00	17.39	1.84	103.30	2094490	5432177	Clean sand	>10	None
J1	0.00	0.00	15.69	0.40	98.00	2095970	5431190	-	-	-
J2	0.00	0.00	0.00	0.26	0.00	2095503	5431478	-	-	-
J3	0.00	0.00	0.00	0.35	0.00	2095407	5431639	-	-	-
J4	0.00	0.00	0.00	0.38	0.00	2095025	5431772	-	-	-